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Backwash of dead-end capillary membranes: numerical simulation of multiphase flow with initial homogeneous particle distribution

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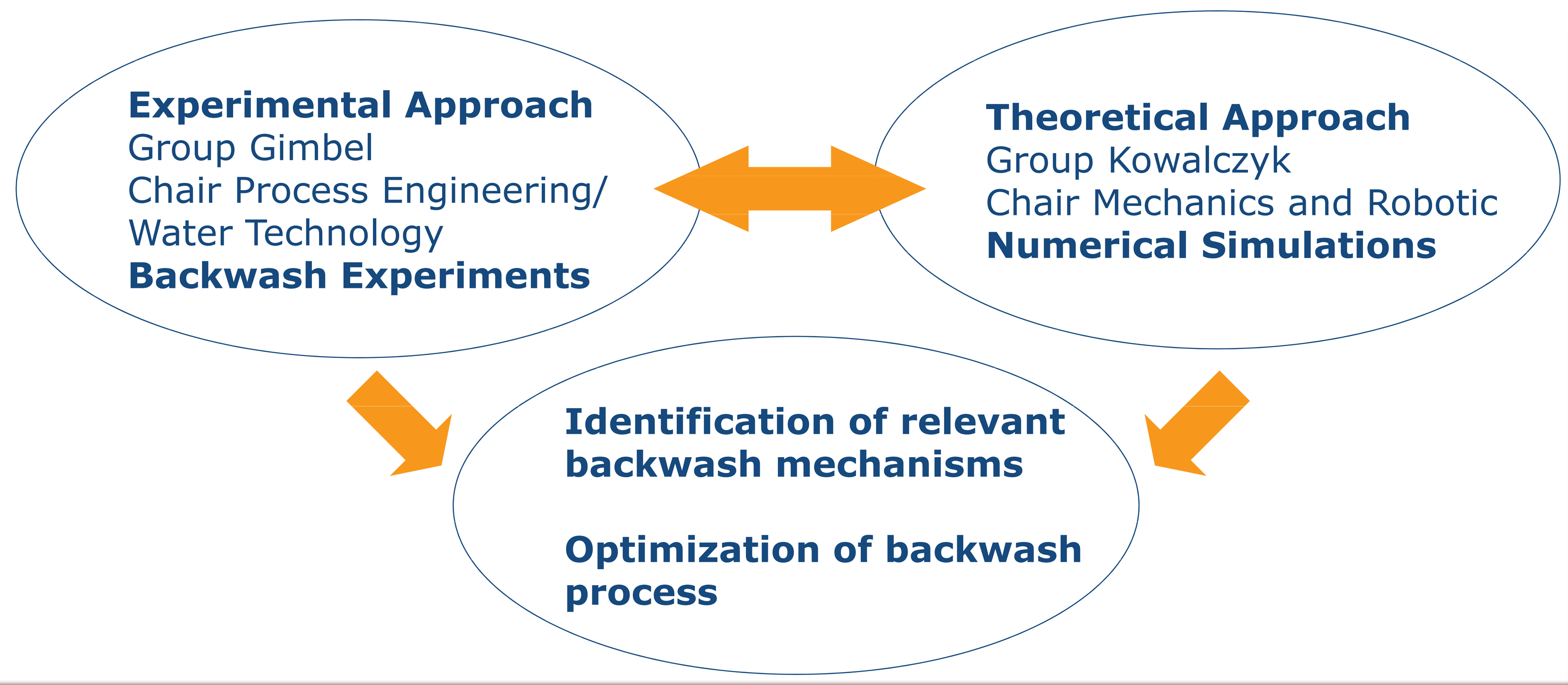
Objective

Development of an innovative method to investigate the fundamental physico-chemical mechanisms of the detachment of fouling layers within single ultrafiltration capillaries and its transport out of the capillary during backwash to

- Determine the influence of different backwash procedures on particle layers
- Optimize the backwash process



Methods

- Two phase model based on Euler-Euler approach is built within OpenFOAM 2.0.0
- The fluid flow is simulated as a continuous phase whereas the particles as a dispersed phase.

$$\frac{\partial(\alpha_k \rho_k)}{\partial t} + \nabla \cdot \left(\rho_k \alpha_k \bar{u}_k\right) = 0$$

$$\frac{\partial\left(\rho_k \alpha_k \bar{u}_k\right)}{\partial t} + \nabla \cdot \left(\rho_k \left(\alpha_k \bar{u}_k \otimes \bar{u}_k\right)\right) = -\alpha_k \nabla p + \nabla \cdot \left(\mu_{eff,k} \alpha_k \left(\nabla \bar{u}_k + \left(\nabla \bar{u}_k\right)^T\right)\right) + \bar{M}_{k,l} A$$

- Drag, lift, virtual mass and gravity forces are included in interfacial momentum exchange between the two phases.
- The capillary is backwashed with a constant flux of pure water 300 L h^{-1} m^{-2}.
- Monodisperse particles (10 µm, density 1050 kg m^{-3}) are homogeneously distributed in the capillary with a volume fraction of 10% at the beginning of the simulation.

