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Modeling Leakage Through Faults of CO_2 Stored in an Aquifer

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Abstract

For secure storage of CO_2 within geologic formations, the integrity of caps – overlying strata that are impervious to CO_2 – is an important factor. Geologic structures, notably faults and the damage zones surrounding them may provide a conduit for CO_2 to escape through a cap. If the fault encounters shallower permeable formations, the CO_2 rising along the fault can enter them. This lateral migration would attenuate the rate at which CO_2 enters sensitive formations such as aquifers used for drinking water. Thus, CO_2 leakage along faults will have three behaviors: upward migration from the storage formation along a fault, lateral movement from the fault into permeable layers, and a continued but attenuated CO_2 flux along the fault above the layers.

Here we develop a quasi-1D single-phase flow model for these three behaviors. The model is highly simplified and intended to be suitable for inclusion in a certification framework for geologic storage projects. The model accounts for flow from the fault into a permeable formation using a leakoff coefficient. The coefficient can vary spatially and depends on the geometry and petrophysical properties of the formation. We apply a commercial simulator to verify the quasi-1D model. A series of examples illustrates the controlling mechanisms for leakage rate from the reservoir and its attenuation by flux into shallower layers.

Nonlinearities arise even in this simple model. For example, leakage flux and the degree of attenuation vary nonlinearly with the permeability of the fault and the permeability of the shallower layer(s) intersected by the fault. Layers nearest the CO_2 storage formation produce the most attenuation. But the percentage of CO_2 entering overlying formations from the fault varies linearly with the ratio of fault permeability to leakoff coefficient. A simple estimate of the leak-off coefficient compares favorably with 2D, full-physics simulations. If the permeable layer is dipping, CO_2 enters it asymmetrically and estimating the leakoff coefficient is less straightforward. The difference arises because of preferential flow within the layer (CO_2 in the upper part, water below).

Introduction

If society elects to reduce anthropogenic emissions of CO_2, geologic storage will be one of the key technologies for achieving this goal. In the standard approach to storage, CO_2 is captured from fixed sources such as coal-fired power plants, compressed and injected at supercritical conditions into a suitable target formation. For typical geothermal gradients, suitable formations are found at depths of 800 m (2600 ft) or more, as their temperatures and pressures will be above the critical point of CO_2. Trapping the injected CO_2 involves one or more mechanisms (Bachu *et al*. 1994; IPCC 2006): (1) permeability trapping by an impervious confining layer or cap rock; (2) solubility trapping by CO_2 dissolution into the aqueous phase in the pore space; (3) mineralogic trapping by chemical reaction of cations with dissolved CO_2 to precipitate carbonate minerals; (4) residual phase trapping as the nonwetting CO_2 phase becomes disconnected in pores or small clusters of pores; (5) stratigraphic trapping below a formation whose capillary entry pressure is greater than the capillary pressure of the CO_2 phase. An intact confining layer is necessary for several trapping mechanisms. However, sedimentary basins often contain geological discontinuities which are potential pathways for leakage through the confining layer. Faults are one such discontinuity and are prevalent in many regions where CO_2 storage is likely to be implemented. Wells are a man-made discontinuity, likewise prevalent in likely storage regions. We do not treat them here, but the conceptual model for faults provides a foundation for assessing leakage along wells (Huerta *et al*. 2008).

It is therefore important to examine the consequences if injected CO_2 encounters a fault. Figure 1 illustrates the situation of interest. A conductive fault can be a major pathway for the CO_2 plume due to its large transfer capacity. However CO_2 leaking