EGU24-19156, updated on 15 Aug 2024
https://doi.org/10.5194/egusphere-egu24-19156
EGU General Assembly 2024

Understanding the effects of heterogeneity, salinity and background flow on convective dynamics of CO2-brine mixture in fully saturated porous media at geologic carbon storage conditions

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Capturing large quantities of CO2 from the atmosphere and sequestering voluminous amounts into deep saline aquifers form one of the key aspects of modern-day climate change mitigation strategies. However, the technical challenge lies in understanding the non-linear dynamics which govern the flow and transport of CO2 in the subsurface. Diffusion of CO2 into brine causes the development and growth of a diffusive layer having a density greater than the ambient brine. This layer yields to small scale perturbations in the flow field thereby producing fingers which propagate with time, facilitating dissolution and trapping. In natural systems, the solubility of CO2 and the mixing behavior is influenced largely by the simultaneous impact of ambient pressure, temperature, brine salinity, heterogeneity and background flow. Although, previous studies have mainly investigated fingering dynamics for homogeneous and heterogeneous cases, employing little or no background flow, a full-scale study collectively considering the different parameters remains to be done.

For our research we developed a 2D particle tracking reservoir simulator to model the transport dynamics of single-phase CO2-brine mixture for a system with spatially varying density, viscosity and local diffusion coefficient, governed primarily by variations in salinity and mixture concentration. Using this simulator, we perform a large-scale Monte Carlo parametric study to establish a thorough understanding regarding the influence of heterogeneous permeability-porosity fields, variable background flow, multicomponent electrolyte brine systems and dispersion anisotropy on the fingering dynamics and transport behavior of CO2-brine mixtures in the subsurface. We will demonstrate how salinity gradients in typical aquifers influence the viscosity and density variations of the mixture at wide ranges of reservoir heterogeneities and investigate its effect on the convective mechanism and mixing behavior. Additionally, in this regard, we will also examine how transverse shearing disrupts fingering thereby influencing the dissolution rate of CO2 into the aquifer. We will also present results highlighting fingering dynamics in preferential permeability pathways of aquifers having very high heterogeneities at different salinities and background flow. Finally, we will investigate how the interplay of these above physical parameters at different degrees affect the standard transition regime stages that are developed previously for homogeneous and heterogeneous cases. The novelty of study lies in considering a much wider range of attributes deemed important to influence large scale fingering

dynamics and mixing behavior, where currently to our knowledge, no studies have been performed.