Numerical Study on the Effects of Change of Contact Angle on Sealing Capacity

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For geological storage of CO_2 in Japan, general aquifer storage site often have geological characteristics favorable for geochemical reactions. When pH-lowered pore water due to CO_2 dissolution causes geochemical reactions in such formations, some kind of mineral may envelop the surface of rock, change the wettability (contact angle), and result in change of the capillary pressure. In this study, we will present the results of the numerical analysis of the effects of change of contact angle on seal capacity and the long-term behavior of injected CO_2.
We constructed a two-dimensional radial model with 20 km width and 0.5 km depth for the simulation. Subsurface conditions of 31 °C and 9.0 MPa are assumed for the top boundary. Reservoir is located at 1,000 m depth with 100-m or 200-m thickness. A 100-m thick seal layer overlies it. Basement underlies the reservoir, and second aquifer overlies the seal layer. CO_2 is injected into the reservoir at a rate of 1 Mt/year. The injection interval is 50 years. We conducted numerical simulations on the long-term behavior of CO_2 for the injection period and 450 years of shut-in. Simulations are carried out using the “STAR” reservoir simulation code with the “SQSCO2” equation of state.
Reservoir and seal layer have vertical/horizontal permeabilities of 10/100 mD and 0.1/1 mD, respectively. 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. Irreducible water saturation and residual CO_2 saturation are 0.2 and 0.05, respectively. Hysteresis model is adopted for the relative permeability. Capillary pressure was represented by van Genuchten type, and the threshold pressure (P_{th}) was given as the capillary pressure at the residual CO_2 saturation. P_{th} of reservoir is set to be 0.1 MPa, and that of seal layer is 0.5 MPa or 1.0 MPa. In this study, the initial contact angle of water-CO_2-rock system is assumed to be water-wet 0°. We assume the contact angle θ changes at some point, to be 15°, 30°, 60°, and 75°. According to the change of contact angle, threshold pressure P_{th} will change following Laplace’s equation: $P_{th} = 4\sigma\cos\theta/d$, being proportional to $\cos\theta$ at all CO_2 saturation. Interfacial tension σ and throat diameter d remain unchanged in this study. For case study, P_{th} is i) unchanged all over simulated time, changed at ii) 25 years, iii) 50 years, and iv) 100 years later from the start of the injection.
Simulated results showed that i) for unchanged case, part of CO_2 intrudes into the seal layer during the injection period, however, it almost stops in shut-in period. ii) CO_2 remains with in the reservoir and seal layer, and do not reach the second aquifer after 450 years later from the stop of the injection in the all cases of this study. Low permeability of the seal layer and residual gas trapping are presumed to contribute it. iii) When capillary pressure is lowered due to change of contact angle, CO_2 intrusion into the seal layer continues during shut-in period in some cases. iv) This effects are pronounced especially in the cases where the initial capillary pressure is low, and/or buoyancy is large due to thick reservoir. These results indicate that change of contact angle due to geochemical reaction can affect long-term seal capacity at CO_2 storage site.
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