Hydrogeology Perspectives on Carbon Sequestration

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Summary

Carbon sequestration in geologic strata has the potential to help global efforts in reducing carbon dioxide emissions to the atmosphere. The physics behind injecting CO_2 into deep aquifers is well understood and its practical application has benefited from many decades of experience with hydrocarbon production, water production, and wastewater disposal across the globe. Recently published letters from some scientists, however, raise concerns about the feasibility and long-term success of carbon sequestration. It is our contention that concerns about the efficacy of carbon sequestration can, and should, be addressed through transparent and purpose specific quantitative evaluation.

Numerical and analytical modelling should be used to support planning and decision making around CO_2 sequestration projects. This presentation provides perspectives from our experience with regional scale, long-term numerical modelling of deep aquifers. The presentation also provides support for a risk-based evaluation framework including the possible use of multiple, purpose-specific assessment methods that seek to evaluate containment risk. The central thesis is that when addressing a skeptical audience, it is more important to understand the likelihood of possible negative outcomes (hypothesis testing) than to develop a detailed simulation of the most likely outcome.

Theory

Two key outcomes are necessary in order to have a successful sequestration project: 1) the receiving formation needs to have sufficient permeability and extent to accommodate CO_2 injection for the lifetime of the project; and 2) the CO_2 has to remain contained in the subsurface.

From our hydrogeological perspective, these two key outcomes should be approached from different angles and with different tools. This means that in order to assuage stakeholder concerns, the analysis should consider more than one conceptual and mathematical model of the surface; emphasis should be placed on hypothesis testing not necessarily on an attempt to incorporate all physical processes into a single, complex numerical model.

The evaluation of feasibility of CO_2 injection is an evaluation of the short-term and long-term pressure response to injection. Pressure in the receiving formation is a function of the rate of CO_2

injection, the formation geometry, and the formation permeability. Of these, the spatially averaged hydraulic property of permeability is usually the most uncertain variable when evaluating long-term feasibility. Because pressure propagation is not limited by the fluid type, there is pressure continuity between supercritical CO_2 and groundwater. Increased pressure near the injection well can propagate through groundwater, which is nearly incompressible, and result in an aerial and vertical extent of pressure increase that is much larger than the CO_2 plume. Hydrogeologic insights to long-term feasibility have been gained from numerical modelling of industrial volumes of groundwater withdrawal and wastewater disposal in the Western Canada Sedimentary Basin (WCSB) over decades. Perspectives gained from this work that are transferable to the evaluation of CO_2 injection feasibility include the importance of scale, upscaling approaches for spatially variable permeability, and the importance of boundaries in the receiving formation.

The second concern associated with CO_2 sequestration is the risk that CO_2 will not remain in the subsurface. Celia and Nordbotten (2009) describe three leakage pathways that need to be evaluated when considering the potential for CO_2 to escape the receiving formation: 1) diffusive leakage through the caprock; 2) leakage through faults and fractures; and 3) leakage through active or abandoned wells. The potential for CO_2 to migrate out of the receiving formation is analogous to solute transport problems commonly assessed by hydrogeologists.

In contrast to predictions of pressure propagation, the rate and extent of CO_2 migration is sensitive to the effective porosity of the receiving formation and the degree of interconnection of high permeability pathways within the formation. This means discrete and interconnected permeable pathways (e.g. interconnected high permeability facies, fractures, or well bore pathways) are much more important to prediction uncertainty than the characterization of spatially averaged hydraulic properties.

We propose a risk-based evaluation framework including the use of multiple, purpose-specific models to support project planning and address stakeholder concerns. The approach would involve identifying potential outcomes of highest risk and constructing one or more models for each outcome. Furthermore, the proposed approach for each model would focus on defining the predictions of interest at the start of the modelling effort and keeping the predictions in mind when developing all aspects of the modelling plan.

To illustrate these concepts, three examples of purpose specific models are provided for a hypothetical CO_2 sequestration project. The modelling tool, model domain, model parameterization, are all described in the context of exploring the likelihood of potential outcomes and identifying data gaps or valuable monitoring opportunities that can prepare operators to adapt quickly to undesired outcomes.