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Coupled Multiphase Flow and Geomechanics for Analysis of Caprock Damage During CO_2 Sequestration Operations

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The initial and primary trapping mechanism for long term subsurface sequestration of CO_2 is structural trapping beneath a low permeability caprock layer. Maintaining caprock integrity during injection operations is paramount to successful sequestration. In this work we evaluate the potential for caprock damage during injection scenarios using coupled three-dimensional multiphase flow and geomechanics modeling. Two models of geomechanical damage are considered: critical shear-slip criteria and a sub-grid joint model. The latter model is the primary focus of this work, however, the damage from the joint model is compared and contrasted to the critical shear model.

Evaluation of jointed/fractured caprock systems is of particular concern to CO_2 sequestration because creation or reactivation of joints (mechanical damage) can lead to enhanced pathways for leakage. Fluid flow rates in fractures are strongly dependent on the aperture, based on the so-called cubic law. In general, the hydraulic aperture is a non-linear function of effective normal stress, fracture morphology, material properties, etc. In this study, we assume equally spaced anisotropic joint sets with non-linear stiffness based on the effective normal stress. The dynamically evolving aperture field updates the effective, anisotropic permeability tensor, thus resulting in a highly coupled multiphysics problem. The resulting leakage rates through the caprock are compared to those assuming intact material, allowing a correlation between potential for leakage and injection rates/pressures, for various in-situ stratigraphies.

These simulations utilize a new parallel-processing computational capability for coupling of multiphase porous flow with geomechanics. The coupling can be dynamically controlled by monitoring a norm measuring the degree of variation in the deformed porosity, thereby controlling the frequency of mechanics solves compared to flow solves. If time steps are synchronized, the controller allows intra-time-step iterations. The coupling strategy allows for different, unstructured grids and solution algorithms for flow and mechanics.

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