Numerical and Analytical Modeling of Geomechanical Risks Accompanying CO2 Storage in Aquifers

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Abstract

Objectives/Scope: We develop numerical and analytical models for evaluating geomechanical risks associated with CO2 injection into underground reservoirs. Our goal is to study the following undesirable processes: loss of reservoir integrity and CO2 leakage, activation of tectonic faults and rock jointing, initiation of artificial hydraulic fractures, and rise in Earth's surface above the injection zone. These events can contribute to the pollution of freshwater aquifers, seismic activity, and damage to surface infrastructure.

Methods, Procedures, Process: We develop several models predicting geomechanical risks associated with CO2 storage. The first numerical model utilizes MUFITS and FLAC3D simulators coupled with a data exchange algorithm. We describe permeability dynamics due to deformations inside the core and damage zones of the tectonic fault. The second model relies on the one-way coupling between MUFITS and VISAGE simulators, which allows calculating the stress-strain state for large-scale models. We describe alteration of reservoir stress state due to long-term production causing porosity and permeability reduction. Finally, we propose analytical models for estimating the reservoir strength and a rise in Earth’s surface due to injection.

Results, Observations, Conclusions: We apply MUFITS-FLAC3D coupled model for simulations of CO2 injection into the target aquifer intersected by a tectonic fault using a synthetic two-dimensional model of a multilayered formation. We consider two cases of the initial stress state, namely, missing and pronounced tectonic stresses. In the former case, plastic deformations do not develop in the formation, while major crack located in the fault core opens at asperities contributing to an increase in the fault zone permeability along its plane and CO2 leakage. In the latter case, we obtain significant plastic deformations in the fault domain, major crack opening, and CO2 leakage. Fault permeability increases in the directions along and perpendicular to its plane. Next, we simulate CO2 injection into a depleted gas reservoir using a large-scale model of real formation via MUFITS-VISAGE coupling. We model the stress state at the end of 35 years gas production period and after 50 years of CO2 injection. Eventually, pore pressure does not exceed the initial reservoir pressure, and all deformations are elastic. We compute the surface uplift and compare it with an analytical estimation showing an acceptable agreement. Finally, we demonstrate several examples of numerical and analytical calculations of the target layer strength.
**Novel/Additive Information:** We propose a novel analytical model describing the tectonic fault permeability, including the contribution of major crack opening at asperities in the fault core and activation of natural fracturing in the damage zone. We embed the closure relations into MUFITS-FLAC3D coupled simulator. Fault permeability depends on stresses and strains estimated numerically via FLAC3D. We simulate the CO2 injection into a depleted gas reservoir with high matrix permeability via MUFITS-VISAGE coupled model.