Fundamental Analysis of Heterogeneity and Relative Permeability on CO₂ Storage and Plume Migration*

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Abstract

Relative permeability is a critical flow parameter for accurate forecasting of long-term behavior of CO₂ in the subsurface. In particular, for clastic formations, small-scale (cm) bedding planes can have a significant impact on multiphase CO₂-brine fluid flow, depending on the relative permeability relationship assumed. Such small-scale differences in permeability attributable to individual bedding planes may also have a substantial impact on predicted CO₂ storage capacity and long-term plume migration behavior. Relative permeability model calibration in this study was accomplished by analyzing previously published laboratory-scale measurements of relative permeability of Berea sandstone. A core-scale model of the flow test was created in TOUGHREACT to elucidate the best-fit relative permeability formulation that matched experimental data. Among several functions evaluated, best-fit matches between TOUGHREACT flow results and experimental observations were achieved with a calibrated van Genuchten-Mualem function. Using best-fit relative permeability formulations, a model of a small-scale Navajo Sandstone reservoir was developed, implemented in TOUGHREACT with the ECO₂h module. The model was one cubic meter in size, with eight individual lithofacies of differing permeability, instigated to mimic small-scale bedding planes. The model assumes that each lithofacies has a random permeability field, resulting in a model with heterogeneous lithofacies. Three different relative permeability functions were then evaluated for their impact on flow results for each model, with all other parameters maintained constant. Results of this analysis suggest that CO₂ plume movement and behavior are directly dependent on the specific relative permeability formulation assigned, including the assumed irreducible saturation values of CO₂ and brine. Model results also illustrate that, all other aspects held constant, different relative permeability formulations translate to significant contrasts in CO₂ plume behavior.
Fundamental analysis of heterogeneity and relative permeability on CO₂ storage and plume migration

Introduction

Data for the relative permeability of CO₂ and water/brine for most reservoir rocks is lacking in the current literature. Relative permeabilities of the Navajo sandstone in particular have not been measured, or at least are not published. One of our research goals was to investigate the validity of using experimentally-derived relative permeability functions for a well-known formation, in this case the Navajo sandstone, to calibrate a relative permeability function effective for modeling CO₂ behavior in Navajo sandstone.

Numerical Model

Core flood model has dual injection (COM1, COM3) along one face of the model. There are 153 injection cells

Model Domain – Core Flood Model

• Total dimensions are 2 inches by 4 inches long
• 20x20x28 cells with a cell volume of 2.87E-08 m³

Model Domain – Navajo Bedform Model

• Total dimensions are 1 meter by 1 meter by 0.88 meters with 10x10x12 cells
• Cell volume of 1.0e-03 m³ for the GFOx layers and 2.0E-04 m³ for the WRLGx, WRLDx, and CLOOx layers.
• There are no injection cells in the bedform model. There is a dummy layer at the bottom of the model with 50% CO₂ saturation.

Relative Permeability Curve fitting

To get a fair representation of the experimental relative permeability data for Berea sandstone, a single cell “batch” model was created and specific CO₂ mass fractions were assigned. The relative permeability data was then plotted against the Berea sandstone experimental data to determine which relative permeability function and associated parameters gave the best fit. While the Brooks-Corey function gave the best fit it was not a function that was part of TOUGH2. The van Genuchten function gave almost as good a fit so it was used to represent the experimental Berea sandstone curve as measured by Krevor et al. (2011).

Navajo Sandstone Bedform Model Results

The plots show the supercritical CO₂ saturation for the whole domain and the chart highlights the saturation values at two location in the model; cell ABS 5 is near the bottom and cell AS5 is near the top of the model domain. The table highlights the total predicted mass of CO₂ at the end of the simulation.

Conclusions

The results of this analysis has shown that the choice of relative permeability function and the parameters used in that function can have a huge impact on predicted CO₂ plume migrations, phase behavior, and storage capacity. It was clear that having experimentally derived relative permeability curves for the target reservoir is essential for getting accurate predictions of CO₂ and phase behavior. Our study has indicated that supercritical phase CO₂ is very sensitive to the relative permeability curve used in the numerical simulation.

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