Particle tracking in porous media to estimate aerosol filtration

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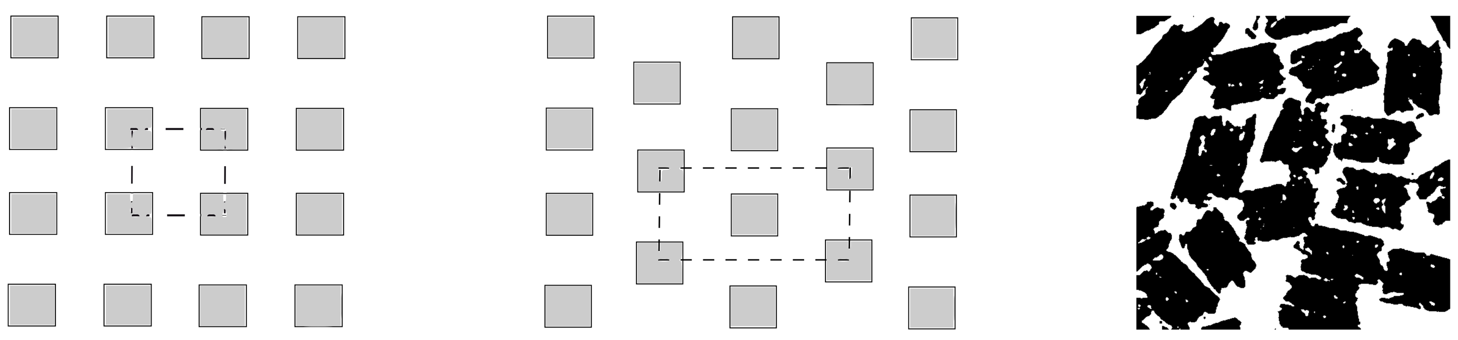
Motivation

- Study impaction and diffusion filtration of aerosols in various porous media



Gas-particle two-phase flow

- Gas phase

$$\begin{cases} \dfrac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u} = -\nabla p + \mu\nabla^2\mathbf{u} - \dfrac{1}{\epsilon}\Gamma\mathbf{u} \quad (\epsilon \ll 1) \\ \nabla\cdot\mathbf{u} = 0 \end{cases}$$

with

$$\Gamma(x) = \begin{cases} 1 & \text{if } x \in \text{solid} \\ 0 & \text{if } x \in \text{solid} \end{cases}$$

- Particle phase: Including Stokes and Brownian dynamics

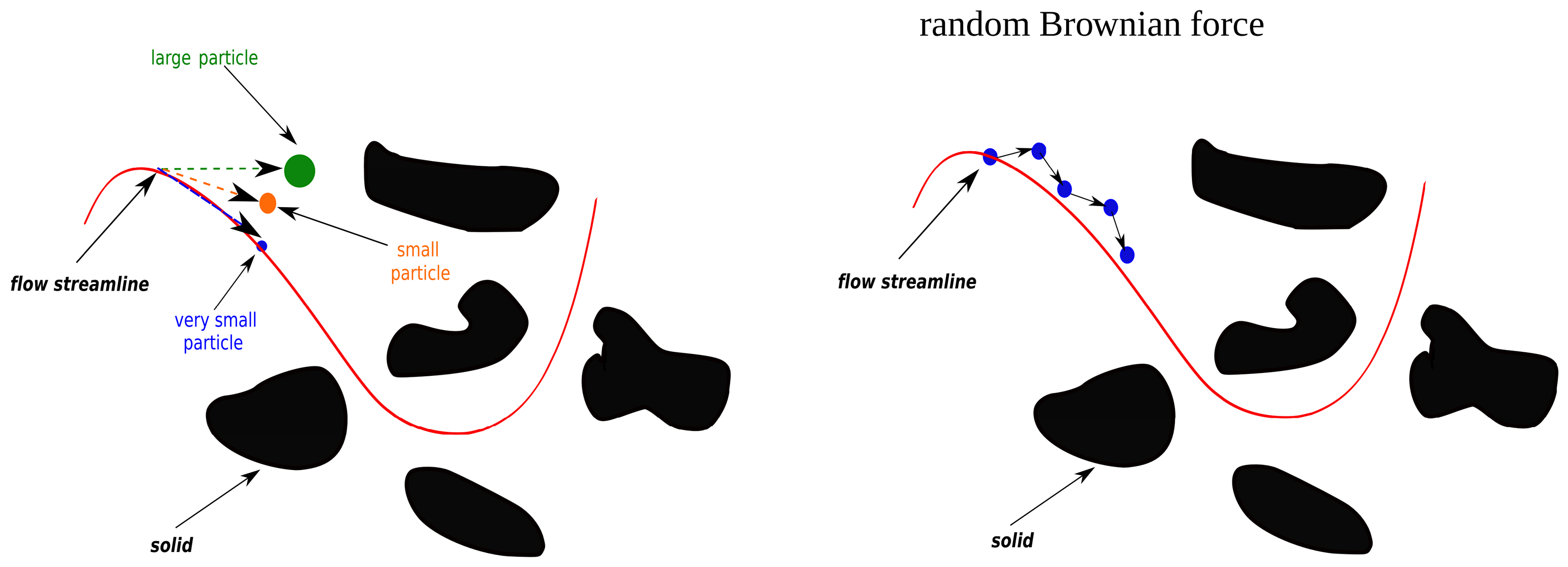
$$\begin{cases} \dfrac{\mathrm{d}\mathbf{x}}{\mathrm{d}t} = \mathbf{v} \\ \dfrac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = \beta(\mathbf{u}-\mathbf{v}) + \mathbf{A}(t) \end{cases}$$

