Pore-Scale Modeling of Evaporation-Induced Salt Crystallization for CO_2 Storage and Utilization

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Evaporation-driven salt precipitation is a key process affecting fluid transport and injectivity during CO_2 injection in saline systems, with relevance to both geological storage and utilization within CCUS (Carbon Capture, Utilization and Storage) framework. When dry or under-saturated CO_2 is injected into brine-filled porous media, evaporation increases local salt concentration, leading to crystallization that alters pore connectivity and flow pathways [1].

In this work, we develop a sequentially coupled pore-scale modeling framework that combines two-phase CO_2–brine flow with evaporation [2] and solute transport, followed by salt crystal growth modeling. The first stage resolves capillarity-dominated two-phase flow and evaporation-induced salt concentration evolution under different injection and salinity conditions. This concentration field is then used as input for crystal growth simulations to investigate the spatial development and morphology of precipitated salt.

The approach enables systematic analysis of how operational parameters control the location and extent of salt precipitation, and how different crystallization patterns influence pore-scale obstruction. It is based on multiphysics, multiphase-field modeling methods implemented within the advanced high-performance material simulation framework Pace3D [5], enabling the coupled treatment of phase evolution, transport, and interfacial processes.The simulation modeling strategy is informed by microfluidic experiments that directly visualize evaporation and salt precipitation during gas injection in simplified pore networks, providing qualitative guidance for process representation [3,4].

By separating flow–transport processes from crystallization while maintaining a physically consistent workflow, the Pace3D simulation framework offers a flexible tool for studying salt precipitation in carbon capture and storage contexts. Beyond injectivity impairment in storage operations, the results are also relevant for utilization concepts involving controlled drying, cyclic injection, or salt recovery in engineered subsurface systems.

Keywords: CCUS, two-phase flow, crystallization, salt precipitation, pore-scale

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