Geophysical monitoring of geological CO2 sequestration in saline aquifers –Lessons from the Nagaoka pilot-scale project–

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A pilot-scale CO2 sequestration project supported by the Japanese Government (METI) has been conducted by Research Institute of Innovative Technology for the Earth (RITE) in cooperation with Engineering Advancement Association of Japan (ENAA). Cumulative 10400 tonnes of CO2 was injected into an onshore saline aquifer within eighteen months. A series of observations and measurements consisted of bottom-hole pressure and temperature measurement, crosswell seismic tomography, and time-lapse well logging has been performed at the injection site along with laboratory tests and simulation studies, the results of which provided a valuable insight into the CO2 movement in the sandstone reservoir.

The reservoir for CO2 injection is a sandstone bed of the Haizume Formation of early Pleistocene age lying about 1100m below the ground surface with a thickness of 60m, overlaid by a cap rock mudstone bed also belongs to the Haizume Formation of about 150m thick. The injection site is located at the east wing of an anticline, where the aquifer and the cap rock are dipping at 15 to the ESE. The upper part the reservoir of about 12m thick, which is called Zone-2, was found to have higher porosity and permeability, therefore, the CO2 injection was decided to be concentrated to Zone-2 of the aquifer. The CO2 injection started on 7 July 2003and ended on 11 January 2005 with the total injected amount of 10400 tonnes. Purchased CO2 of 99.9% purity was injected in the supercritical state at the rate of 20-40 tonnes per day.

The crosswell seismic tomography was conducted between OB-2 and OB-3 in a distance of 160 m to monitor the injected CO2. The baseline survey was conducted in February 2003 prior to the start of CO2 injection. The monitoring surveys were carried out four times at the stages of cumulative injection amount of 3,200, 6,200, 8,900 and 10,400 tonnes. Difference tomograms obtained from dividing each monitor velocity by the baseline velocity show an outstanding area of velocity decrease around the injection well, indicating distributions of the injected CO2. As the amount of injected CO2 increased, the low velocity zone expanded preferentially to the formation up-dip direction in the reservoir.

Time-lapse well loggings of induction, gamma ray, neutron and sonic were performed almost once a month. On 10 March 2004, a breakthrough was first detected at OB-2 after the cumulative injection of 4000 tonnes. Changes appeared in results of sonic, induction and neutron logs. The sonic P-wave velocity decreased significantly up to 23% after the breakthrough, and then results of sonic log showed the CO2-bearing zone getting wider during the injection of CO2. Differences appeared in widths of CO2-bearing zone of induction and neutron logs. On 16 July 2004, a breakthrough of CO2 was detected at OB-4 as changes in sonic and neutron logs. No sign of CO2 breakthrough has been confirmed at OB-3. CO2 saturation was estimated from the time-lapse well logging data together with open-hole log data.

During the injection, flow simulation studies were carried out to match with the observed results. Bottom-hole pressures at IW-1 and OB-4 were considerably lower and the breakthroughs of the injected CO2 were detected late in comparison to the simulation results prior to the injection. To obtain reasonable history matching results, relative permeability curves and their end points were adjusted and areal heterogeneity of permeability was assumed. Using the final reservoir model of history matching, long-term fate of the injected CO2 was predicted and the results showed the injected CO2 will be safely sequestered for the period.