

Density-driven convection in a fractured porous media: Implications for geological CO₂ storage

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Abstract

Dissolution trapping is one of the primary mechanisms of carbon dioxide (CO₂) storage in a geological formation. In this study, a numerical model was used to examine the impacts of single and multiple fractures on the transport of dissolved CO₂ plumes in various geological settings. The effects of the fracture angle, fracture-matrix permeability ratio, fracture intersection, and matrix heterogeneity on density-driven CO₂ convection were systematically investigated. The fractures were found to play time-varying roles in both homogeneous and heterogeneous media by serving as preferential pathways for both CO₂-rich plumes (fingers) and CO₂-free water. The competition between the enhancement of convective mixing and the inhibition of finger growth by the upward flow of fresh water generated a complex flow system. The interaction between the strong upward flow of fresh water through the fractures and the falling CO₂-rich fingers through the porous matrix induced a positive feedback, resulting in accelerated domain-scale circulation and CO₂ dissolution. While the CO₂-rich fingers grew relatively evenly at the top boundary in the homogeneous media, they selectively developed through the high permeable zones in the heterogeneous media. Compared with homogeneous media, the heterogeneous media preserving fractures particularly generated a more dynamic fracture-matrix mass transfer, resulting in more rapid CO₂ dissolution. The findings of this study were extended to examine the effects of fracture connectivity on the enhancement of CO₂ transport and dissolution on a field scale.

Key words: Carbon dioxide; Convection; Dissolution trapping; Fractured porous media; Numerical simulation