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Particulate transport in porous media at pore-scale

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Particulate transport and retention in porous media are crucial processes influencing permeability reduction and clogging, particularly in natural and industrial systems. In this work, we present a novel hybrid Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) approach that combines unresolved and resolved coupling strategies [1]. This innovative method allows the simulation of particulate flows across complex pore geometries, accommodating particles of varying sizes relative to the computational grid. Our model efficiently identifies grid cells interacting with particles and accurately computes the fluid-solid momentum exchange term, ensuring robust and efficient simulations. The model further incorporates colloidal forces using the DLVO (Derjaguin-Landau-Verwey-Overbeek) theory and adhesive contact forces based on the Johnson-Kendall-Roberts (JKR) model to account for electrochemical interactions (e.g., Van der Waals attraction, electrostatic double-layer repulsion) and particle adhesion dynamics [2]. Coupled with hydromechanical forces (e.g., drag, buoyancy, collision), the model enables realistic pore-scale simulations of particle transport, sieving, bridging and aggregation phenomena. The robustness and accuracy of our CFD-DEM framework are demonstrated against reference analytical and experimental cases. We showcase its capabilities by investigating pore-clogging and permeability reduction under varying conditions, such as fluid salinity, particle size distribution, concentration, flow rates, and pore geometry. Unlike conventional approaches, this hybrid model is not constrained by particle size relative to the grid, offering enhanced flexibility and reliability for simulating particulate transport in porous media. This work paves the way for improved understanding of pore-scale mechanisms and their impact on macroscopic flow properties.

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References

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