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Measurement of Non-Wetting Phase Trapping in Sand Packs

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Abstract

We measure the trapped non-wetting phase saturation as a function of initial saturation in sand packs. The application of the work is for carbon dioxide (CO₂) storage in aquifers, where capillary trapping is a rapid and effective mechanism to render the injected fluid immobile: the CO₂ is injected into the formation followed by chase brine injection or natural groundwater flow that displaces and traps it. Current models to predict the amount of trapping are based on experiments in consolidated media; while CO₂ is likely to be injected at depths greater than around 800 m to render it super-critical, it may be injected into formations that tend to have a higher porosity and permeability than deep oilfield rocks. We use analogue fluids – water and refined oil – at ambient conditions. The initial conditions are established by injecting oil into vertical or horizontal sand packs 1 m long at different flow rates and then allowing the oil to migrate due to buoyancy forces. The packs are then flooded with water. The columns are sliced and the residual saturation measured with great accuracy and sensitivity by gas chromatography. This method allows low saturations to be measured reliably. The trapped saturation initially rises linearly with initial saturation to a value of around 0.11, followed by a constant residual as the initial saturation increases further. This behavior is not predicted by the traditional Land (1968) model, but is physically consistent with poorly consolidated media where most of the larger pores can easily be invaded at relatively low saturation and there is, overall, relatively little trapping. The best match to our experimental data was achieved with the Aissaoui (1983) trapping model.

Introduction

If we are to avoid potentially dangerous climate change, we need to capture and store CO₂ emitted by fossil-fuel burning power stations and other industrial plants (Orr, 2004). Saline aquifers provide the largest potential for storage and the widest geographical spread (Hawkes *et al.*, 2005). Subsequent leakage of CO₂ into the atmosphere, even over hundreds of years, would render any sequestration scheme inefficient. However, based on the experience of the oil and gas industry, there is a good understanding of trapping mechanisms that take place in geological formations.

Hydrodynamic trapping is the primary mechanism by which hydrocarbons accumulate in the subsurface. The same mechanism would take place during carbon sequestration, with the less dense CO₂ rising due to buoyancy forces until it is trapped under impermeable cap-rock (Bachu *et al.*, 1994). However, this process relies on there being an intact barrier to upwards flow.

Solution trapping occurs when there is dissolution of CO₂ in the aquifer brine. The CO₂ saturated brine is denser than the surrounding brine leading to convective mixing where the denser brine migrates deeper into the formation (Lindeberg and Wessel-Berg, 1997; Riaz *et al.*, 2006; Ennis-King and Paterson, 2005).

Mineral trapping occurs over longer timescales than other trapping methods. As CO₂ dissolves in formation brine carbonic acid is formed (H₂CO₃) which dissociates and can subsequently react with the host rock or brine to generate solid minerals over periods of thousands to billions of years (Gunter and Perkins, 1993; Gunter *et al.*, 1997; Egermann *et al.*, 2005; Lin *et al.*, 2008).

The final trapping mechanism involves CO₂ becoming immobile at the pore scale by capillary forces. This process occurs as the CO₂ migrates upwards, when it is displaced by natural groundwater flow or by the injection of chase brine. It is a rapid and effective trapping mechanism that reduces the need to ensure cap-rock integrity (Kumar *et al.*, 2005; Hesse *et al.*, 2006; Obi and Blunt, 2006; Juanes *et al.*, 2006; Qi *et al.*, 2007; Saadatpoor *et al.*, 2008).