The impact of multiple injection cycles on capillary trapping: comparison of ambient- and reservoir-condition experiments

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Abstract

The success and safety of geologic CO₂ sequestration operations relies on accurate predictions and modelling of CO₂ plume migration after the CO₂ has been injected into a subsurface reservoir. The transport of a buoyant CO₂ plume will be inhibited by multiple physical and chemical processes, including hydrodynamic trapping beneath low permeability layers, dissolution into reservoir brine, mineral carbonation of the reservoir host rocks, and capillary trapping of CO₂ bubbles within the pores of the porous reservoir formation. These trapping mechanisms are inter-related, for example, higher levels of capillary trapping increase the surface area of CO₂-brine interfaces, enhancing dissolution and subsequent mineral carbonation processes. Similarly, mineral carbonation causes mineralogical and sometimes structural transformation of the solid matrix, which may result in changes to local flow properties (e.g. permeability) affecting hydrodynamic stability. Capillary trapping is fundamentally a pore-scale process, dependent on the interfacial interactions between the fluid phases present and the solid surface, but this pore-scale mechanism significantly impacts the reservoir-scale fate and transport of the entire CO₂ plume.

Thus, accurate estimates of CO₂ capillary trapping capacity are crucial to the design of safe and efficient CO₂ sequestration operations; to this end, numerous recent studies have investigated capillary trapping of supercritical CO₂ in geologic formations. However, there are still significant uncertainties in the long-term stability and fate of capillary trapped CO₂; and in particular, there have been conflicting reports regarding capillary trapping levels when multiple cycles of CO₂ and brine are injected in alternating patterns, or when the solid matrix is exposed to CO₂ over long periods of time. For example, Herring et al. [2016] demonstrated that levels of capillary trapped supercritical CO₂ significantly increased over the course of three cycles of alternating drainage (CO₂ injection) and imbibition (brine injection) - a result that is not predicted by conventional understanding of capillary trapping mechanisms. Other studies have also observed capillary trapping effects which appear to be unique to supercritical CO₂; e.g. Wang and Tokunaga [2015] showed increases of approx. 20-30% in capillary trapping for sand packs which had been exposed to supercritical CO₂ for 4 months, relative to fresh sands. These interesting results suggest that the traditional description of capillary trapping may lack the complexity to fully describe the long term behavior of capillary-trapped CO₂.
We present analysis of capillary trapping of nonwetting phase (ambient condition air and supercritical CO₂) for multiple multi-cycle drainage-imbibition experiments in sandstones. We focus on a comparison of ambient condition (air-brine) studies and those conducted with supercritical CO₂ and brine under high pressure, high temperature conditions relevant to storage reservoirs. All experiments were characterized with x-ray microtomography, which provides full three dimensional information on the structure of the porous material and fluid phases residing within the pore space of the sandstone. The topology and geometry of the nonwetting phase were analyzed using the image analysis program Diamorse, which uses persistent homology to link topological features to their size, and which has recently been used to develop a universal capillary trapping relationship for ambient condition air-brine flows in a variety of sandstones [Herring et al., 2017]. We investigate the topology and geometry of the nonwetting phase from both global (whole column) and local (on the scale of individual pore bodies) perspectives to investigate and isolate the causes of the anomalous capillary trapping trends observed in supercritical condition experiments. The results inform predictions of CO₂ capillary trapping and long-term CO₂ stability in geologic formations.

References

Herring, A., V. Robins, Z. Liu, R. Armstrong, and A. Sheppard (2017), Persistent Homology to describe Solid and Fluid Structures during Multiphase Flow, American Geophysical Union Fall Meeting, New Orleans, Louisiana, USA.
