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Modeling CO₂ Storage in Fractured Reservoirs: Fracture-Matrix Interactions of Supercritical and Dissolved CO₂

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The injection and storage of supercritical CO₂ (scCO₂) have been conducted in fractured sandstone reservoirs at In Salah, Algeria and Snøhvit, Norway, and planned in fractured sandstone, carbonate, and dolomite reservoirs at Longyearbyen, Norway, Hontomin, Spain, and Kevin Dome, USA, respectively, with matrix permeability varying from 0.01 to 60 md. For densely fractured reservoirs with low matrix permeability (e.g., at Longyearbyen, Norway), injected scCO₂ can dissolve into the resident brine at fracture-matrix interfaces and the dissolved CO₂ (dsCO₂) can diffuse into the rock matrix making solubility trapping the dominant trapping mechanism. For fractured reservoirs with intermediate matrix permeability (e.g., at In Salah, Algeria), the storage of scCO₂ in the rock matrix dominates with strong fracture-matrix interactions observed through field monitoring at In Salah. We developed a comprehensive conceptual model for enhanced CO₂ storage to account for global migration of scCO₂ in the fracture continuum, local storage of scCO₂ and dsCO₂ in the matrix continuum, driving forces for scCO₂ invasion and dsCO₂ diffusion from fractures, and brine outflow through connected matrix blocks.

For the dominant matrix scCO₂ storage, we developed high-resolution fracture-matrix models for individual matrix blocks, homogeneous columns of fractures and matrix blocks, and heterogeneous REV's consisting of multiple columns of matrix blocks with varying flow properties and sizes. The multiscale modeling results show that the equilibrium efficiency of local scCO₂ storage strongly depends on matrix entry capillary pressure, matrix-matrix connectivity, and reservoir thickness, while dynamic efficiency and transfer function are also sensitive to fracture spacing and matrix flow properties. The transfer functions calculated for various REV's were used along with reservoir-scale dynamics of scCO₂ plume flow in fractures, showing that the preferential migration of scCO₂ through fractures is coupled with bulk dsCO₂ storage in the rock matrix that in turn retards the scCO₂ fracture plume. The bulk matrix storage is mainly driven by buoyancy between fracture scCO₂ and matrix brine and facilitated by matrix-matrix connectivity that allows displaced brine to outflow, enabling the rock matrix to act like an open system. Conventional dual-continuum models cannot capture these processes because they model isolated matrix blocks with no capillary continuity, thereby underestimating storage efficiency.

For the dominant matrix dsCO₂ storage, we developed the unified-form equations of diffusive flux of dsCO₂ into brine-bearing matrix blocks of varying shapes (i.e., spheres, cylinders, slabs, squares, cubes, rectangles, and rectangular parallelepipeds) and sizes (Zhou et al., 2017a, b). We then applied the flux equations to a fractured reservoir with various scenarios of matrix blocks by assuming 1-D and 2-D radial scCO₂ flow in fractures and by using diffusion of dsCO₂ from fracture-matrix interfaces into matrix blocks as the sink for scCO₂ in fractures. For each scenario, the dynamic dsCO₂ plume with different mass fraction was produced analytically, showing that solubility trapping is significant in fractured reservoirs with low matrix permeability and small fracture spacing.

References

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