Role of Continuous Brine Access on Salt Precipitation Dynamics ─ Implications for Injectivity and Containment Integrity during Geological CO_2 Storage

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Geological carbon storage emerges as a critical strategy for mitigating climate change via capturing and storing human-made CO_2 emissions. Salt precipitation during CO_2 injection in saline aquifers can cause pore clogging near the wellbore, reducing permeability and increasing pressure buildup, which may find significant consequences for injectivity, containment integrity, and the overall safety and efficiency of CO_2 storage operations. While increasingly more literature focuses on CO_2-induced salt precipitation, the underlying physics, growth dynamics, and fluid-solid interface behavior remain elusive. This study investigates the role of continuous brine access on pore-scale salt precipitation dynamics, significance for self-enhancing growth nature, and its broader implications for injectivity and containment criteria. Using laboratory techniques, including microfluidics, a Hele-Shaw cell, a flow-through system, a large-scale sandbox setup, and a triaxial geomechanical cell we explore the mechanisms governing brine evaporation and salt crystal growth, their pore occupancy and chemo-mechanical couplings. A key finding is the critical role of continuous brine sources, which significantly alter salt nucleation and growth dynamics by controlling solute availability and continuity through water film movement. Laboratory results reveal substantial salt accumulation near the injection port, emphasizing the importance of solute availability in exacerbating salt accumulation severity. Two mechanisms accelerate growth dynamics. First, evaporation shifts the gas-liquid interface from larger to finer pores, expanding the surface area for brine evaporation and salt formation. Second, hydrophilic, hygroscopic halite crystals, nucleating on existing precipitates as secondary substrates via probabilistic nucleation, amplify reactive surface area and create a feedback loop. Salt crystallization can weaken reservoir rock, reducing mechanical strength and increasing susceptibility to shear failure. This weakening, evidenced by reduced Young's and shear moduli, may lower the fracture gradient, posing a risk of unintentional fracturing during injection. By elucidating the role of continuous brine access on precipitation dynamics and the interplay of hydro-mechanical-chemical processes, the research offers insights for optimizing injection strategies and enhancing containment integrity. The findings underscore the need to incorporate these mechanistic aspects into reservoir-scale models to predict better and manage the impacts of salt precipitation on subsurface injection operations.

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