Numerical Investigation of the Impact of Washcoat on Particulate Filter Performance

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GPS Génie par la simulation — SBES Simulation - Based Engineering Science

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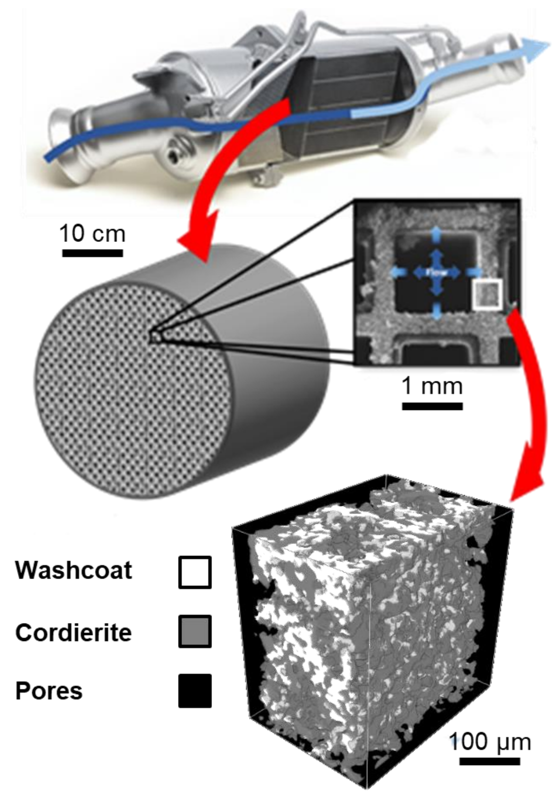
1 CATALYST-COATED PARTICULATE FILTERS



- → Gasoline Direct Injection (**GDI**) engines are **fuel efficient** but release **soot nanoparticles** and **harmful gases**
- → Gasoline Particulate Filters (**GPF**) coated with Three-Way Catalyst (**TWC**) have been developed to **capture soot** while **reducing NO_x, CO and HC emissions**
- → Optimizing exhaust gas after-treatment systems is making our **air cleaner** and our **lives longer**

