Residual Trapping during Sequestration of Supercritical CO2 in Carbonate Saline Aquifers: A Core-Scale Experimental Study Using In-Situ Saturation Measurement Technique

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Abstract. Deep saline aquifers provide significant capacities for storing vast quantities of CO2 and thereby can help mitigate its emission to the atmosphere. However, the injection of CO2 into these aquifers can create complex multiphase flow dynamics that may impact the storage process and effective trapping of CO2. While early research on CO2 sequestration focused largely on sandstone formations, there has been growing interest in carbonate rocks in recent years as potential storage sites due to their abundance and distinctive properties, such as mineralogy. This requires formulating investigations that would help develop a deeper understanding of the flow dynamics, storage mechanisms, and the relevant multiphase flow properties to improve the design and implementation of the sequestration process in carbonate aquifers. Such investigations must include careful examination of residual trapping as a critically important, permanent storage mechanism. This is the main objective of the present study.

Previous studies on the residual trapping of CO2 in sandstones have considered flow conditions mainly in capillary-dominated regimes, where the capillary number is typically less than 10-5. However, the capillary number has a negligible impact on the residual trapping and mobilization of CO2 at flow rates under the capillary-dominated regime. In this study, we conduct two-phase supercritical CO2 (scCO2)/brine flow experiments on an outcrop carbonate rock using a high-pressure, high-temperature, closed-loop core-flooding system, which is integrated with a state-of-the-art robotic x-ray imaging system. The generated images are processed to determine in-situ fluid saturations and investigate fluid distributions and CO2 trapping under various flow conditions ranging from capillary- to viscous-dominated regimes. In each experiment, we first saturate the core sample, approximately 3.8 cm in diameter and 25.4 cm in length, with brine and then subject it to scCO2 flooding to establish the desired initial water saturation. Next, we inject brine until residual CO2 saturation is achieved. The experiments are conducted at the elevated temperature and pressure of 50 °C and 10 MPa, respectively. The experimental data are analyzed to probe the physics of scCO2 trapping in carbonate rocks and the impact of varying initial water saturation on the residual trapping of CO2 under varying capillary numbers. We generate capillary desaturation curves for the scCO2/brine system to determine the ranges of capillary numbers within which scCO2 remains trapped or is mobilized and displaced. Investigation of in-situ fluid saturation profiles along with capillary desaturation curves contribute to advancing the current understanding of residual trapping mechanisms and their efficiencies in carbonates.