26th ETH-Conference on
Combustion Generated Nanoparticles

Effects of GPF Substrate Structure on Pressure Drop and Filtration Efficiency

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Session 5: Particle emissions control of combustion engines (Part B)

Outline of Presentation

(1) Introduction

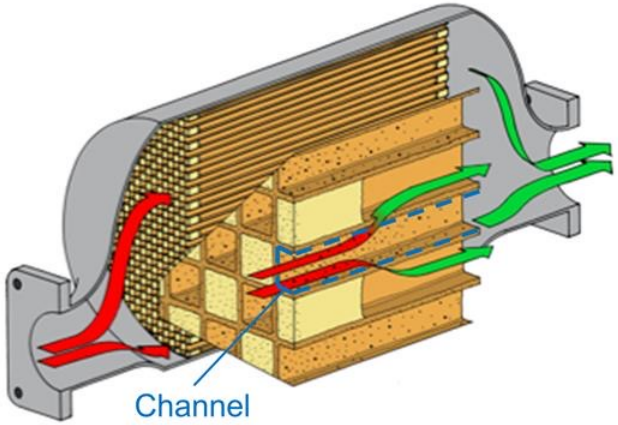
(2) Numerical method
1. Approach for initial filtration efficiency
2. Substrate by X-ray CT (original) and three samples

(3) Results
1. Effects of substrate structure on flow (no soot)
2. Initial pressure drop and filtration efficiency
3. Effects of substrate structure on soot filtration

(4) Summary

GPF (Gasoline Particulate Filter)

- Reduction of gasoline soot from GDI
- Honeycomb structure with alternate closure of inlet and outlet channels
- Similar to DPF, but different conditions
- For less space, catalyzed GPF is preferred
  = GPF + thee-way catalyst (four-way)



Plachá et al., Chem Eng Sci, (2020)

Exhaust gas of GDI

- **Low** soot concentration
- **Smaller** diameter
- **High** temperature

→ **Less chance** to form soot layer on GPF

→ Initial Δp_0 and filtration efficiency η_0 are more important

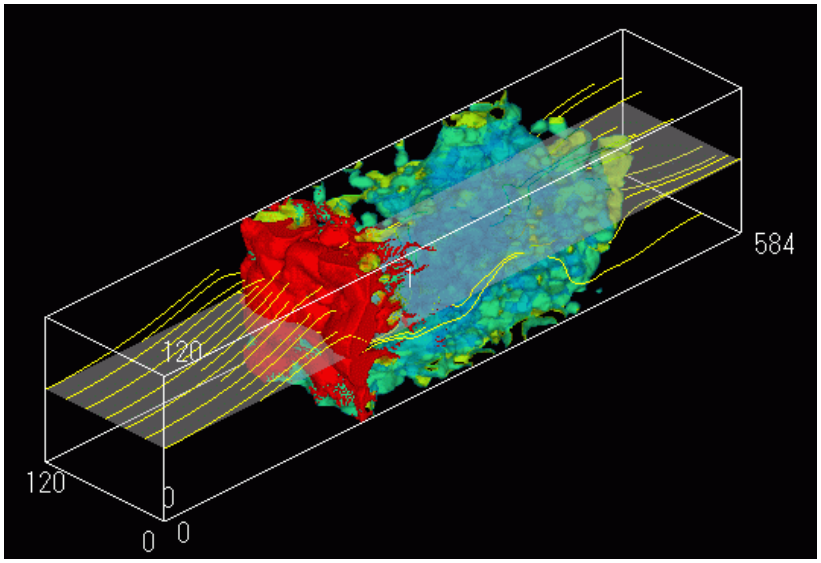
Once soot is trapped, its filtration efficiency is not the initial value.
Thus, it is difficult to estimate η_0 experimentally and numerically.

Previous Study and Objectives

Previous simulation of filtration

- Lattice Boltzmann method was used
- Soot deposition on filter wall was realized, which largely affects the filtration efficiency (η)
- η depends on soot size and the exhaust gas velocity, which are related with soot layer formation

⇒ How to determine η_0 ?



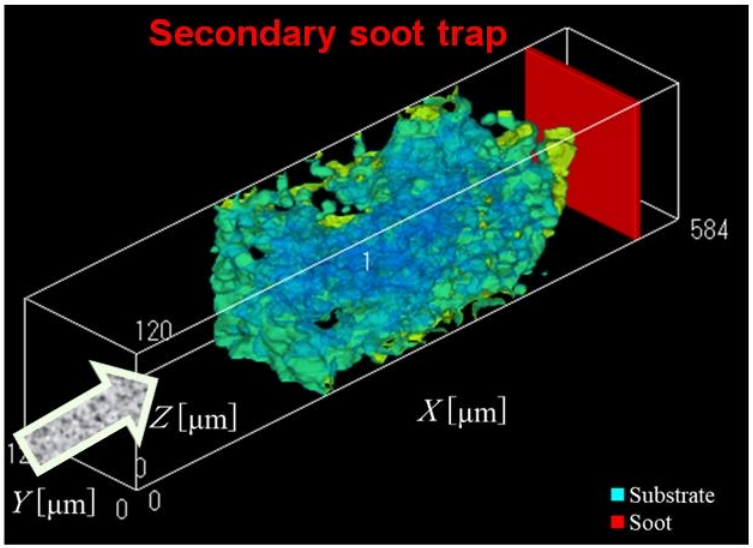
Objectives of present study

- For evaluating η_0, an approach by Plachá et al. is adopted
- By using filters with **similar** substrate structure, the pressure drop and filtration efficiency are investigated
- Information on catalyzed GPF is obtained