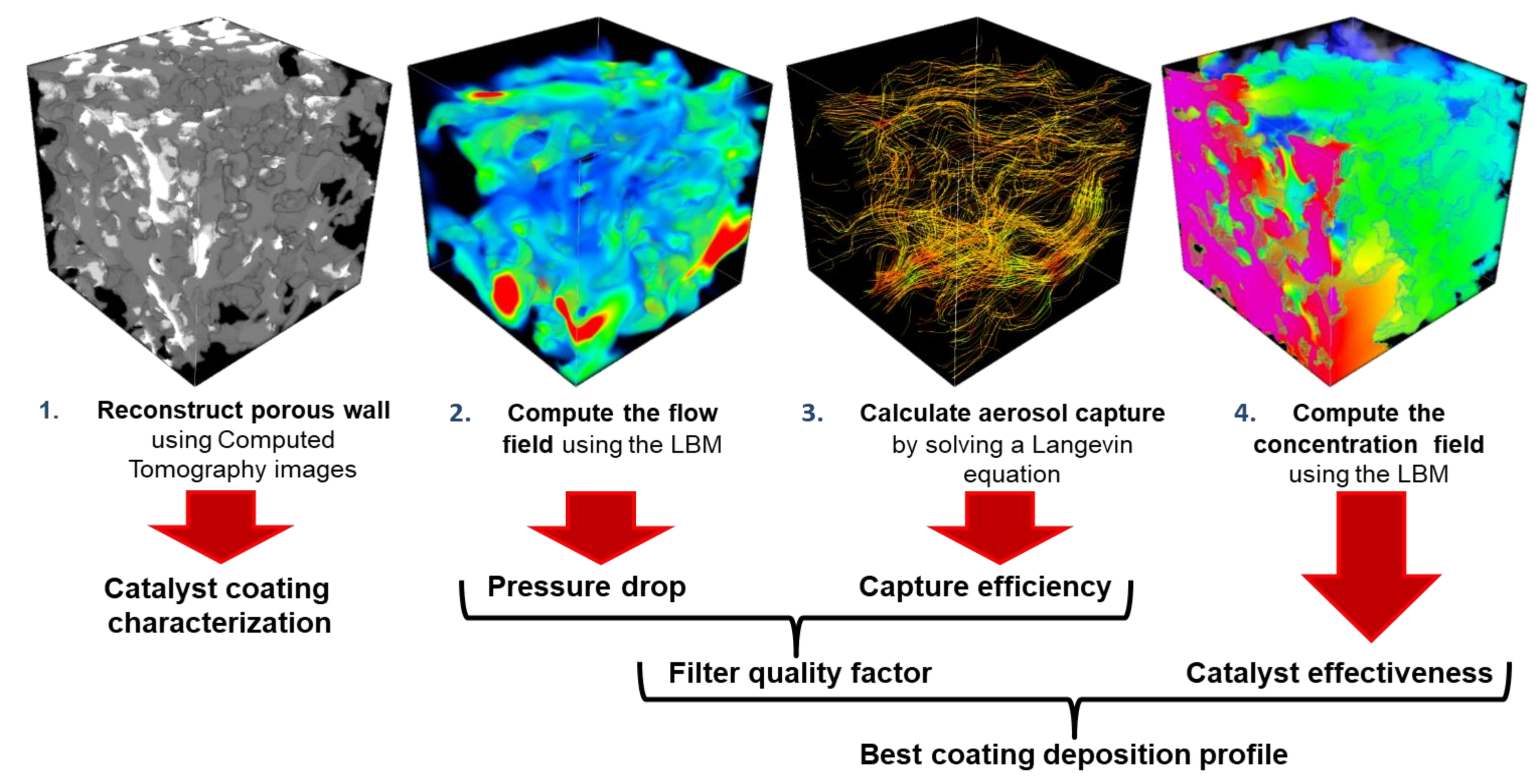
2 OBJECTIVE

Determine the optimal catalyst amount and profile into the GPF porous wall

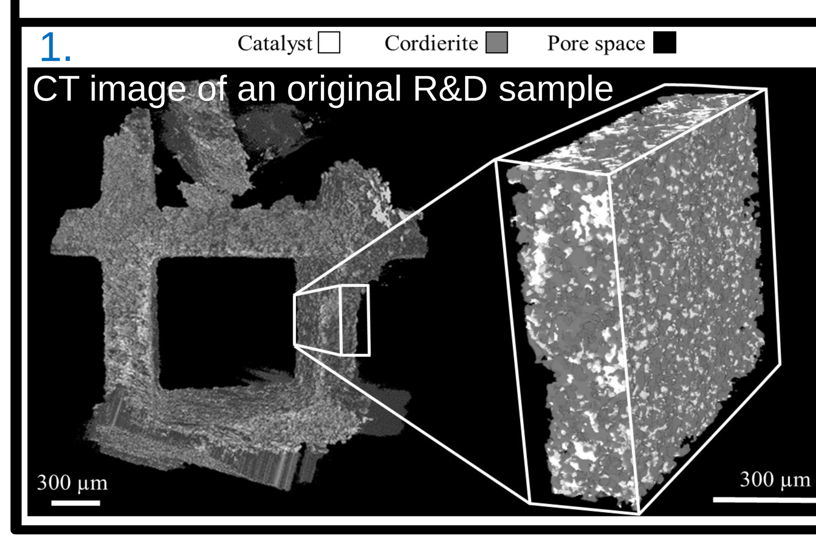
1. Pressure drop (ΔP)
2. Filter efficiency (E_F)
3. Catalyst coating conversion

To help address the problem of air quality in our cities

3 FOUR-STEP NUMERICAL METHODOLOGY



1.



2.

