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Estimation of In Situ Stress and Permeability from an Extended Leak-off Test

Quoc Nghiep Quach (1), Yeonguk Jo (1), Chandong Chang (1), and Insun Song (2)

(1) Department of Geology, Chungnam National University, Daejeon, Korea, Republic Of (cchang@cnu.ac.kr), (2) Deep GeoEnvironment Research Center, KIGAM, Daejeon, Korea, Republic Of

Among many parameters needed to analyze a variety of geomechanical problems related to subsurface CO_2 storage projects, two important ones are in situ stress states and permeability of the storage reservoirs and cap rocks. In situ stress is needed for investigating potential risk of fault slip in the reservoir systems and permeability is needed for assessing reservoir flow characteristics and sealing capability of cap rocks. We used an extended leak-off test (XLOT), which is often routinely conducted to assess borehole/casing integrity as well as fracture gradient, to estimate both in situ least principal stress magnitude and in situ permeability in a CO_2 storage test site, offshore southeast Korea.

The XLOT was conducted at a casing shoe depth (700 m below seafloor) within the cap rock consisting of mudstone, approximately 50 m above the interface between cap rock and storage reservoir. The test depth was cement-grouted and remained for 4 days for curing. Then the hole was further drilled below the casing shoe to create a 4 m open-hole interval at the bottom. Water was injected using hydraulic pump at an approximately constant flowrate into the bottom interval through the casing, during which pressure and flowrate were recorded continuously at the surface.

The interval pressure (P) was increased linearly with time (t) as water was injected. At some point, the slope of P-t curve deviated from the linear trend, which indicates leak-off. Pressure reached its peak upon formation breakdown, followed by a gradual pressure decrease. Soon after the formation breakdown, the hole was shut-in by pump shut-off, from which we determined the instantaneous shut-in pressure (ISIP).

The ISIP was taken to be the magnitude of the in situ least principal stress (S_3), which was determined to be 12.1 MPa. This value is lower than the lithostatic vertical stress, indicating that the S_3 is the least horizontal principal stress. The determined S_3 magnitude will be used to characterize the stress regime with the information of the maximum principal stress that will be estimated based on borehole breakout geometry analysis. To estimate the in situ permeability from the XLOT data, we derived a theoretical equation that relates the slope of pressure versus injected water volume (P-V) curve to permeability based on the Darcy's law. The equation is expressed in terms of permeability as a function of some key parameters such as open-hole dimensions, flowrate, porosity, pressure change and injected water volume. We applied this equation to the early stage of the P-V curves prior to the leak-off point to prevent the effect of induced fractures on permeability. The estimated in situ permeability was $(3.1\pm0.4)\times10^{-17}m^2$, which turns out to be quite similar to the laboratory measurements in recovered cores.