Numerical Domain and Conditions

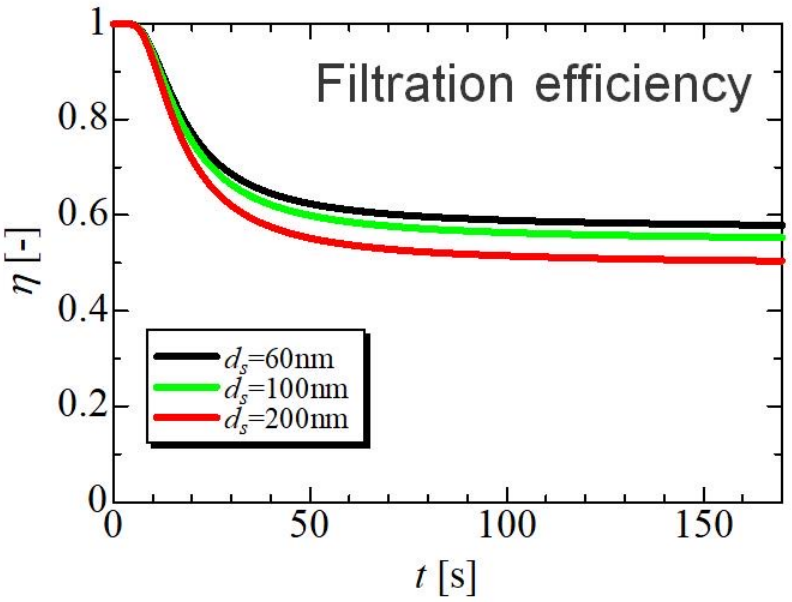
- Numerical domain:
  584μm(X)×120μm(Y)×120μm(Z)
  Grid size = 2μm

- Numerical conditions:
  Inflow velocity = 2 cm/s
  Exhaust gas temperature = 500 ℃
  Soot size = 60 nm

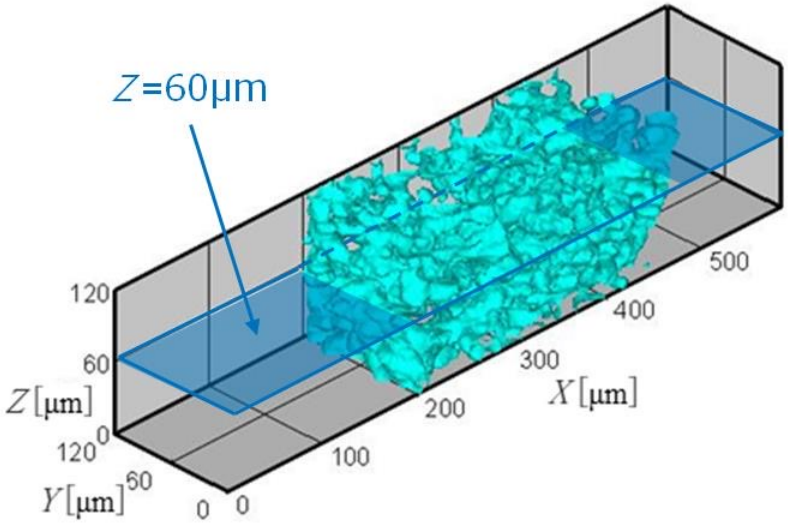


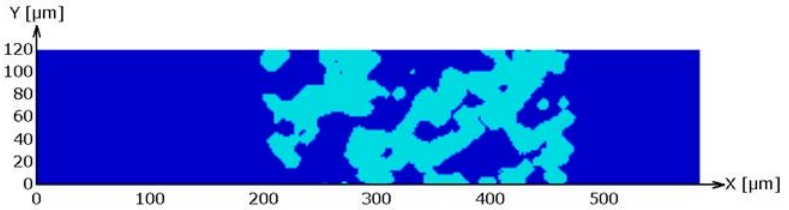
As for the filtration, **Brownian diffusion** and **interception effects** were considered. By neglecting the soot layer formation caused by soot deposition, the saturated value was set to be the initial filtration efficiency.

