In-situ pore-scale imaging and image-based modelling of capillary trapping for geological storage of supercritical CO2

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Abstract

A major concern in Carbon Capture and Storage (CCS) is to ensure the integrity of CO2 sequestration from pore to field scales. This requires an extensive understanding of the trapping mechanisms occurring at different scales. Recent research (Krevor et al., 2015) has demonstrated that capillary trapping of CO2 in the pore space of rocks is a key mechanism in long-term CO2 geo-sequestration. Capillary or residual trapping is pervasive over large distances of the plume extent and plays a significant role in storage security, slowing plume migration and increasing storage capacity. Trapping of CO2 by capillary forces is controlled by the rocks’ pore structure and by rock-fluid interactions. Small-scale heterogeneities and variations in wettability strongly affect the amount of capillary trapping and represent significant uncertainties.

Here we describe a comprehensive imaging and modelling study of capillary trapping in the Precipice Sandstone formation in the Surat Basin, Australia. We used three-dimensional X-ray micro-CT imaging to describe the pore structure within a large suite of storage reservoir core. The images revealed that the Precipice Sandstone exhibits a wide variation in pore sizes and complex thinly laminated sedimentary features. We obtained in-situ pore-scale images of the distribution of supercritical CO2 and brine within more than ten reservoir sandstone samples during drainage and imbibition (see Figure 1). The images were recorded using time-lapse X-ray micro-tomography at elevated temperature and pressure representative of reservoir storage conditions. The images showed that a significant portion of the supercritical CO2 is rendered immobile in the pore space as disconnected clusters surrounded by brine. Trapped CO2 clusters of all sizes are observed, from single pore ganglia to multi-pore ganglia occupying several pores. The observed CO2/brine displacement properties are consistent with a water-wet system and confirm that CO2 acts as a non-wetting phase. The best estimates for receding and advancing contact angles for the supercritical CO2/brine/rock system are 25 and 35 degrees, respectively.

The 3D pore structure images and in-situ measured contact angles are used directly as input to a new geometrically accurate pore-scale model for imbibition (Ruspini et al., 2017). The model accounts for pore-scale wettability, pore geometry, and fluid topology. We compute drainage and imbibition capillary pressure and relative permeability curves for different samples. The results of the simulations are consistent with laboratory data. The new imbibition model is used to compute capillary trapping curves for different pore structure images of the Precipice Sandstone. The amount of trapping and the pore-scale fluid distribution of CO2 and brine are compared directly with the corresponding in-situ X-ray micro-tomography images. Computed capillary trapping curves are in good agreement with experimental results and confirm that residual trapping is a key mechanism for CO2 storage in the Precipice Sandstone formation. We carried out a sensitivity study of the impact...
of small-scale heterogeneities and wettability (i.e. advancing contact angle) on the magnitude of capillary trapping. As expected, the amount of CO2 trapping increases with decreasing contact angle. However, the relative impact of wettability on the magnitude of capillary trapping strongly depends on the geometry and topology of the pore-structure. Heterogeneity or laminations is the major overall uncertainty and the results show that capillary trapping can be significantly enhanced by the presence of small-scale heterogeneities.

The combination of these data is used to help demonstrate the technical viability and safe operation of the CCS pilot project in the Surat Basin of Australia. In–situ CT-imaging shows that disconnected and trapped CO2 clusters occupy a significant portion (about 30%) of the pore volume and provide direct evidence that capillary trapping is an effective storage mechanism in the Precipice Sandstone. These results enable the design of safe CO2 storage through quantifying the processes by which CO2 is trapped in the pore space of the rock.

Figure 1. (a) Image of the in-situ fluid distribution of brine (blue) and trapped supercritical CO2 (green) within a subsample of Precipice Sandstone (grains in yellow, clays in red). Images (c) and (d) show trapped CO2 (dark) clusters from core-flood experiments. The images demonstrate the water-wet nature of the system under aquifer conditions.

References