Deep Monitoring of CO_2 Plumes using Electrical Resistivity Tomography

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Abstract

A monitoring system of crosshole electrical resistivity tomography (ERT) was deployed for tracking migration of a CO_2 plume at a depth of 3200 m in a commercial scale (1 Mt/year) CO_2 injection experiment at the Cranfield site sponsored by US DOE Southeast Regional Carbon Sequestration Partnership (SECARB). The ERT provides daily tomographic CO_2 saturation images between two monitoring wells (F2 and F3) with an autonomous data acquisition system. The CO_2 has been injected since December 1, 2009 for the SECARB Phase III Detailed Area Study (DAS). Two monitoring wells were plugged and abandoned on 6/1/2015. Previously published work was focused on analysis of the ERT data collected during the first 100 days of CO_2 injection because initial ERT data sets have a much higher signal to noise ratio. The remaining hundreds of data sets are under-utilized due to the excessive noise. In this study, we process and analyze all five-year ERT monitoring data sets including daily ERT data sets between December 1, 2009 and March 14, 2011 and two additional data sets collected on January 11, 2013 and February 4, 2015 for obtaining a better understanding of the CO_2 flow process during a longer term.

ERT data became much noisier after 100 days of CO_2 injection, and we develop a model to characterize observational error distribution. We correlate repeat measurement errors and reciprocal errors with the signal strength, contact resistance, measurement configuration, and changes inside the wellbore to improve our understanding of noise sources. We implement a robust inversion algorithm constrained by a well-defined error model to mitigate the effect of large observational errors. The ERT data collected in 2D geometry are inverted using 2D and 3D inversion algorithms for comparison with well logs and fluid samples. The effect of clay content and cooling by supercritical CO_2 on ERT-derived CO_2 saturation is corrected. We anticipate that a properly constrained inversion by a well-defined error model will produce a solution closer to ground truth.

We will study the spatial resolution of ERT with synthetic data based on the Cranfield settings using 2D and 3D inversion algorithms, and estimate the uncertainty in the ERT-derived CO_2 saturation. Our preliminary analysis of ERT data shows that some electrodes started degradation in six months and a few electrodes in F2 were short-circuited near the wellhead after recompletion of that monitoring well in September 2010. ERT data inversion reveals that CO_2 saturation between two monitoring wells had not reached the maximum at 100 days and it

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continued to increase to about 50%. ERT data responded accordingly to changes of CO_2 injection rate.

ERT results are interpreted jointly with well logs and fluid samples for an improved understanding of CO_2 flow process in deep geologic reservoirs during five years of CO_2 injection. Core logs and the pre-injection baseline resistivity model show the discontinuity of thin layers in the reservoir zone, which may imply no direct flow path between two monitoring wells. In particular, we will present our study on the discrepancy between ERT-derived CO_2 saturation and Reservoir Saturation Tool (RST) logs, search for evidence in ERT data that the CO_2 plume reached the farther monitoring well F3 sooner than F2 and bypassed F2 possibly because of braided channeling in the sandstone formation, and characterize the sources of the observational error. By comparing ERT data from the Cranfield site with those from Ketzin, Germany, we highlight the good practices and lessons learned. This study will provide guidelines for future deployment of an ERT system for monitoring a deep CO_2 storage site.

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