$$\eta = \frac{\text{Trapped soot}}{\text{Trapped soot} + \text{Soot leakage}}$$

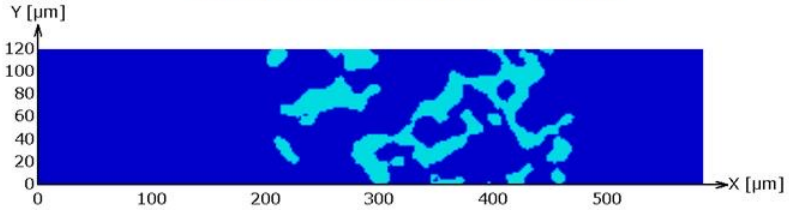


Original Substrate and Three Samples

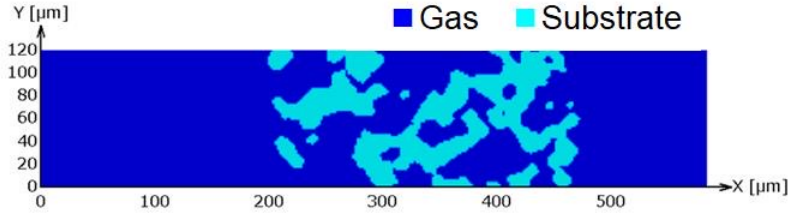




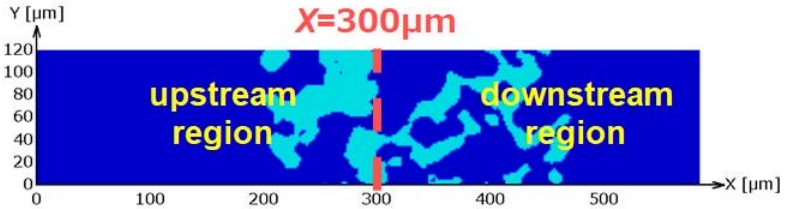
Sample 1: Thick (ε = 0.504)



Sample 2: Thin (ε = 0.739)



Original substrate by Xray CT (ε = 0.630)

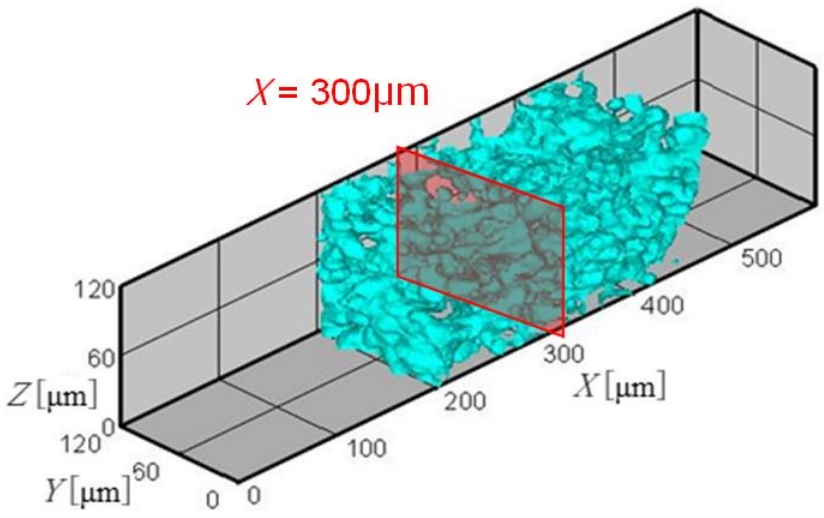


Sample 3: Front thick rear thin (ε = 0.655)

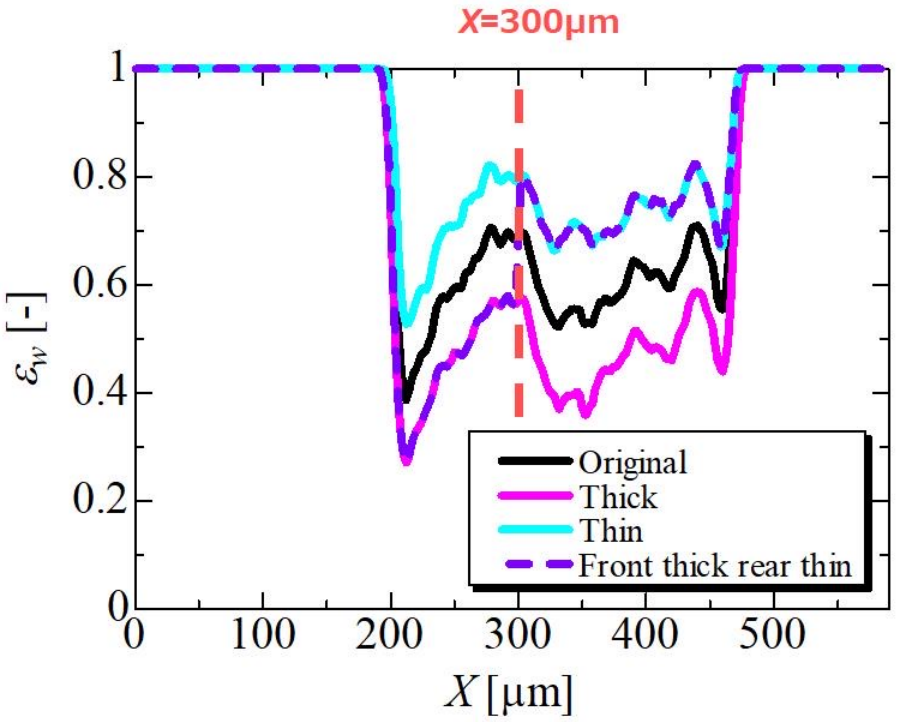
Combination of thick and thin (Front thick rear thin)

- By decreasing porosity (ε) in the upstream region (X<300μm), the filtration efficiency can be **enlarged**
- By increasing ε in the downstream region (X>300μm), ΔP can be **smaller**