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}.\nabla\mathbf{u} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\mathbf{u} + \overbrace{\mathbf{F}}^{\text{External force}}$$

$$\nabla.\mathbf{u} = 0$$

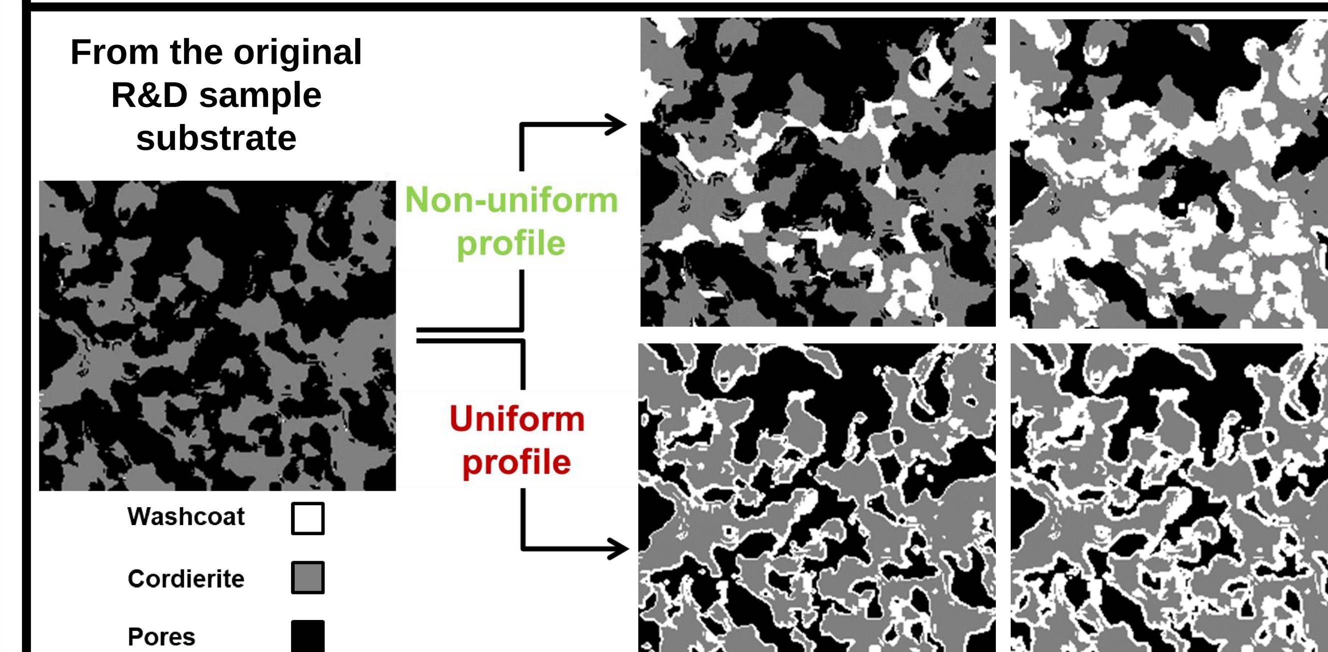
3.

$$m\frac{d\mathbf{v}(t)}{dt} = \frac{3\pi\mu d_p}{C_c}(\mathbf{u}(\mathbf{r}) - \mathbf{v}(t)) + \overbrace{\mathbf{\Gamma}(t)}^{\text{Brownian diffusion}}$$

4.

$$\frac{\partial c}{\partial t} + \mathbf{u}.\nabla c = \nabla.(D\nabla c) + \overbrace{r}^{\text{Reaction rate}}$$

4 TWO CATALYST DISTRIBUTIONS INVESTIGATED



2D representation of 2 of the 10 catalyst amounts

2D representation of 2 of the 5 catalyst amounts

5 THE LATTICE BOLTZMANN METHOD (LBM)

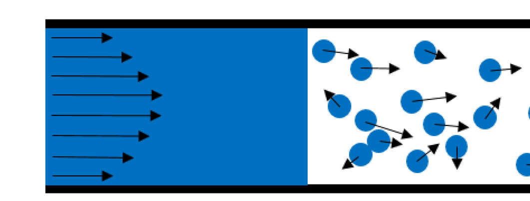
Navier-Stokes Equations (continuum mechanics)

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\mathbf{u} + \mathbf{f}$$

$$\nabla\cdot\mathbf{u} = 0$$

Discretization in space & time FEM/FDM/FVM

$$\mathbf{A}\mathbf{u} = \mathbf{b} \quad \text{or} \quad \mathbf{u}^{t+\delta_t} = \mathbf{f}(\mathbf{u}^t) \rightarrow \mathbf{u}(\mathbf{x},t)$$



