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Density-Dependent Dynamics of Fines Retention and Pore Clogging in Rock Formations: A CFD-DEM Approach

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In the realm of geosciences, the phenomenon of fines migration and subsequent clogging in rock formations presents a complex challenge. This process can occur even when fines are smaller than a specific threshold size, known as the critical throat diameter. The dynamics of pore clogging involve interactions on multiple scales - ranging from the transport at the pore level to the mechanical and hydraulic behaviors at the colloid level, down to the electrochemical interplays at sub-colloid scales. Traditionally, the Colloid Filtration Theory (CFT) has been the go-to model, focusing on predicting how colloidal particles are retained under the assumption of clean bed conditions. This overlooks the significant impact of particle aggregation and clogging at the throat passages. While experimental measurements are ideal for assessing filtration efficiency, they fall short in directly examining the intricate movements and paths of particles at the pore level, especially due to the opaque nature of the media involved. Numerical models addressing the full scope of forces in pore clogging have been limited to two-dimensional simulations of rock structures. This research advances the field by employing a combined fines tracking method that integrates Computational Fluid Dynamics (CFD) with a Discrete Element Model (DEM). The approach is designed to predict the retention and clogging of fines, factoring in surface forces and the impact of gravity forces due to density variations between the fines and the saturating brine.

To accurately represent the complex pore structures and simulate particle movement within the rocks, we use a three-dimensional X-ray computed microtomography image of Bentheimer sandstone. An innovative feature of our method is the use of a dynamically adaptive CFD mesh, which refines itself in areas dense with particles to better resolve the intricate fluid flow around them. We track particle trajectories and link them to specific pores and throats within the rock sample. Furthermore, we apply a method to compare the pairwise trajectories of particles with different density, injected in a flux-weighted procedure through the inlet. This allows us to analyze how particle retention varies within the sandstone, considering the flow direction for fines with different densities. For heavier fines, we observe an interesting spatial variation in particle trapping, suggesting that gravity aids their movement in the direction of gravitational pull, but hinders it along the flow path. Our findings reveal that denser fines can move further along the flow path due to two key mechanisms: their ability to pass through gravitationally lower throats and the alterations in flow pathways caused by pore clogging.

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