Distributions of Porosity



Substrate Structure



Distribution of porosity

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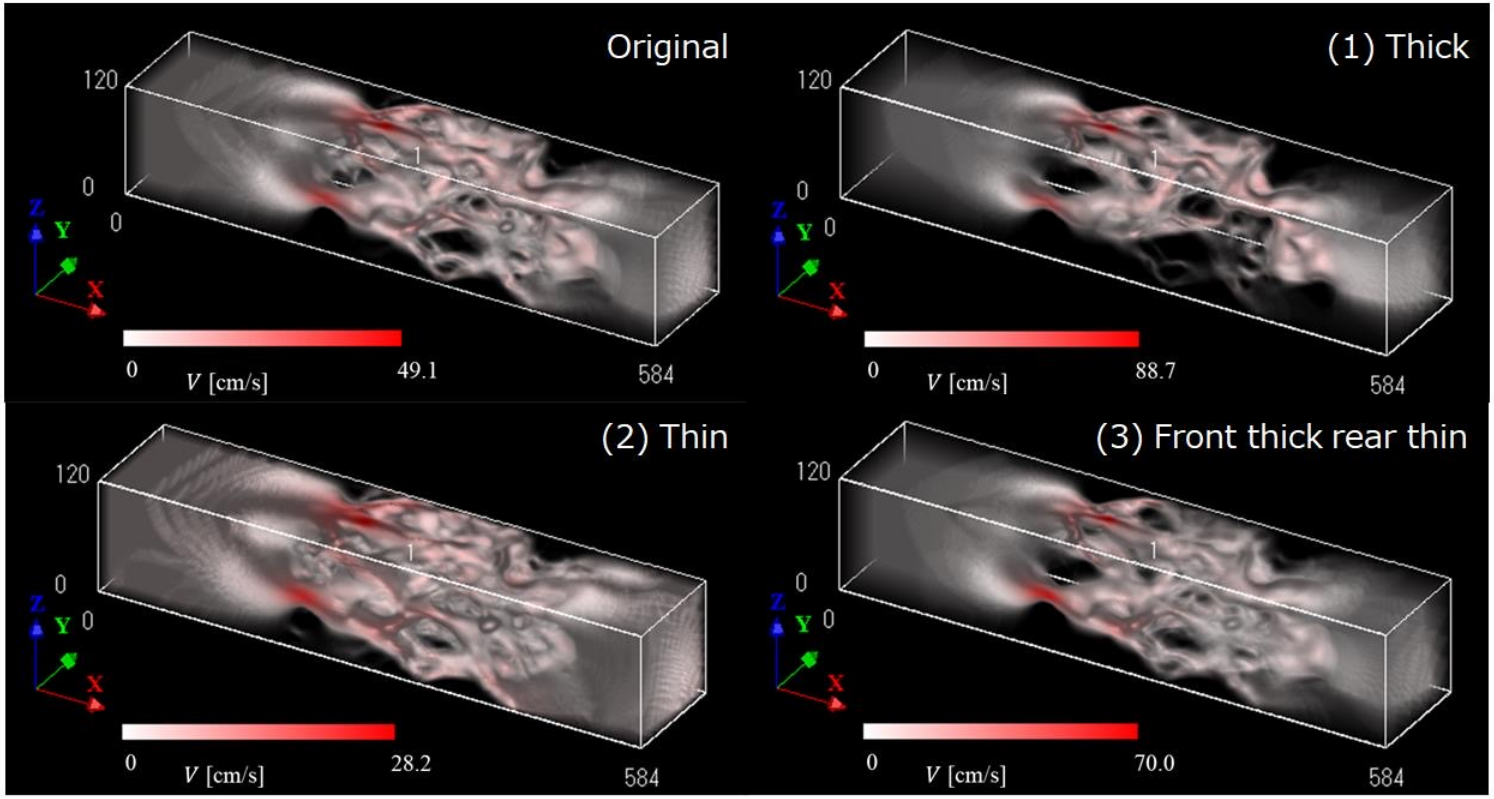
Flow Field and Maximum Velocity

