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Gas trapping dynamics in heterogeneous sandstones imaged using synchrotron time-lapse tomography.

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Geological heterogeneities impact the timescale and distribution of capillary trapping of CO_2 in aquifers [1,2]. Natural capillary pressure barriers trap the non-wetting phase at saturations greater than expected from pore-scale residual trapping processes alone, potentially providing greater CO_2 storage capacity. Capillary heterogeneity trapping has the potential to significantly improve the security of CO_2 storage in underground aquifers by immobilizing a large proportion of the injected CO_2 [1,2], however the connection between pore-scale fluid dynamics and larger scale flow processes have yet to be properly elucidated. The dynamics of the flow through pore throats may play a significant role in geological carbon storage [3,4], particularly at the boundary between different grain sizes. However, it is heterogeneity at centimetre-scale, over many thousands of pores, that leads to the larger scale phenomena of capillary heterogeneity trapping.

In this experimental campaign, state of the art synchrotron-based X-ray micro-CT experiments at the European Synchrotron (ESRF) were performed to investigate pore-scale flow dynamics in heterogenous sandstone cores over centimetre-scale fields of view. To investigate the impact of mm-cm scale natural geological heterogeneities on fluid migration and trapping, we performed experiments on 3 different sandstone samples: Bentheimer with layers perpendicular to flow, Bentheimer with layers parallel to flow and Bunter sandstone from a UK target storage site, the Endurance field. To evaluate the rate dependency of trapping, experiments over 2 different rates were compared to explore potential trapping within a range of carbon sequestration projects.

The high energy of the ID19 beamline at ESRF allowed us to capture frontal advance and trapping dynamics at pore-scale resolution (6.5 µm) in large heterogeneous consolidated samples (6 cm). With time resolution of 3 minutes, we observed unsteady state displacements, the prevailing conditions at most storage sites [1,4]. We captured dynamically both drainage and subsequent imbibition, proceeding until the residual saturation was reached. Pore-scale trapping mechanisms were captured with a field of view over the continuum core-scale, allowing us to investigate how larger scale capillary heterogeneity trapping processes are impacted by pore-scale events. Such experimental observations resolving trapping over many pores, representative of the large-scale process, are crucial for model validation, development and ultimately storage predictions [5].

We were able to observe, at the pore-scale, the transient interaction of the fluids with different types of layered heterogeneity. The heterogeneity impacted pore-filling events, and subsequent imbibition, allowing us to quantify the path to residual trapping. Consistent with numerical simulations [2], injection rate impacted capillary trapping with lower capillary number resulting in a greater amount of capillary heterogeneity trapping. The results from this synchrotron campaign advance our understanding of the impact of heterogeneity on the dynamics of capillary trapping within CO_2 storage sites.

Participation

In-Person

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