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Flow Coupled Jointed Rock Model for Geologic Carbon Storage with Application to In Salah

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Abstract

The crucial trapping mechanism for long-term subsurface sequestration of buoyant CO_2 in deep saline aquifers is structural trapping beneath a low permeability caprock layer. Maintaining caprock integrity during injection operations is paramount to successful sequestration. Evaluation of jointed/fractured caprock systems is of particular concern to CO_2 sequestration because creation of fractures or reactivation of joints can lead to enhanced pathways for leakage. Injection pressure induced joint (rock fractures) reactivation impacts caprock integrity for leakage and may place more stringent limits on overpressures, thereby limiting sustainable injection rates. We discuss a unique jointed rock model to analyze overpressure-induced joint reactivation in geosystems. The theory couples fluid flow and geomechanics during injection of CO_2 into the subsurface. The joint model describes effects of nonlinear joint stiffness on joint opening and permeability enhancement during pore pressure induced joint reactivation. Normal displacement of the joints is mapped into a dynamically evolving effective anisotropic permeability tensor, assuming a cubic law for fracture permeability. The concomitant reduction of effective bulk stiffness may reduce pressures in the system.

A model injection scenario is presented to demonstrate features of the joint model and how it affects the coupled geomechanics and flow during injection of CO_2 into deep saline aquifers. The model problem is not specific to any particular site, but is similar to some current GCS projects and uses geomechanics and flow parameters believed to be representative of potential GCS sites. Joint stiffness variations typical of laboratory experiments are utilized, and the impact of the variability in available data is analyzed. Crucial is the relationship between normal stress and the associated closure of joints, and the relation between joint aperture and effective bulk permeability of the rock. The impact of these and other key parameters for deformation and leakage are demonstrated. The model is used to illustrate injection reservoir properties and injection rates that have potential for inducing leakage through the caprock due to overpressures associated with CO_2 injection. In

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situations where joints are reactivated, leakage rates through jointed caprock during injection scenarios are estimated, enabling a correlation between potential for leakage and injection rates.

The effectiveness of the joint model will depend on how well it can be calibrated to a particular site. The jointed rock is described by a joint normal stiffness and scale for joint opening aperture, which can be used as fitting parameters for a particular data set, for example from the many laboratory experiments on joint closure of various rock types. Experiments of this type can readily be performed on site-specific fractured rock samples. However, the laboratory results may not adequately represent an in-situ fractured rock mass at depth, owing to effects of sample size, and in-situ stress conditions, for example. There is significant variability in fracture closure with normal stress depending on rock type, testing techniques and conditions both in the laboratory and field studies. Hence, it would be preferable to calibrate the jointed rock model to in-situ field tests and actual field injection projects, where possible. Application of the joint model to the In Salah project is a first attempt to compare the model to a field situation, thereby providing some level validation as to the feasibility of the joint model. There is some evidence of natural fractures in the injection layer at In Salah (Ringrose et al., 2011). A coupled flow and jointed rock geomechanics model of the injection process, utilizing publically available petrophysical and stratigraphy data, yields a close match to the uplift history collected via InSAR, indicating that the uplift history is consistent with joint (fracture) reactivation in the injection reservoir due to injection overpressures. Publically available data on In Salah is modest and stronger conclusions cannot be asserted.

In summary, the jointed rock model, if it can be accurately calibrated, is useful to indicate acceptable ranges for storage aquifer permeability and/or injection rates to suppress joint reactivation and potential leakage. Leakage rates with joint reactivation can be assessed. In situations where pore pressure approaches or exceeds lithostatic pressure substantial leakage rates can be predicted. The model can be used to interpret wellbore pressure histories indicating significant joint reactivation. Parametric studies are used to indicate which parameters have the most impact on caprock damage and leakage rates, and thereby describe those parameters most profitable for (expensive) experimental research.