Profiles of velocity across the filter wall

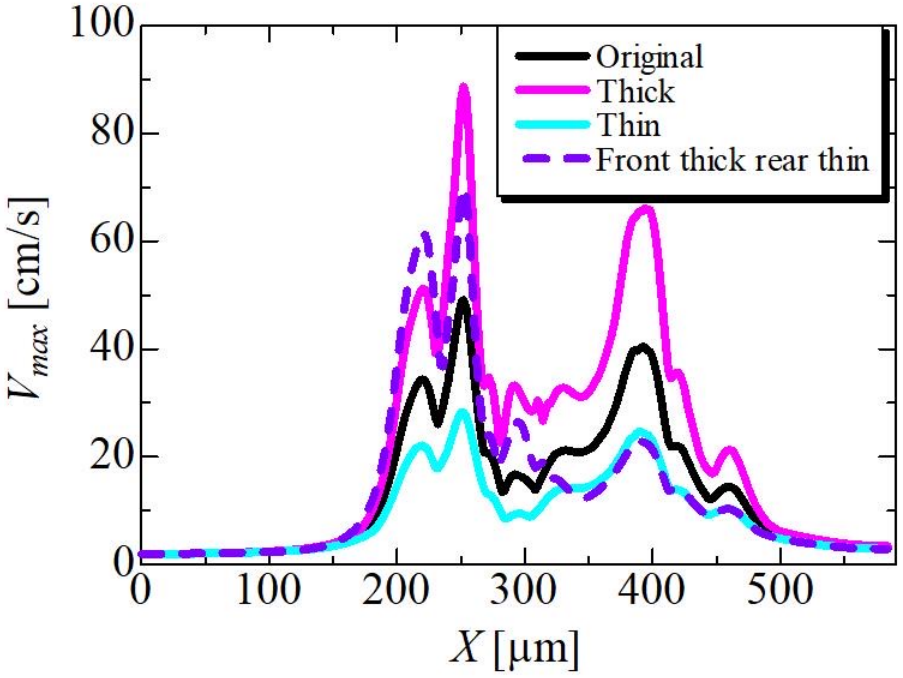


Sample 1: Flow becomes **narrower**, and some channels **disappear**

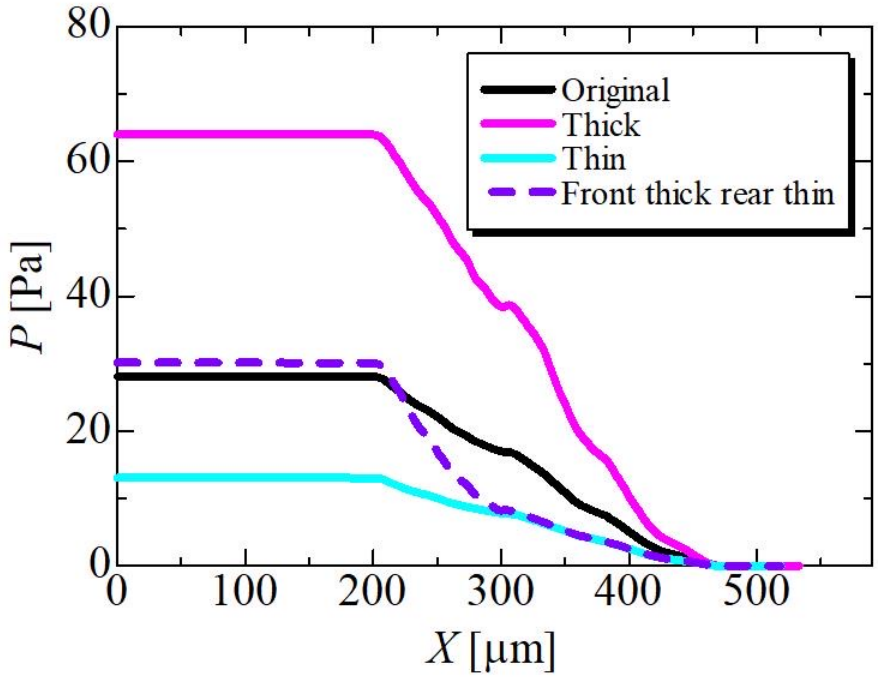
Sample 2: Width of the flow is **wider**, with **lower** velocity

