SIMULATION OF IMPACTION FILTRATION OF AEROSOL DROPLETS IN POROUS MEDIA

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Background

- Detailed description and simulation of droplet dynamics in a porous medium
- Quantify sensitivity of droplet behavior to the flow conditions, particle size and the complexity of the inner structure of the porous medium
- Application: estimation of removal efficiency of various porous filters

Modeling droplet motion in a gas flow

- Governing equations for the gas phase (Eulerian approach) :

$$\nabla \cdot \mathbf{u} = 0 \tag{1a}$$

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho_f}\nabla p + \nu \nabla^2 \mathbf{u} + \mathbf{f}. \tag{1b}$$

where

- * $\mathbf{u}$ fluid velocity
- * p pressure
- * ρ_f fluid mass density
- * ν kinematic viscosity
- * $\mathbf{f}$ body force representing solid porous medium

- Governing equations for the particle phase (Lagrangian tracking):

$$\frac{d\mathbf{x}}{dt} = \mathbf{v}\,(\mathbf{t}) \tag{2a}$$

$$\frac{d\mathbf{v}}{dt} = \frac{1}{\tau}(\mathbf{u}(\mathbf{x}, \mathbf{t}) - \mathbf{v}(\mathbf{t})) \tag{2b}$$

where

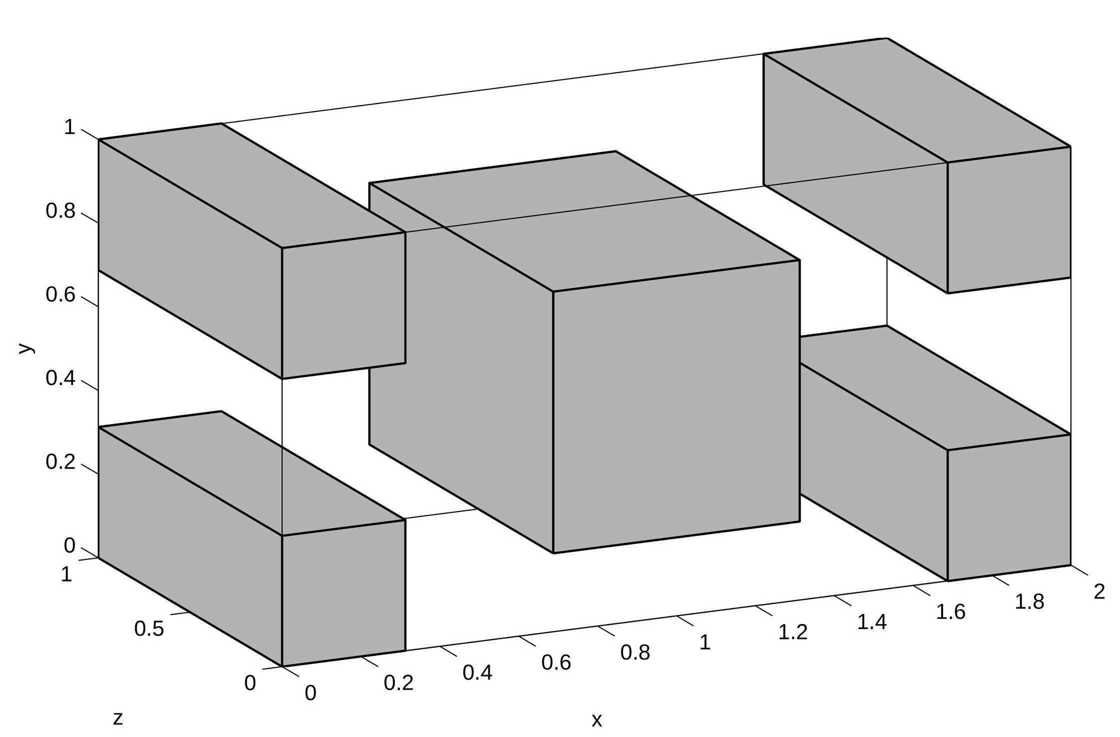
- * $\mathbf{x}$ particle position
- * $\mathbf{v}$ particle velocity
- * τ Stokes relaxation time

