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Vertically-Integrated Dual-Continuum Models for CO2 Injection in Fractured Saline Aquifers

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Injection of CO2 into a saline aquifer leads to a two-phase flow system, including a supercritical CO2 phase and a brine phase. Various modeling approaches, including fully three-dimensional (3D) models and vertical-equilibrium (VE) models, have been used to study the system in unfractured formations. Three-dimensional models solve the governing flow equations in three spatial dimensions and are applicable to generic geological formations. VE models assume rapid and complete buoyant segregation of the two fluid phases, resulting in vertical pressure equilibrium and allowing integration of the governing equations in the vertical dimension. This reduction in dimensionality makes VE models computationally much more efficient, but the associated assumptions restrict the applicability of VE model to formations with moderate to high permeability.

In this presentation, we extend the VE and 3D models to simulate CO2 injection in fractured aquifers. This is done in the context of dual-continuum modeling, where the fractured formation is modeled as an overlap of two continuous domains, one representing the fractures and the other representing the rock matrix. Both domains are treated as porous media continua and, as such, can be modeled by either a VE or a 3D formulation. The transfer of fluid mass between fractures and rock matrix is represented by a mass transfer function connecting the two domains. Because the fracture domain is usually much more permeable than the matrix domain, we apply VE modeling to the fracture domain but not the matrix domain. We refer to the resulting model as a hybrid VE-3D model, with the VE model applied to the highly permeable fractures and the 3D model in the less permeable rock matrix.

Our hybrid VE-3D model includes both dual-porosity and dual-permeability types. The dual-porosity model conceptualizes the rock matrix as sugar-cubes that are isolated uniformly by vertical and horizontal fractures, or as match-sticks that are isolated by vertical fractures through the entire thickness of the aquifer. In contrast, the dual-permeability model explicitly represents the 3D flow dynamics in the rock matrix. We derive mass transfer functions that couple the VE model in the fracture to the different models in the rock matrix. We then apply the hybrid VE-3D model to simulate CO2 migration in fractured saline aquifers and compare with 3D-3D models where both the fracture and rock matrix are modeled in 3D. The hybrid VE-3D models are much more computationally efficient while providing results that are close to those from the 3D-3D models. These vertically-integrated dual-porosity and dual-permeability models provide a range of computationally efficient tools to model CO2 storage in fractured saline aquifers.

References

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Primary author: TAO, Yiheng (Princeton University)

Co-authors: GUO, Bo (Stanford University); BANDILLA, Karl (Princeton University); CELIA, Michael (Princeton University)

Presenter: TAO, Yiheng (Princeton University)

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