Sample 3: The **higher** velocity upstream, the **lower** velocity downstream

Maximum Velocity and Pressure Change



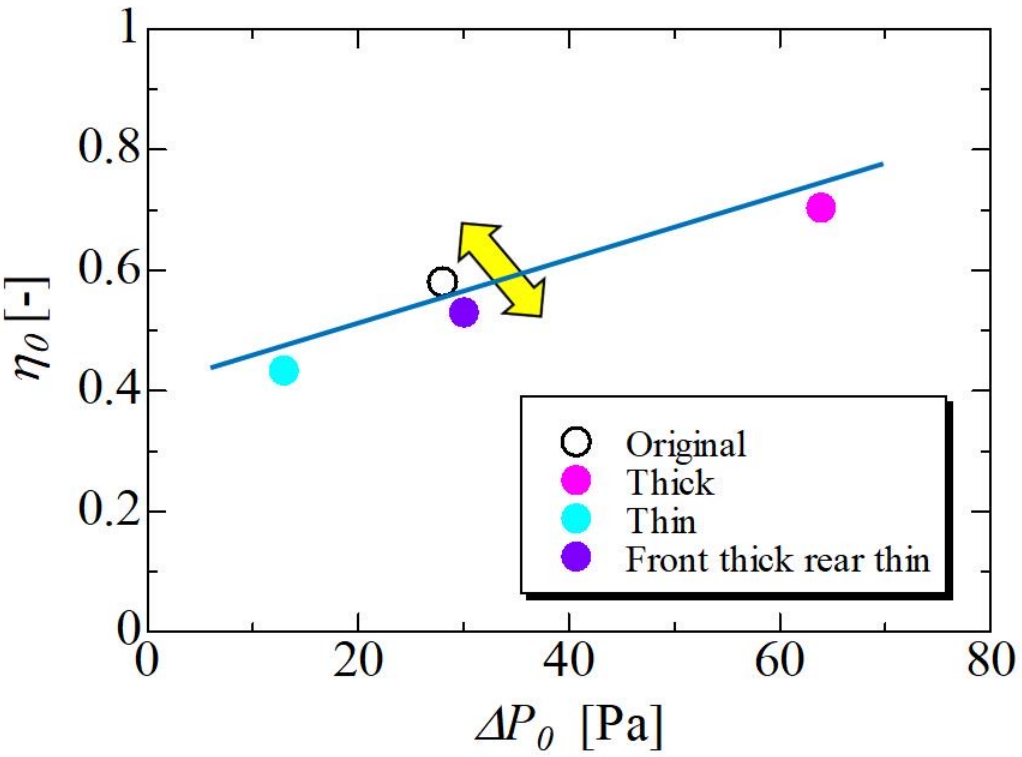
Maximum Velocity



Pressure Change

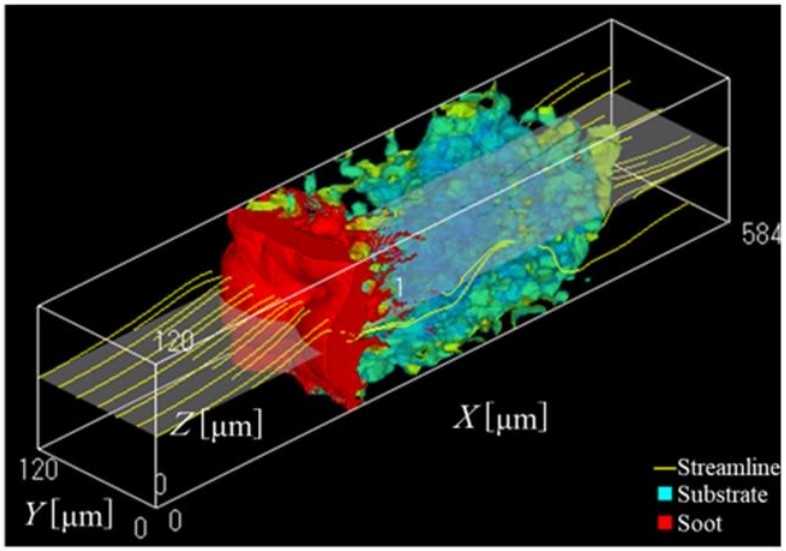
- As the porosity is smaller, the maximum velocity is increased
- In case of front thick rear thin, the initial pressure drop is slightly larger

Pressure Drop and Filtration Efficiency

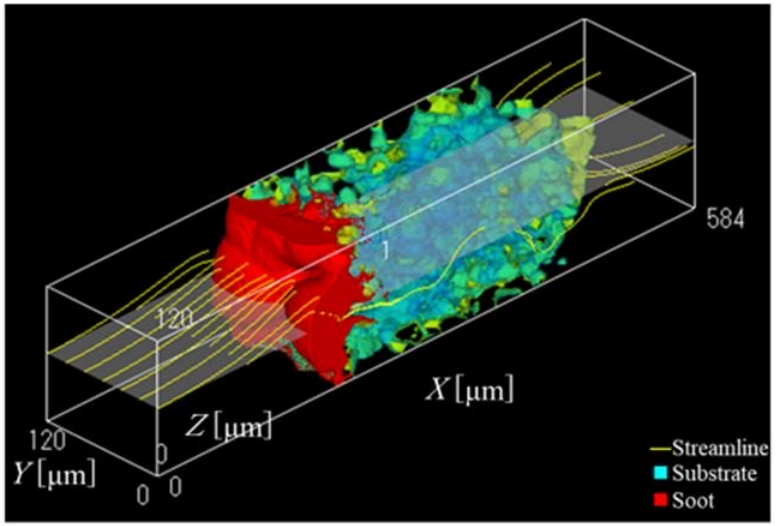


- Between the initial pressure drop and filtration efficiency, a **linearity** is roughly observed (tradeoff between η and ΔP)
- By using combination of front thick and rear thin, the relationship between initial filtration efficiency and the pressure drop is **shifted**

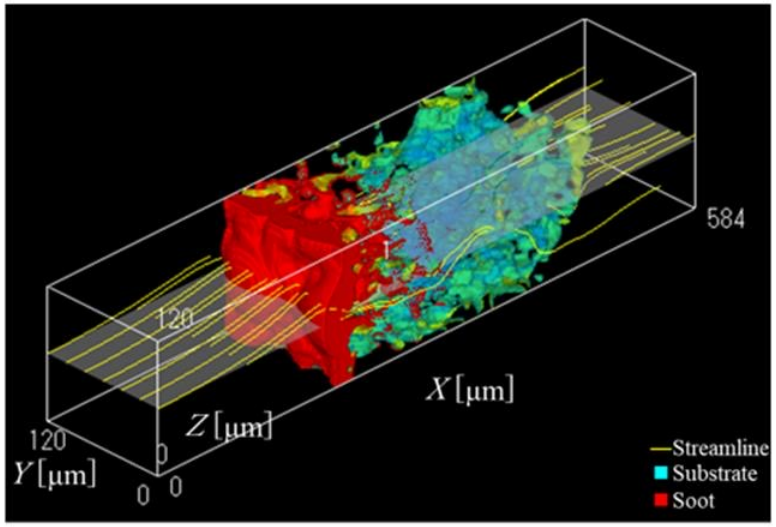
Flow Fields with Streamline (ρ_s=1.0g/L)