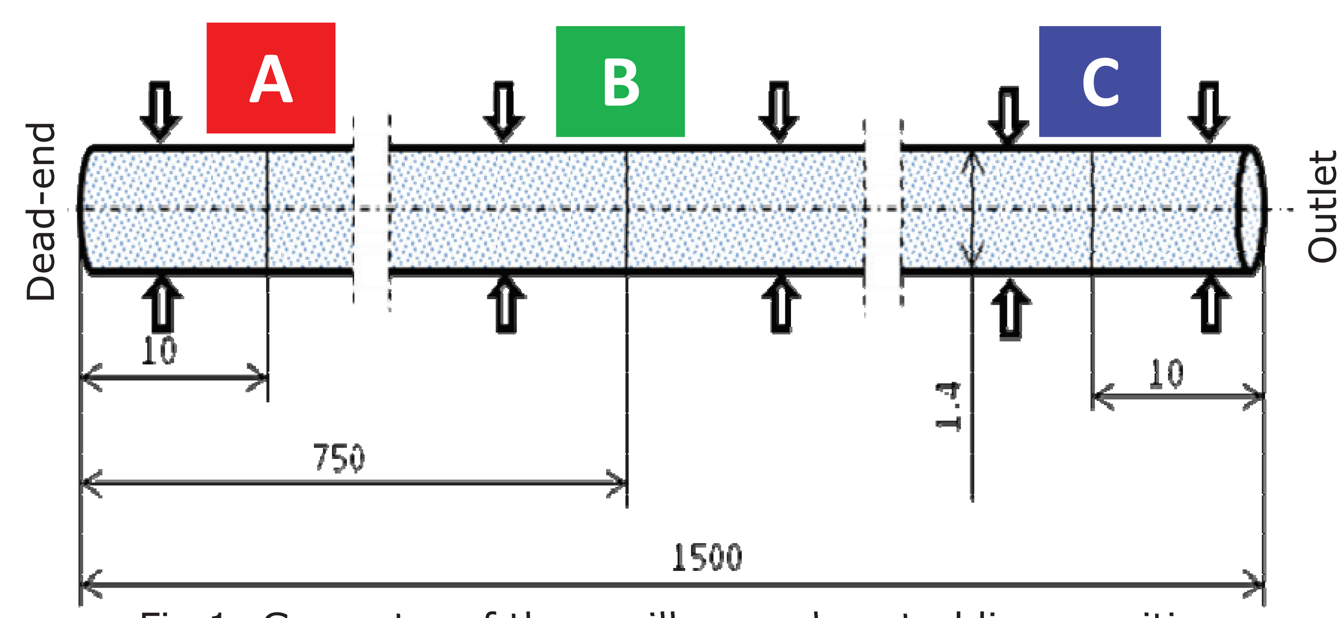


Fig.1: Geometry of the capillary and control lines position

Results

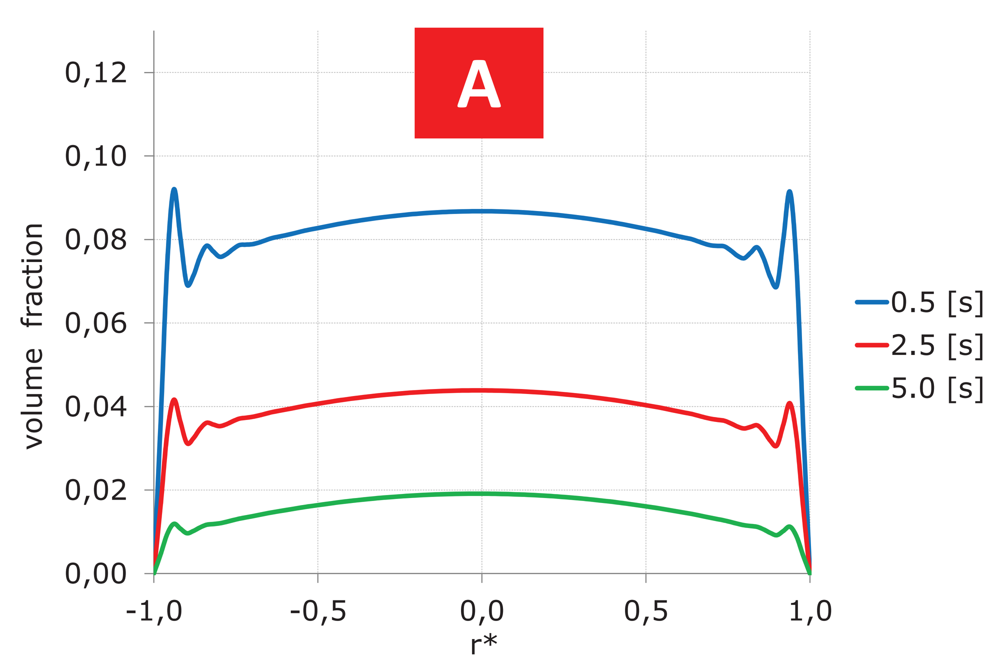


Fig.2: Particle distribution along the