$\mathbf{u}(\mathbf{x},t)$ $\quad \mathbf{u} = \frac{1}{\rho}\sum_i f_i\mathbf{e}_i$

Boltzmann Equation (statistical mechanics)

$$\partial_t f + \mathbf{e}\cdot\nabla f = -\frac{f - f^{eq}}{\tau}$$

Discretization in velocity space ($\mathbf{e}_i$)

$$\partial_t f_i + \mathbf{e}_i\partial_i f_i = -\frac{f_i - f_i^{eq}}{\tau}$$

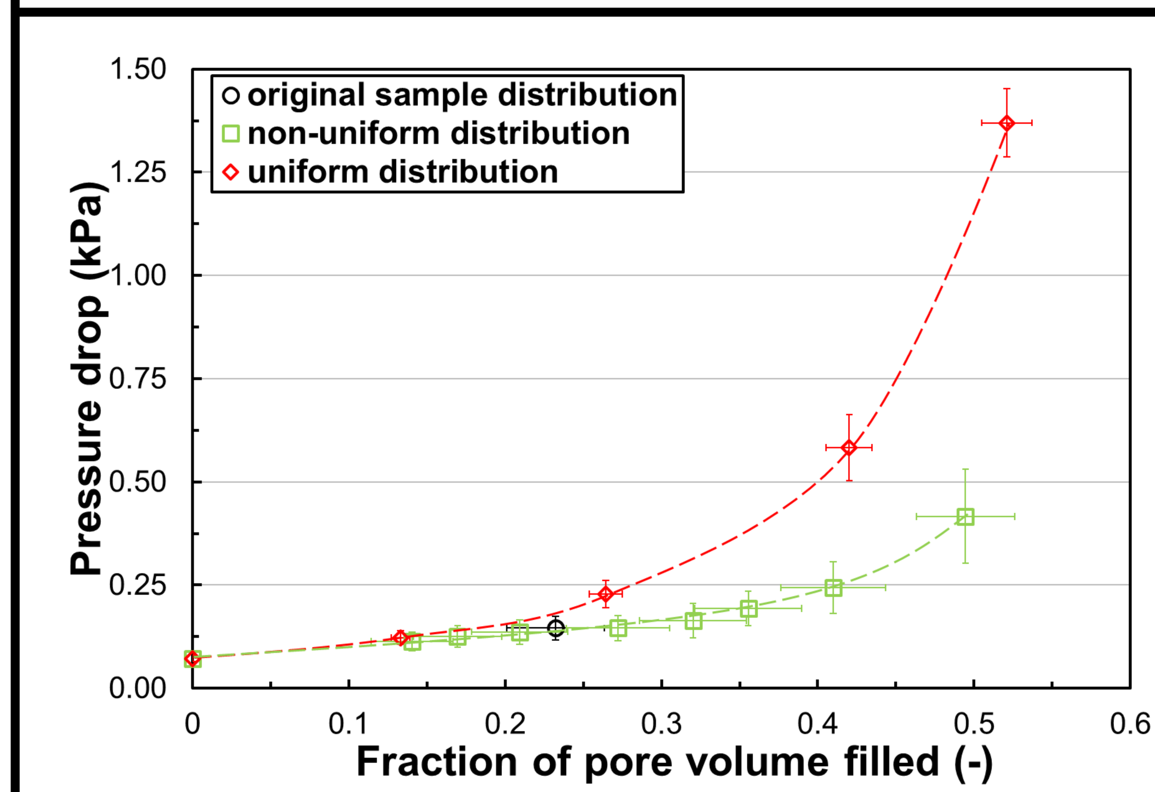
Discretization in time & space by FDM

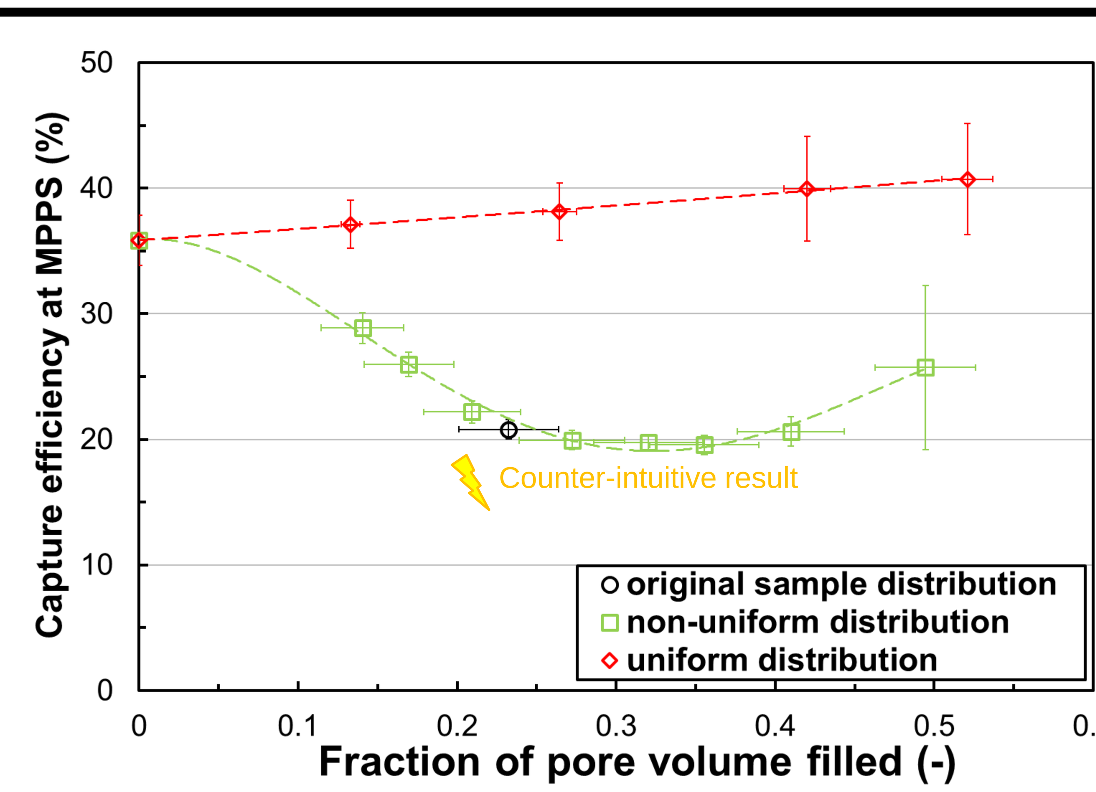
$$f_i(\mathbf{x}+\mathbf{e}_i\delta_t, t+\delta_t) - f_i(\mathbf{x},t) = -\frac{f_i(\mathbf{x},t) - f_i^{eq}(\mathbf{x},t)}{\tau^*}$$

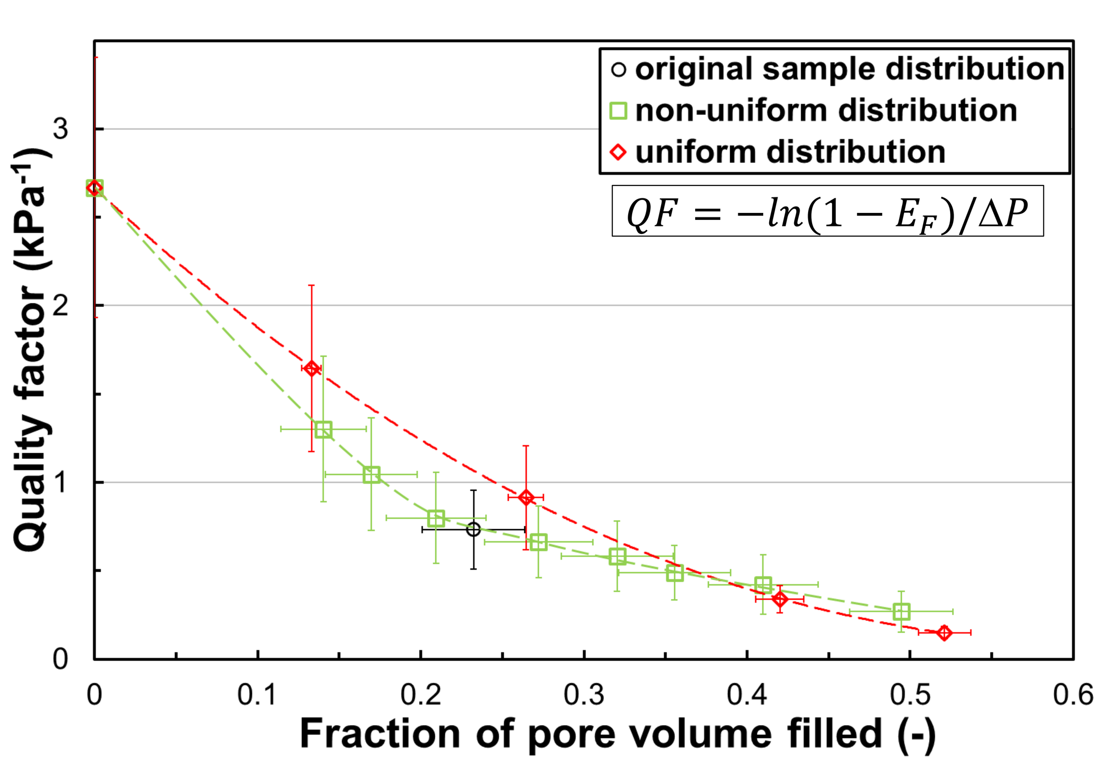
Integration in the velocity space ($\mathbf{e}_i$)