with statistical properties of $\mathbf{A}$:

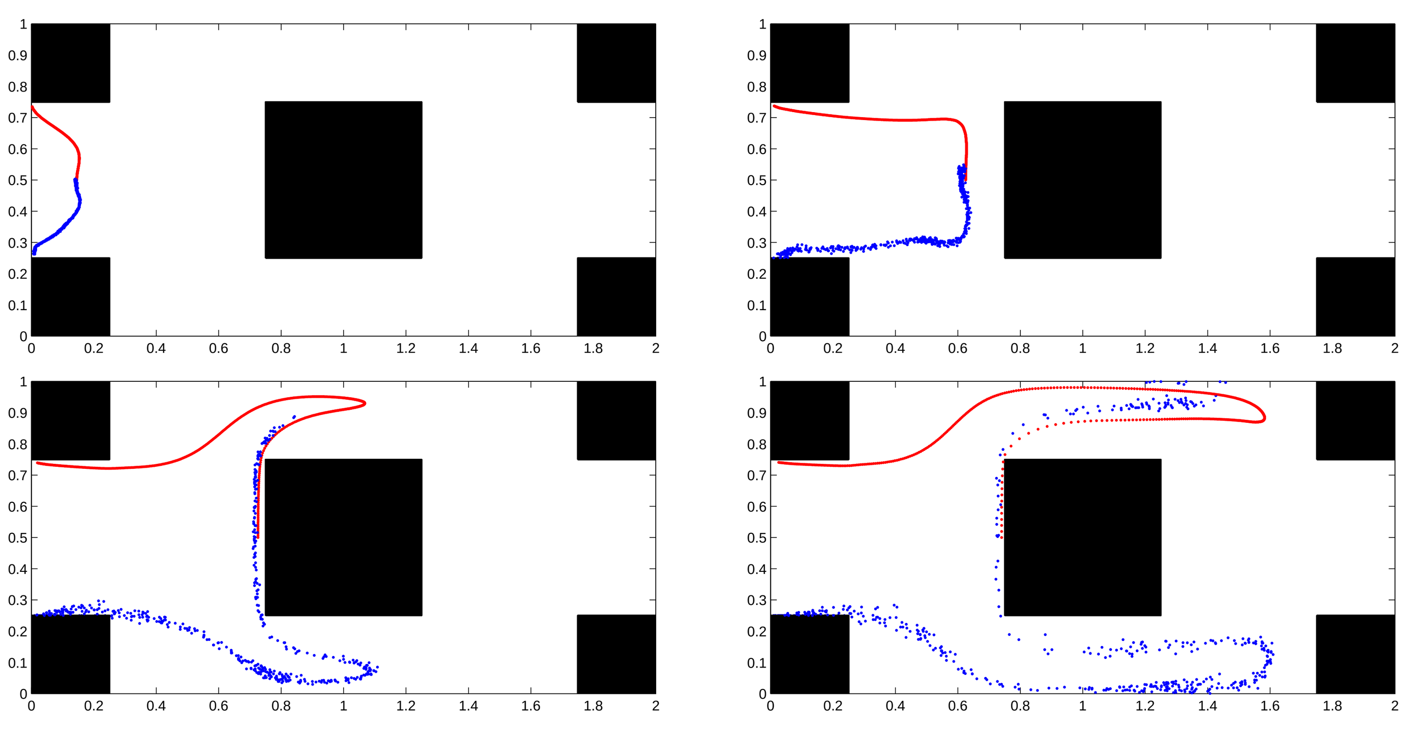
$$\begin{aligned} \langle \mathbf{A}(t) \rangle &= 0 \\ \langle \mathbf{A}(t)\mathbf{A}(s) \rangle &= K\delta(t-s) \end{aligned}$$

