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Evolution of Capillary Trapping of scCO2 Under Repeated Drainage-Imbibition (D-I) Cycles on Bentheimer Sandstone.

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Capillary trapping of supercritical CO_2 (scCO_2) in porous media is a key mechanism that enhances the security of geologic carbon storage. However, the pore-scale processes that control trapping efficiency, especially under repeated drainage-imbibition (D-I) cycles, are not yet fully understood. In this study, we performed a series of core-scale experiments designed to quantify the evolution of capillary trapping behavior in Bentheimer sandstone. Three cycles of drainage and imbibition were conducted using scCO_2 and deionized water, under reservoir-relevant temperature and pressure conditions of 40oC and 1250 psi respectively on a Bentheimer Sandstone of 6 inches length, 1.5 inches diameter and 20% estimated porosity. Pressure differential across the core was continuously monitored during each cycle to capture dynamic fluid displacement events. Distinct pressure signatures were observed: drainage events were characterized by sharper rises or spikes in differential pressures due to capillary resistance of scCO2 invasion into water-occupied pores, while imbibition phases showed lower rises in differential pressure aided by the water-wetting nature of the Bentheimer sandstone. The capillary numbers for drainage and imbibition were calculated as 6.37E- 7 and 5.7E-7 respectively, indicating capillary-dominated flow in both phases.
Injection during both drainage-imbibition phases was continuous, without flow interruptions and core-averaged saturation was calculated based on a mass balance of fluids, recorded via acoustically-monitored separator during injection. These saturation measurements quantify the residually trapped scCO_2 saturations after each drainage-imbibition cycle, providing a direct metric for trapping efficiency. Preliminary results indicate that repeated imbibition cycles lead to progressive increases in trapped scCO_2 volumes, consistent with enhanced capillary trapping due to pore-scale hysteresis effects. Observed trends in pressure and saturation are being analyzed to better understand the relationship between pore throat distribution, wettability evolution, and trapping performance.
This experimental work serves as a foundational component of broader research aimed at linking pore- scale mechanisms to core- and reservoir-scale trapping behavior. Ongoing efforts include high-resolution micro-CT imaging of selected core samples and numerical pore-network modeling to simulate multiphase flow and validate experimental findings. By integrating experimental observations with imaging and modeling approaches, we aim to provide a comprehensive understanding of capillary trapping controls across scales. The findings will contribute to better predictions of CO_2 retention in geologic formations and improve storage design and evaluation.

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References

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