Contribution ID: **157**

Type: **Oral Presentation**

Three-Dimensional Imaging of Density-Driven Convection in Consolidated Rock Samples Using X-Ray CT Scanning

Monday, 22 May 2023 15:15 (15 minutes)

The determination of realistic rates of CO2 dissolution associated with geological CO2 storage in deep saline aquifers requires an understanding of the mixing process that takes place during the emplacement of CO2 into these formations. The mixing process is triggered by the local density increase in the ambient brine following the CO2 dissolution. As a result, gravitational instabilities occur, and perpendicular elongated finger-like patterns form that are enhancing the mixing between CO2 and water compared to a purely diffusive process. This density-driven mixing process is important because it accelerates the CO2 dissolution into brine and could eventually form a stable stratification in the aquifer, thereby reducing the chances of leakage.
Owing to the difficulty of imaging the time-dependent convective process, experiments so far have largely focused on two-dimensional systems (e.g., Hele-Shaw cells), which inherently limit the lateral spreading of the downwelling plumes. Here, we present the development of an experimental approach to investigate the evolution of the convective mixing process in three-dimensional porous media using X-ray Computed Tomography. To this end, we have considered consolidated rock samples (two sandstones, two carbonates), for which observations have thus far been lacking.
We characterize the rocks based on the different scales of heterogeneities using different measures such as the representative elementary volume (REV), the coordination number and the pore size distribution.
To imitate the dissolution process of CO2 in brine in the rocks under laboratory conditions, a salt is used with a high X-ray attenuation coefficient that dissolves in water and creates a heavier solution than pure water. We observe that the mixing structures, that arise upon dissolution in the consolidated rock samples, differ among those and are strongly impacted by heterogeneities, especially by macro-heterogeneities such as fractures and vuggy pores.
A key advantage of the three-dimensional X-ray CT images is the possibility to monitor and compare the temporal evolution of individual plume structures between the different rock types.
Further, we compute the temporal evolution of the spatial moments of the vertical concentration distribution, including the cumulative dissolved mass, the location of the centre of mass and the spreading length. We find correlations between the scaling of the moments with the heterogeneities of the pore space. This suggests that apart from characteristics of the advective transport (such as permeability and porosity, included in the Rayleigh number), other micro- and macro-structural features are influencing the overall mixing.
These observations provide therefore more representative information towards the investigation of convective mixing in the context of CCS as well as the selection and evaluation of sequestration sites.

Participation

In-Person

References

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Session Classification: MS08

Track Classification: (MS08) Mixing, dispersion and reaction processes across scales in heterogeneous and fractured media