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Simulation Studies of Effect of Gravity, Flow Rate, and Small Scale Heterogeneity on Multiphase Flow of CO2 and Brine

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In order to most effectively use the large storage capacity in saline aquifers, improved fundamental understanding of multiphase flow and trapping mechanisms is needed. We have conducted a series of core flood experiments in a heterogeneous Berea Sandstone, which demonstrated that the saturation distributions are dependent not only on the fractional flow of CO2, but the total flow rate as well. The flow rate dependent behavior of CO2 is explained by the interplay between viscous, capillary and gravity forces. If this type of physical behavior can be understood at the core-scale, then the results can be extrapolated to the reservoir scale. Therefore, the influences of sub-core scale heterogeneity, gravity, flow rate and interfacial tension on brine displacement efficiency have been studied in this work.

The multiphase flow simulator TOUGH2 MP with the ECO2N module is used to simulate a series of steady state multiphase flow experiments at the core scale by using Berea Sandstone. A wide range of capillary and gravity numbers representative of those expected for a typical sequestration project is used to investigate the complex interaction between viscous, capillary and gravity forces in the core floods. Sensitivity studies show that the brine displacement efficiencies fall into three separate regimes: a viscous-dominated regime at high flow rates, a transitional regime dominated by the interplay of gravity and viscous forces at moderate flow rates, and a capillary-dominated regime at very low flow rates. The brine displacement efficiency is nearly independent of flowrate in the viscous-dominated regime while it is slightly dependent on flowrate in the capillary-dominated regime. The flow rate dependence becomes very large in the transition regime. The physical explanation for these three different behaviors is discussed in this work. Three degrees of heterogeneity have been used to study the influence of heterogeneity. Larger heterogeneity decreases brine displacement efficiencies, increases the flow rate dependency in the transition regime and causes the initiation of the transition regime to occur at lower capillary numbers.

Three different upscaling procedures may apply to the field scale modeling based on our core-scale simulation results. In the viscous-dominated regime, a homogeneous model without considering gravity and capillarity can quite accurately predict CO2 saturation. In the transition regime, gravity and capillary forces are as important as viscous forces and need to be considered. This significantly increases the complexity for solving the mass and energy conservation equations. In the very low flow rate regime, gravity-capillary equilibrium can be assumed and used to simplify upscaling.