dimensionless inner capillary radius (control section A)

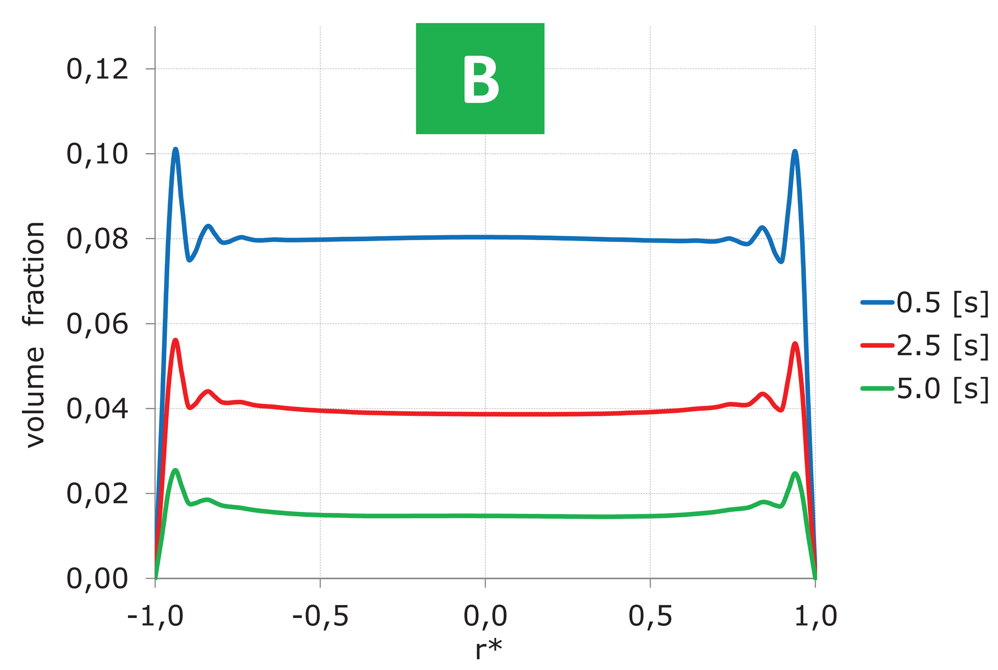


Fig.3: Particle distribution along the dimensionless inner capillary radius (control section B)

