Contribution ID: **409**

Type: **Poster Presentation**

Pore-scale investigation into dynamics of salt crystal nucleation, precipitation and growth in porous media during CO2 sequestration in saline aquifers

Thursday, 25 May 2023 15:30 (1h 30m)

In a full-scale CCS, millions of tons of CO2 must be stored underground. Injection of dry or undersaturated (with respect to water) CO2 leads to dry-out of the brine formation water and salt precipitation, particularly in the near wellbore region, causing reduced injectivity and deteriorated reservoir rock properties. We report a series of microfluidic experiments on glass- and geomaterial (real rock) microchips representing matrix and fractured systems to provide insights into some open questions regarding the pore-scale physics and dynamics of CO2-induced salt nucleation, precipitation, and growth in porous media. The study is complemented with LBM reactive transport simulation of nucleation and growth to further elucidate the evolution dynamics from precipitation of single crystal to eventual clogging of flow pathways. The results introduce two interrelated phenomena –self-enhancing of salt growth and water film salt transport, which together remarkably intensify the rate and amount of precipitations. It is shown that salt crystals, although at different rates, grow in both aqueous and gas phases. The pore-scale observations indicate that the trapped water films in porous or fractured media have enough continuity and conductivity to transport residual brine to an evaporating front and cause an increase in the rate and amount of precipitated halite crystals. The results also indicate that CO2 phase states and pressure-temperature conditions control the magnitude, distribution, and precipitation patterns of salt precipitates. Injection of gaseous CO2 resulted in higher salt precipitation compared to liquid and supercritical CO2. The thermodynamic conditions influence salt precipitation via water solubility in CO2, maximum water flux into the CO2 stream, and balance between the imposed viscous forces and capillary-driven backflow. The mutual impacts of the continual growth of salt crystals toward the injection point, the affinity of salt bodies to become connected, access to brine pools via conductivity of water films, porous structure of many salt bodies, imposed capillary suction towards the evaporation front, concentration gradients, in addition to the extent of CO2-induced salt accumulations suggest that the salt precipitation during injection of CO2 into the geologic formations can be a critical phenomenon with a complex interplay on coupled THMC processes. The research outcome highlights processes and dynamics crucial to consider when investigating salt precipitation induced by CO2 injection, as this phenomenon has implications for injectivity and containment. For better reservoir-scale numerical modeling, such mechanisms must be incorporated and scaled up in the reservoir simulator, along with a representative physically-sound scale-aware clogging model. We provide insights into the applicability of present clogging models and porosity-permeability relationships for predicting dynamics changes induced by solid accumulation in pore space. Present-day reservoir-scale simulators of salt precipitation consider mechanisms such as water evaporation into CO2 and capillary backflow of water into the dried zone, suggesting only a limited impact on the porosity and permeability. Additionally, the current approach for modeling salt precipitation using the volumetric method in the reservoir-scale numerical simulator may not reflect the required physics for investigating salt precipitation induced by CO2 injection.

Participation

In-Person

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Session Classification: Poster

Track Classification: (MS01) Porous Media for a Green World: Energy & Climate