Filtration mechanisms: Inertial Impaction and Diffusion

- Particles deposit at the solid surface since they deviate from the streamlines
  - Large particles deviate due to the inertial forces
  - Very small particles deviate due to the random Brownian force

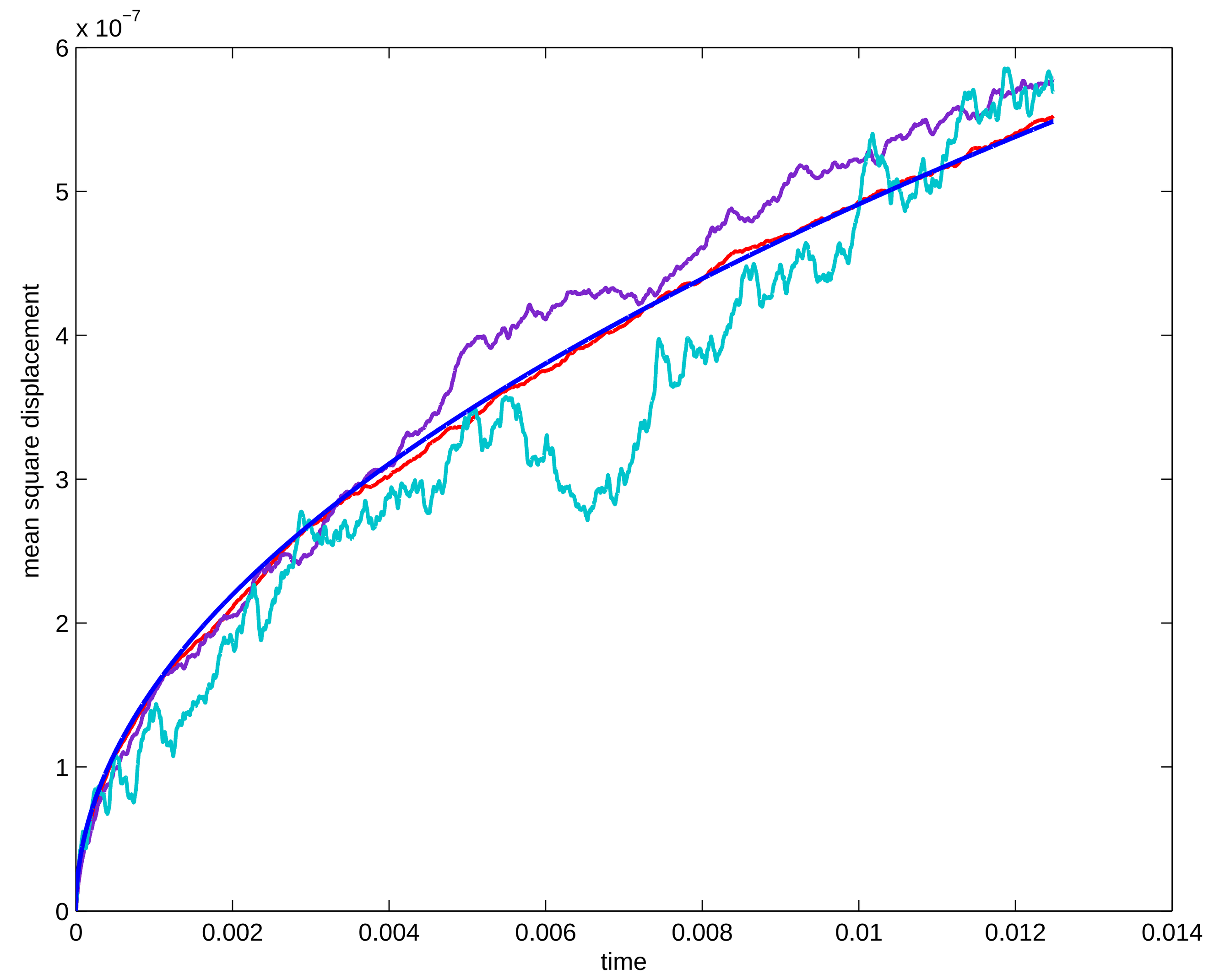


Particle dynamics in a staggered porous medium



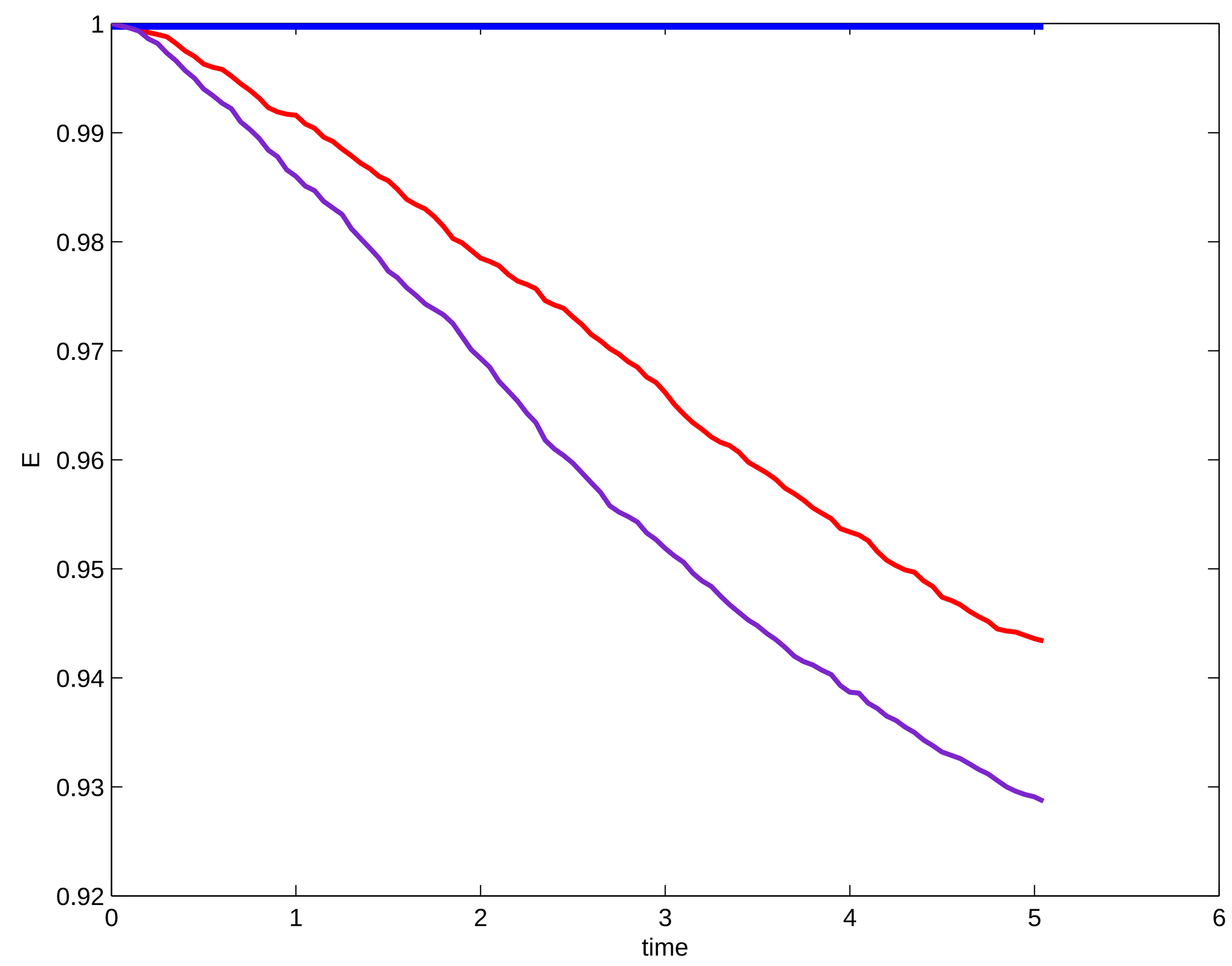
- Snapshots of particle positions. Initially particles are placed on $x = 0, z = 0$ line. Brownian force is applied on blue particles, while red particles move only due to the Stokes drag.

Validation: Motion of a Brownian particle in 1D



- Numerically obtained mean square displacement and its theoretical prediction (blue curve) for N number of particles : $N = 10$ (cyan curve), $N = 10^2$ (purple curve) and $N = 10^3$ (red curve).

Impaction and Diffusion filtration in a staggered porous medium



- Filtration of $0.1\mu m$ size water droplets when Brownian force is absent (blue curve), when Brownian force is present at low temperature (red curve) and at high temperature (purple curve).

Summary and Outlook

- Particle tracking method is developed to study behavior of particles in flow through porous media
- Developed method provides accurate description of inertial and diffusion impaction
- Filtration properties of complex porous media can be quantified