Numerical treatment

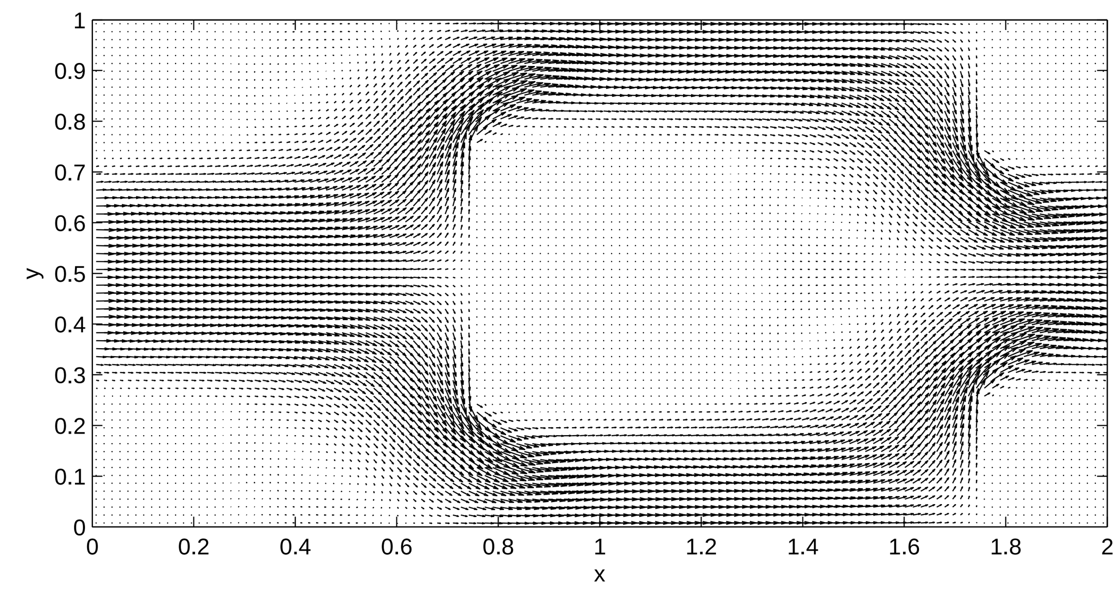
- Gas phase: skew-symmetric finite volume discretization method
- Porous media: immersed boundary (IB) method with volume penalization forcing
- Particle phase: first order time integration, trilinear interpolation of fluid velocity at particle position
- Filtration: particle is filtrated if its trajectory crosses the solid surface

Particle filtration in structured porous media

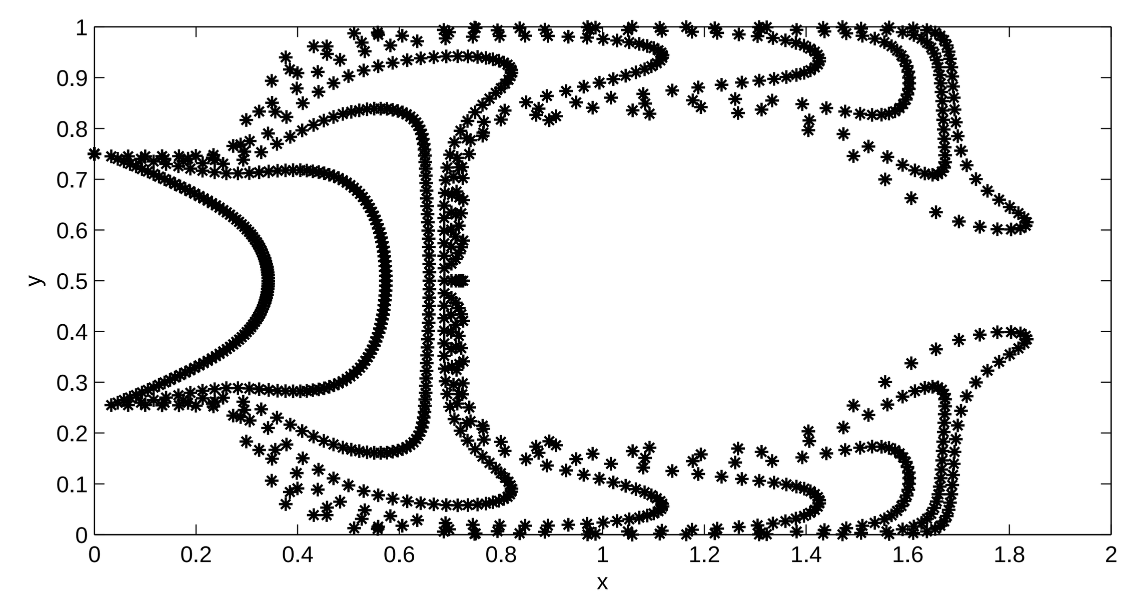
- Model porous medium: composed of periodic arrangements of staggered square rods in 3D. The solid part occupies 1/4 of a representative elementary volume.