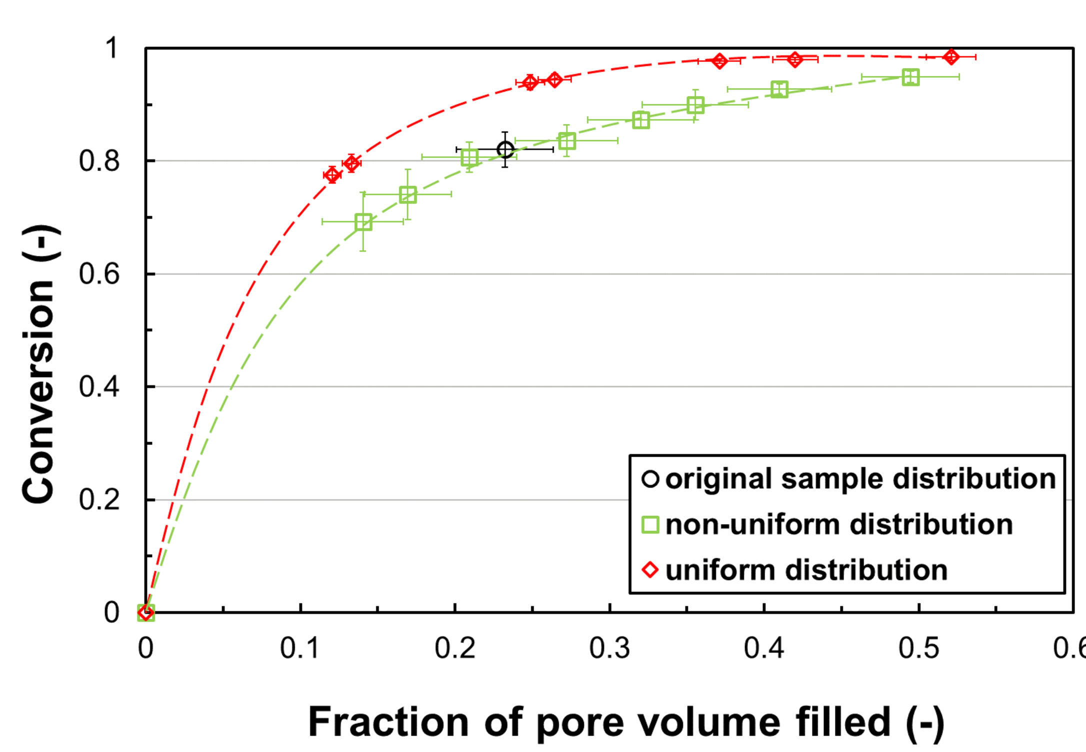
$$\mathbf{u} = \frac{1}{\rho}\sum_i f_i\mathbf{e}_i \rightarrow \mathbf{u}(\mathbf{x},t)$$