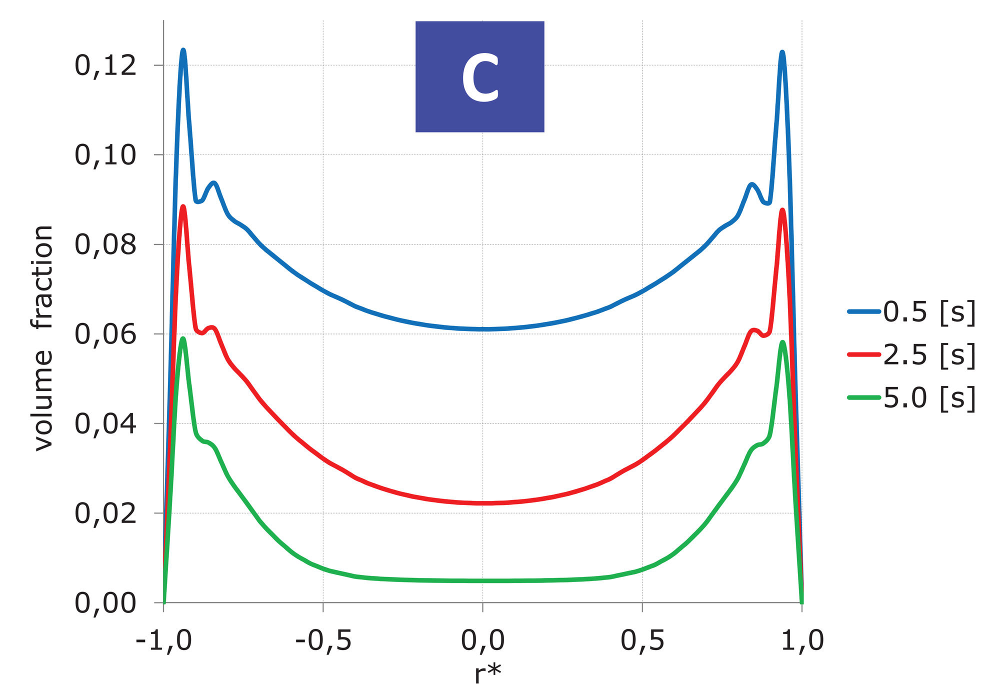


Fig.4: Particle distribution along the dimensionless inner capillary radius (control section C)

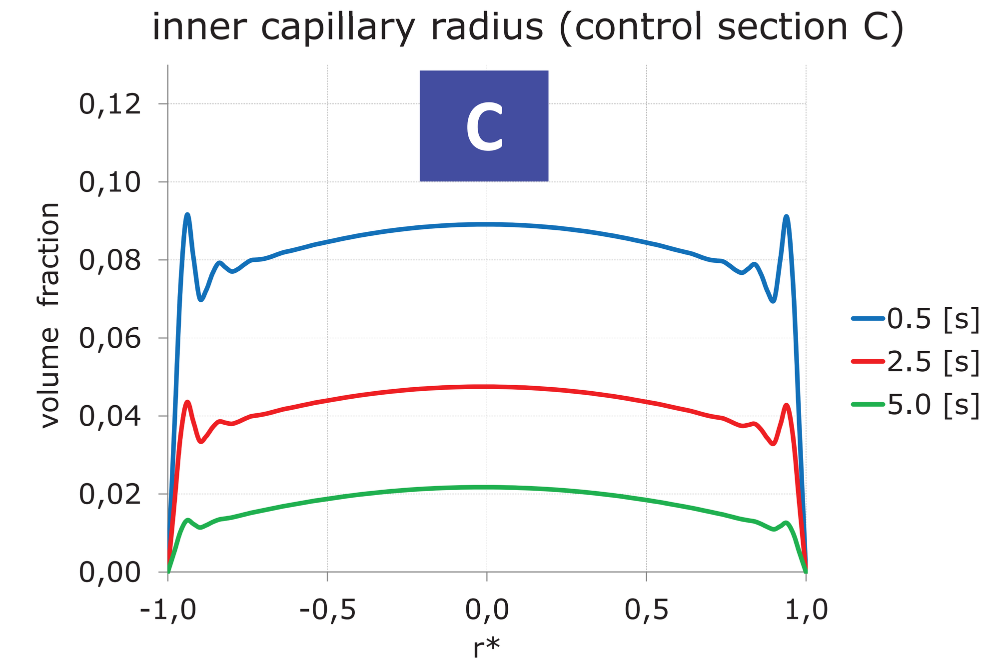


Fig.5: Particle distribution along control section C without lift force

- The velocity of the suspension in the capillary increases towards outlet.
- A parabolic flow is quickly reached inside the capillary with a maximum velocity of 0.0047, 0.34, 0.68 m/s at the control lines A, B, C respectively.
- The laminar flow characteristic is defined with the diameter and the maximum fluid velocity at the outlet of the capillary resulting with the Re number of 950.
- The concentration of the particles closer to the dead-end is relatively higher than in the centre of the capillary.
- This concentration of the particles in the vicinity of the outlet is significantly higher close to the wall.

Conclusions

- The results show an inhomogeneous particle distribution within the capillary.
- The relation between the normal inlet velocity of water (perpendicular to the surface of membrane) as well as the normal and tangential velocity components within the capillary significantly influence the accumulation of the particles.
- The high concentration of the particle near the wall of the capillary confirm the main role of the lift force during the backwashing process
- Lift force is supposed to enhance the particle enrichment close to the wall which will influence the removal of still deposited particles or may even lead to formation of plugs in the capillary.

Perspectives

- Investigation of the contribution of separate fluid dynamical forces
- Simulation of different operating parameters and capillary configurations
- Analysis of different initial particle distributions
- Modelling and simulation of capillary bundles

Literature

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