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Sensitivity Analysis of internal structure and rock properties on Long-term Behavior of CO2 Injected into Multi Layers

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Multi-layer formations composed of alternating sandy, high-permeable layer and muddy, low-permeable layer are expected to trap CO_2 due to dissolution and residual gas mechanism. In general, anisotropic permeability is allocated to sedimentary formations, however, this anisotropy is possibly due to finer alternating structure and/or intrusion of sandstone channels into mudstone in actual. Such difference of internal structure can affect on the long-term behavior of injected CO_2. In this study, we will present the results of the sensitivity analysis of internal structure and rock properties on the long-term behavior of CO_2 injected into multi-layer formations.

We constructed a two-dimensional radial model with 20 km width and 1.4 km depth for the simulation. Submarine conditions of 10 ℃ and 2.0 MPa are assumed for the top boundary. The topmost 300-meter region is composed of the unconsolidated sediment, and the alternating layers of 120-meter sandy formation and muddy formation underlie it. The lowermost 100-meter region is assumed to be the basement. Each sandy formation has vertical/horizontal permeability of 10/100 mD. We investigated two cases of permeability of muddy formation, that is, 1/10 mD and 0.1/1 mD. We represented these 120-meter-thick formations by i) homogeneous porous model as a base case, "finer multi-layer model" composed of alternating sandstone layers and mudstone layers which have isotropic permeabilities and thickness of ii) 30-meter and iii) 10-meter, and iv) 120-meter "MINC" double-porosity model with impermeable matrix and sandstone channels. For "finer multi-layer model", we defined permeabilities of sandstone layers and mudstone layers in such a way that their harmonic and arithmetic averages were equivalent to vertical and horizontal permeabilities of sandy/muddy formation, respectively.

Capillary pressure was represented by van Genuchten type, and the threshold pressure (P_{th}) was given as a function of vertical permeability (k_z) obtained from experiments using either sintered compacts or rocks. We also assumed two cases for the presence of hysteresis of relative permeability for sandstone. Except for hysteresis, models of relative permeability for water and CO_2 were assumed to be common to all formations. They are represented by functions of van Genuchten type and Corey type, respectively. CO_2 is injected into a sandy formation at a depth from 940 m to 1,060 m at a rate of 1 Mt/year. The injection interval is 50 years.

Using this model, we conducted 32 cases of numerical simulations on the long-term behavior of CO_2 for the injection period and 1000 years of shut-in. Simulations are carried out using the "STAR" reservoir simulation code with the "SQSCO2" equation of state.

Simulated results of the cases where kz of muddy formation was 1 mD and P_{th} was defined by experimental results of rocks showed that i) CO_2 migrated upward to a depth of 640 m by 1000 years after shut-in with the 120-meter porous model, however, ii) its upward migration was restricted with the "finer multi-layer model" due to enhancement of multi-layer trapping. On the other hand, iii) presence of sandstone channels with high permeability and low capillary pressure allowed buoyant migration of during shut-in period. However, presence of liquified phase between depths from 360 m to 700 m slowed down CO_2 upward migration to a depth of 120 m by 1000 years after. These results indicate that internal structures significantly affect long-term behavior of CO_2, even if their 120-meter-average permeabilities are equivalent.

Additionally, upward migration of CO_2 significantly restricted with P_{th} defined by experimental results of sintered compacts, and effects of relative permeability hysteresis are relatively limited in this study, especially for "finer multi-layer model".

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Keywords: geological CO2 storage, saline aquifer, multi layers, anisotropy, numerical simulations