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New insights into the mechanisms leading to the formation of localised pathways in water-saturated clayey geomaterials exposed to pressurised non-wetting fluid emulating supercritical CO2

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The successful deployment of carbon dioxide (CO2) geological sequestration in porous media is reliant on the sealing efficiency of the overlying clay-rich caprock to act as a physical barrier. Clay-rich caprock formations are considered as favourable materials to act as a seal due to them characteristically consisting of small pores providing high capillary entry pressures, hence preventing the intrusion of a non-wetting fluid (e.g., CO2).
In relation to CO2 sequestration, past experimental campaigns have traditionally focused on determining the capillary breakthrough pressure of caprock geomaterials. Only until recently have experimental results demonstrated that CO2 breakthrough is dominated by the creation of very localised channels (e.g., cracks) across the sealing barrier (Espinoza & Santamarina, 2010; Harrington et al., 2012; Busch et al., 2016 and Gonzalez-Blanco & Romero, 2022). The underlying hypothesis of this experimental work is that pore size heterogeneity governs the micro-mechanisms that ultimately control crack formation and thus, eventually, CO2 breakthrough. Therefore, this experimental campaign aims to provide evidence at the micro-scale to develop our understanding of the micro-mechanisms that lead to (or underly) the formation of large, localised channels (e.g., cracks) that pressurised CO2 is generating, causing an early breakthrough. An innovative experimental set-up which allowed for the onset of surface crack formation to be captured during gas injection into clayey geomaterials is presented. Post-mortem assessment of the aperture, volume and internal nature of these localised pathways was then visualised using the non-invasive and non-destructive xCT imaging technique.
Preliminary data on different cracking patterns when non-wetting gas (i.e., air) is injected into consolidated clay show the formation of large cracks that nucleate from the centre of the sample. Upon air pressurisation, before crack formation, the sample undergoes volumetric deformation, as the resulting action of the vertical stress applied at the air-water interface (menisci). Once a crack forms, volumetric deformation stops, and breakthrough occurs. Changing the particle size distribution, by using clay-silt mixtures, shows the potential effect of pore size heterogeneity on breakthrough and cracking patterns. Clay-silt mixtures with higher silt mass fraction result in earlier and larger crack formation, subsequently lowering the breakthrough pressure. This is opposed to the uniform pore size distribution of clay and silt materials alone, which display smaller cracking patterns. Our results, therefore, indicate that heterogeneity at the particle and subsequent pore-scale is a controlling parameter in the formation of localised pathways (e.g., cracks) in clayey geomaterials. Gas invasion into the tested clayey geomaterials occurred at lower pressures than the expected air-entry-values traditionally recorded throughout the literature. The mechanisms of air intrusion are expected to be of a similar nature as CO2 intrusion. Understanding the parameters which control the formation of localised pathways is therefore paramount when assessing the security of a geological CO2 reservoir.

Participation

In-Person

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