A Pore-Scale Investigation of Fluid Displacement and Residual Trapping Under Intermediate-Wet Conditions

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Residual trapping in which ganglia of fluid are isolated and immobilised in porous media by capillary forces is innate to several subsurface engineering applications including carbon sequestration. Residual trapping is highly significant in carbon dioxide (CO₂) sequestration, as entrapment of supercritical CO₂ in rock pore spaces, limits upward migration of the buoyant CO₂ plume and enhances long-term CO₂ storage security. It is estimated that residual trapping contributes up to 40% of overall trapping CO₂ in the first century following injection (1). The amount of residual trapping depends largely on the wettability of the porous rock.

Brine filled saline aquifers have been identified as having the largest potential for CO₂ storage with an estimated cumulative storage capacity of 10⁴ Giga-tons of CO₂ (2). Likewise, the focus of many studies has been devoted to investigating residual trapping in water-wet, brine filled sandstone reservoirs, and little attention has been given to intermediate-wet and oil-wet carbonate reservoirs. However, until CO₂ storage technology reaches maturity, initial CO₂ sequestration projects will most likely be conducted in depleted and oil producing carbonate reservoirs due to economic benefits associated with CO₂ enhanced oil recovery and the existence of installed infrastructure which can be reassigned for CO₂ injection purposes (3).

Accordingly, in this work, the intrinsically water-wetting surfaces of laser fabricated glass micromodels (4); which are two-dimensional representations of natural porous rock structures, were chemically modified to imitate intermediate-wet reservoir conditions through a silanization procedure. Imbibition experiments were conducted in the micromodels using two proxy, CO₂-brine fluid pairs; deionized (DI) water and n-decane as well as DI water and air.

Fluid displacement under intermediate wettability was analysed and compared with water-wet conditions and residual fluid saturations were quantified for different porous structures. The Volume of Fluid method was used to simulate the experiments in OpenFOAM. Results from the micromodel experiments were used to validate the simulations.

This work has demonstrated that fluid displacement during the imbibition process occurs through a series of cooperative pore-filling events under intermediate-wet conditions and the presence of dead-end pores was found to enhance residual trapping of the non-wetting fluid. Coupling
experimental and simulation studies provides a unique insight to multiphase flow under intermediate wet conditions.

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References