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Pore-scale hydrodynamic evolution within carbonate rock during CO_2 injection and sequestration

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The continuously rising threat of global warming caused by human activities related to CO_2 emission is facilitating the development of greenhouse gas control technologies. Subsurface CO_2 injection and sequestration is one of the promising techniques to store CO_2 in the subsurface. However, during CO_2 injection, the mechanisms of processes like injectant immobilizations and trapping and pore-scale geochemical reactions such as mineral dissolution/precipitation are not well understood. Consequently, the multi-physics modeling approach is essential to elucidate the impact of all potential factors during CO_2 injection, thus to facilitate the optimization of this engineered application.

Here, we propose a coupled framework to fully utilize the capabilities of the geochemical reaction solver PHREEQC while preserving the Lattice-Boltzmann Method (LBM) high-resolution pore-scale fluid flow integrated with diffusion processes. The model can simulate the dynamic fluid-solid interactions with equilibrium, kinetics, and surface reactions under the reactive-transport scheme. In a simplified 2D spherical pack, we focused on examining the impact of pore sizes, grain size distributions, porosity, and permeability on the calcite dissolution/precipitation rate. Our simulation results show that the higher permeability, injection rate, and more local pore connectivity would significantly increase the reaction rate, then accelerate the pore-scale geometrical evolutions. Meanwhile, model accuracy is not sacrificed by reducing the number of reactants/species within the system.

Our modeling framework provides high-resolution details of the pore-scale fluid-solid interaction dynamics. To gain more insights into the mineral-fluid interfacial properties during CO_2 sequestration, our next step is to combine the electrodynamic forces into the model. Potentially, the proposed framework can be used for model upscaling and adaptive subsurface management in the future.