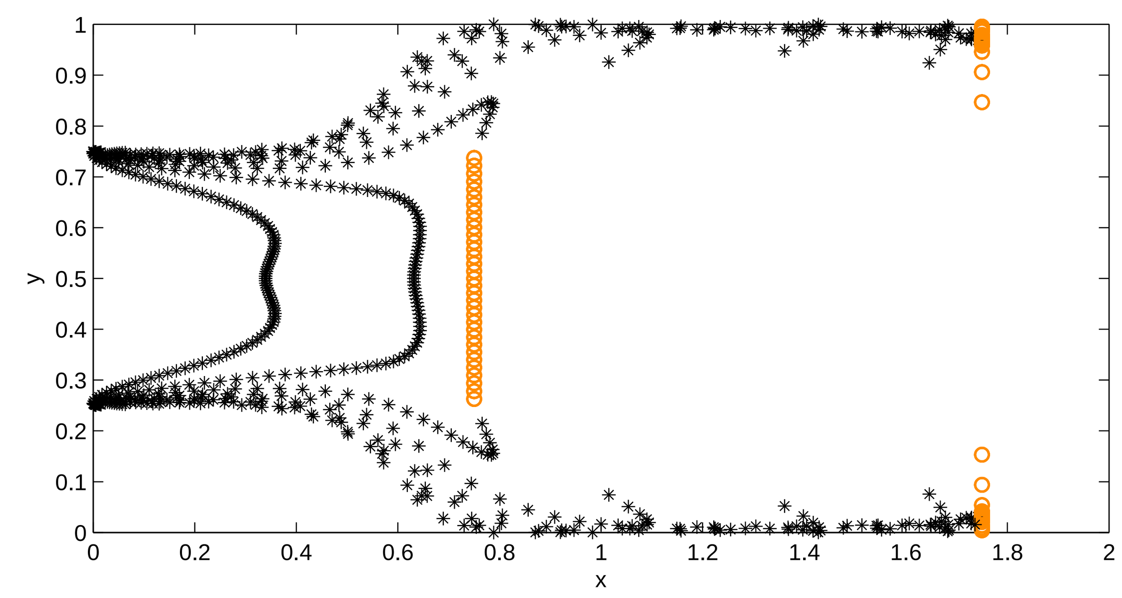
- Shown are in-plane velocity vectors of simulated flow through model porous medium corresponding to Reynolds number $Re = 100$, resolution of $(128 \times 64 \times 4)$ in (x, y, z) direction



- Particle trajectories emanating from a line of initial positions at $x = 0$ for different Reynolds numbers: (a) $\tau = 0.05, Re = 10$ and (b) $\tau = 0.05, Re = 100$ (unfiltered particles are denoted by $(*)$ and particles that hit an object by $(\circ)$). Each curve corresponds to a particular point of time.

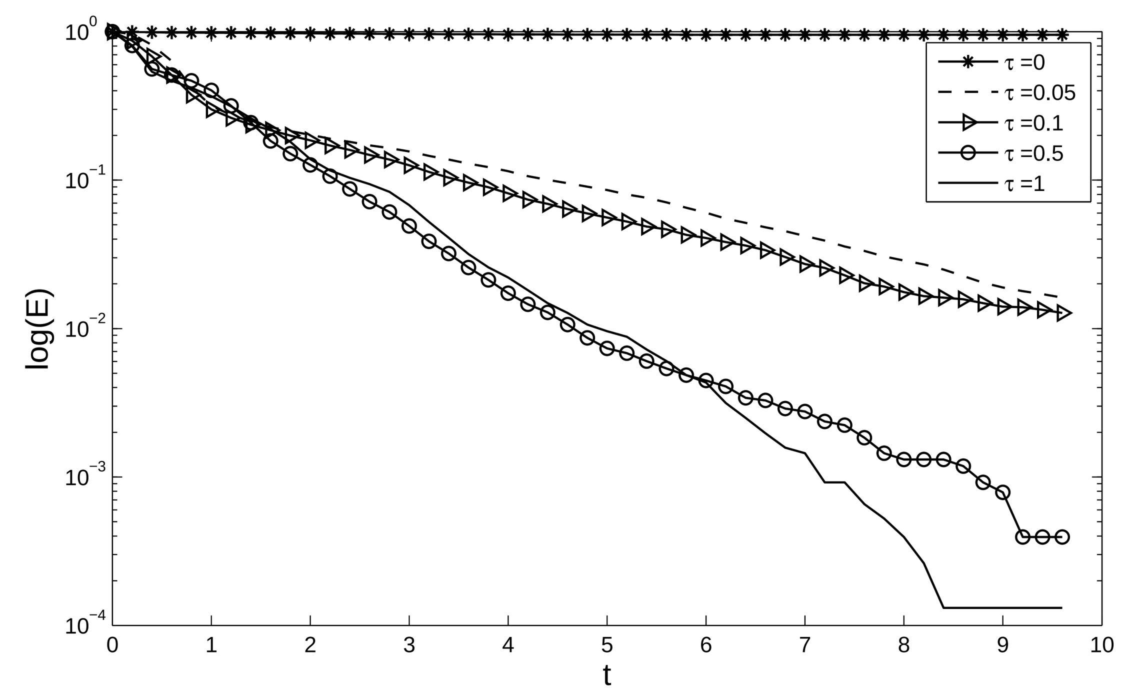


(a)



(b)

- Decay of the fraction of unfiltered aerosol droplets with time at different Stokes numbers and $Re = 100$: $\tau = 0$ (*), $\tau = 0.05$ (- -), $\tau = 0.1$ (▷), $\tau = 0.5$ (○) and $\tau = 1$ (-)



Concluding remarks

- Euler-Lagrange approach provides detailed microscopic information about the behavior of droplets inside the porous medium
- For considered Reynolds number an increase in the droplet inertia implies an increase in the filtration efficiency
- The decay of unfiltered particles follows an exponential trend

Outlook

- Further development of the algorithm to avoid numerical filtration at $\tau = 0$
- Include Brownian diffusion effect for low Stokes numbers
- Parameter study for filtration efficiency of realistic filters