6 PREDICTED FILTRATION AND CONVERSION PERFORMANCE

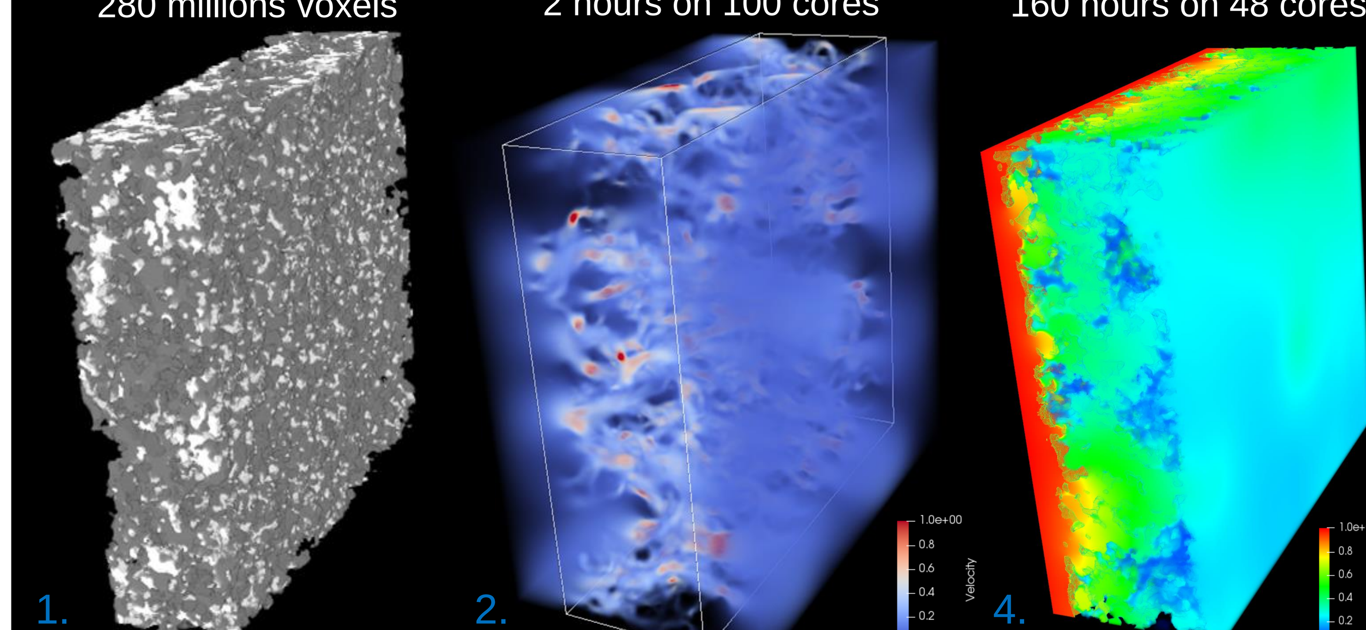




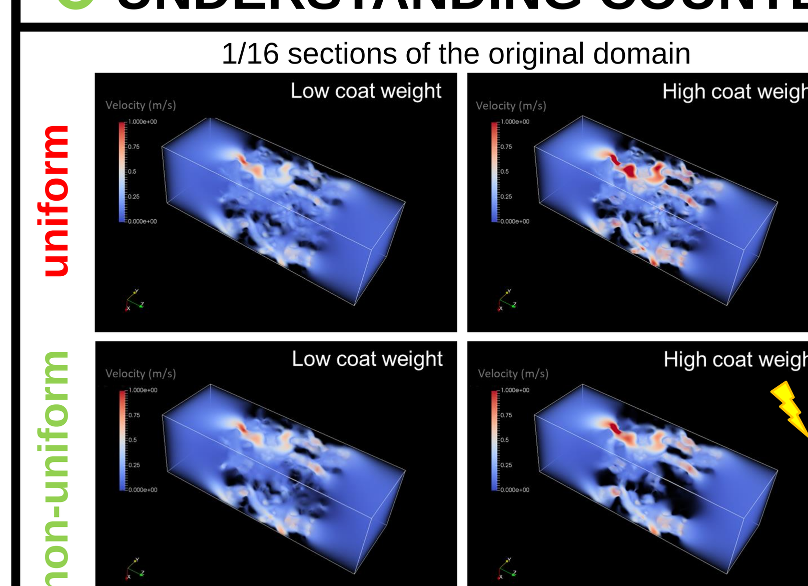




7 LBM: A LARGELY PARALELIZABLE METHOD



8 UNDERSTANDING COUNTER-INTUITIVE RESULT

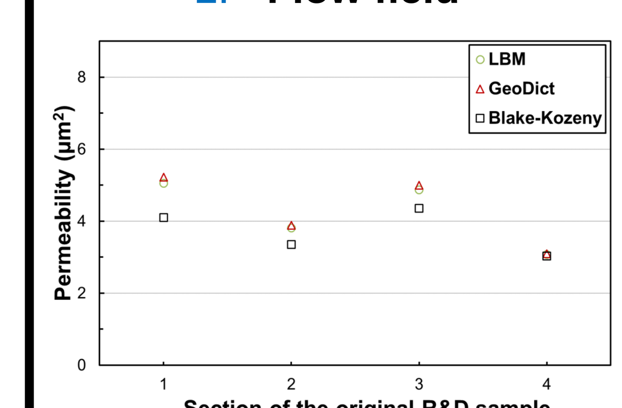


The fluid pathways remain the same from a low to a high coat weight but channel cross-sections are reduced leading to a better capture efficiency

Enhanced channeling results from an increase of coat weight, but largest channels are less efficient at capturing aerosols

9 LBM VERIFICATION

2. **Flow field**

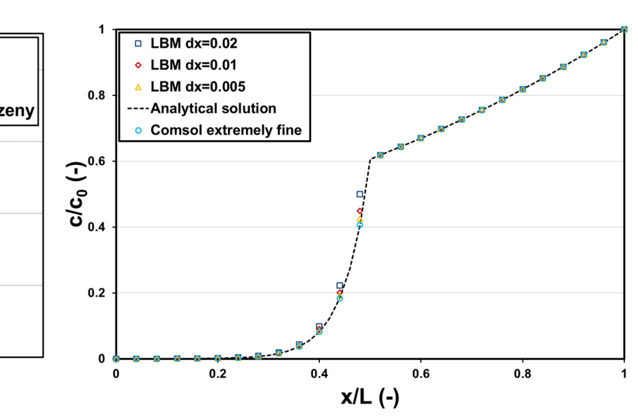


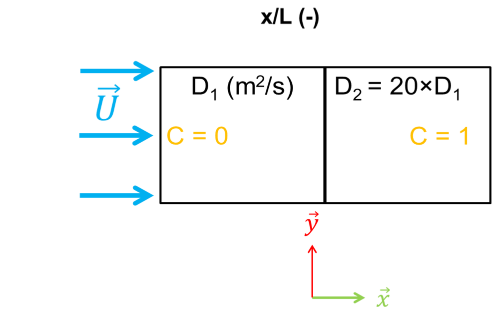
$$k_{Darcy} = \frac{\mu U L}{\Delta P}$$

$$k_{BK} = \frac{1}{4.16 S_0^2}\left[\frac{(1-\varepsilon)^2}{\varepsilon^3}\right]$$

$S_0 = specific\ surface\ area$

4. **Concentration field**





10 CONCLUSIONS

- → **A uniform catalyst distribution profile provides up to 30% better filtration and 10% better conversion**
- → **Detailed flow field analysis provides good insights in the physical phenomena impacting GPF performance**
- → **The proposed model provides guidelines to GPF manufacturers in search of a simple and controllable way of optimizing the integration of TWC and GPF**

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d_p	Particle diameter	U	Superficial flow velocity
E_F	Filter efficiency	ΔP	Pressure drop
k	Filter wall permeability	ε	Filter wall porosity
D	Diffusion coefficient	C_c	Cunningham correction factor
L	Filter wall thickness	c	Concentration
v	Particle velocity	ν,μ	Fluid cinematic/dynamic viscosity
p	Pressure	ρ	Fluid density