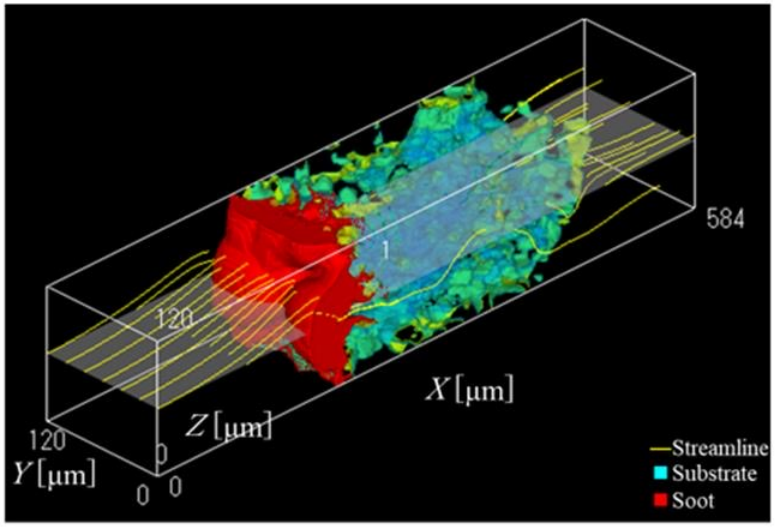
(a) Original



(b) Thick

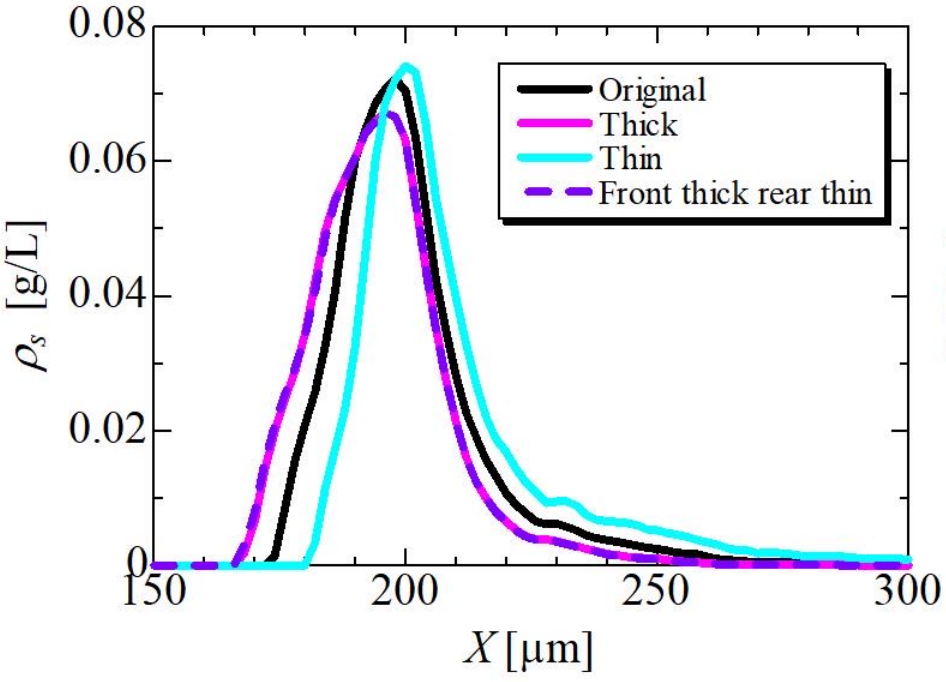


(c) Thin

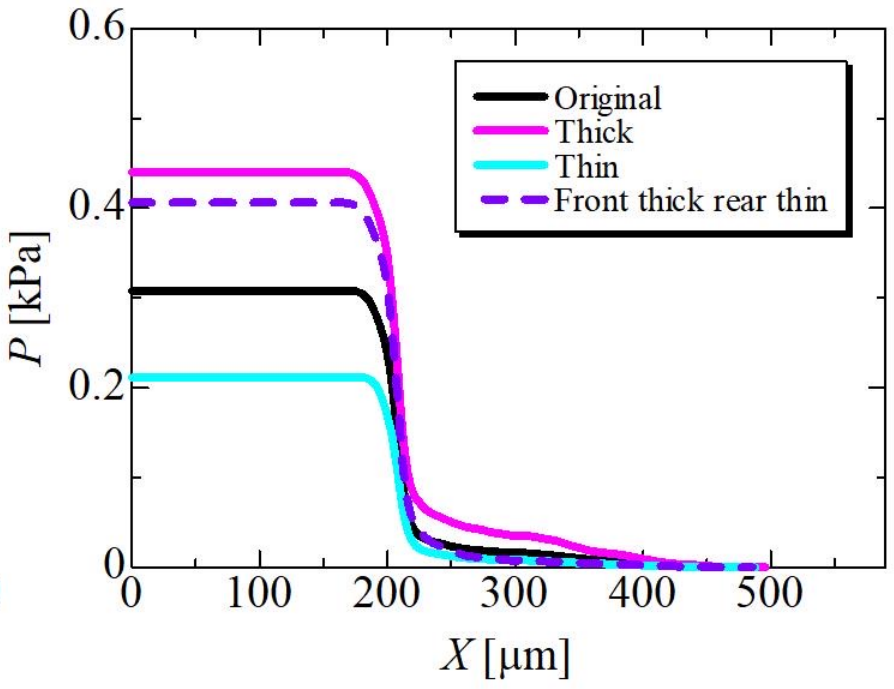


(d) Front thick rear thin

Deposited Soot Mass and Pressure Change



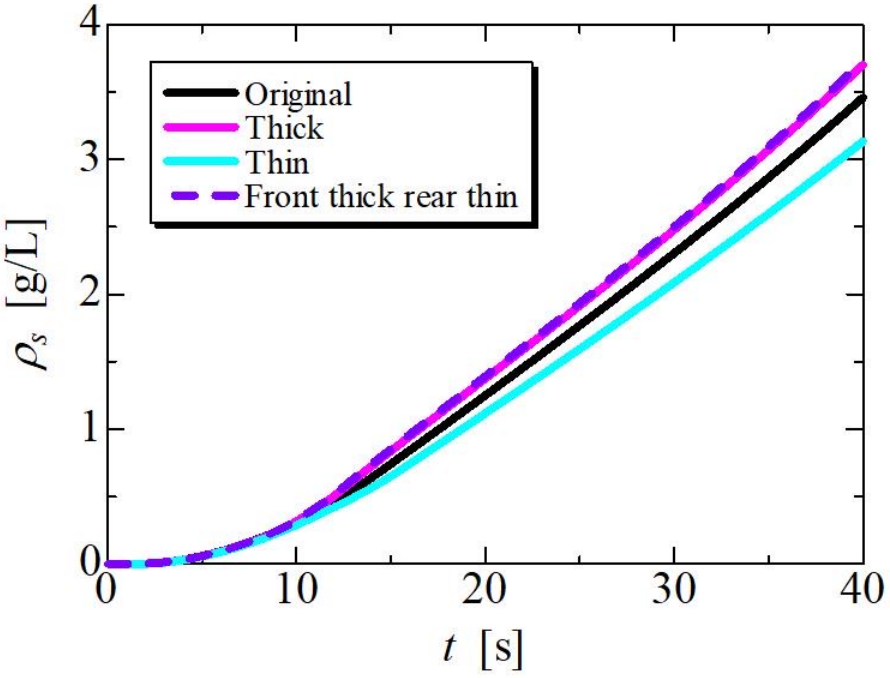
Distribution of deposited soot mass



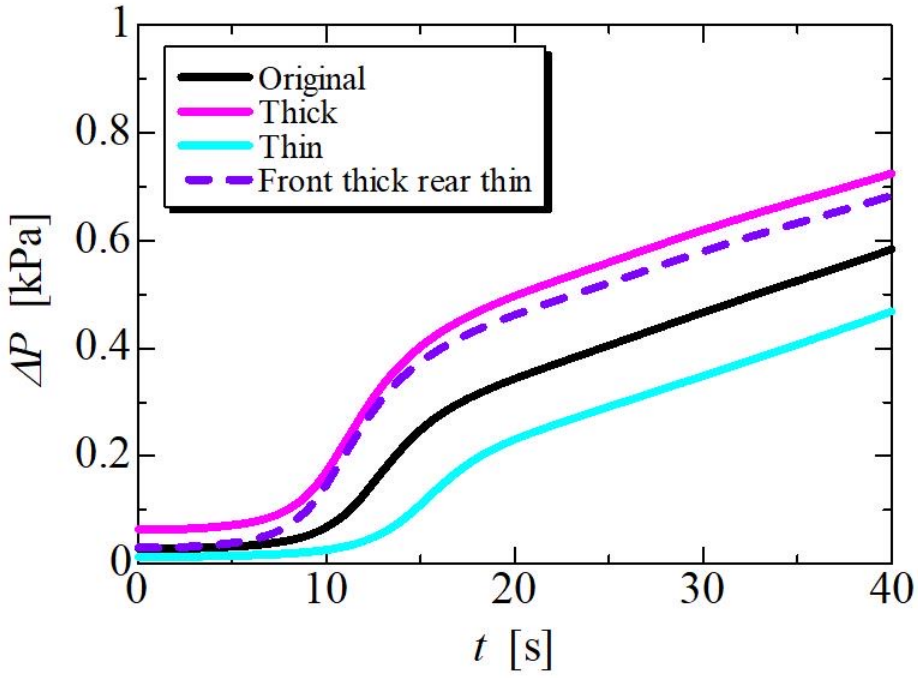
Pressure change

- As the porosity is lower, **more** soot is deposited in the **upstream** region
- In case of front thick rear thin, the pressure drop is larger than the original substrate, but it is smaller than thick filter.

Deposited Soot Mass and Pressure Drop



Deposited Soot Mass



Pressure Drop

- As the porosity is lower, **more soot is trapped**
- In comparison with the thick filter, the pressure drop of front thick rear thin is reduced when the amount of deposited soot is the same

Summary

- Simulations of GPF were conducted by the lattice Boltzmann method
- Substrate structure by X-ray CT and three more samples were used
- Approach for evaluating the initial filtration efficiency was explained
- Pressure drop and filtration efficiency were discussed
- More simulations will be needed for optimization of substrate structure

END