Pore-scale simulation of multi-phase flow and reactive transport for CO2 storage

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Geological storage of CO2 via injection into porous sub-surface formations is considered a promising solution for reducing carbon emissions into the atmosphere. Injected CO2 in the pore space between rock grains can be trapped according to several mechanisms, including structural and stratigraphic trapping, capillary trapping, chemical reaction (mineral precipitation), and dissolution. To evaluate the injection efficiency, storage capacity, and leakage risk for geological carbon storage, the fundamental understanding of physical and chemical processes during CO2 injection is strongly required. Our aim is to develop a pore-scale numerical model to predict the multiphase reactive flow behavior and investigate these trapping mechanisms in porous media. This pore scale modelling is based on lattice Boltzmann method (LBM) and GPU parallel computing technology. The developed highly efficient complex fluid simulator have the capability to calculate various physical properties for reservoir core including absolute/relative permeability, capillary pressure, initial/residual saturation, and solute dispersion/dispersion coefficient etc.

Using the developed solver, we first investigated the interfacial tension (IFT) effect on fluid flow characteristics inside porous media. Under different IFT conditions, numerical analyses were carried out to investigate the variation in relative permeability, and then to clarify evolution of the saturation distribution of injected fluid. These hydrological properties are crucial for reservoir characterization as well as reservoir simulation in CCS projects. We confirmed that the relative permeability decreases with increasing IFT due to growing capillary trapping intensity. It was also observed that two certain crucial IFT values, $\sigma 1$ and $\sigma 2$, exist, creating three zones in which the displacement process has totally different characteristics.

Then, we extend this simulation method to explore the evolution of pore-geometry and relative permeability due to carbonate precipitation (mineralization trapping mechanism) on the real rock microstructures. Two precipitation models for considering the pore clogging have been proposed: CT threshold adjustment model and reactive transport based clogging model. By comparison of the precipitated and initial pore geometry, it is found that deposition location and precipitate growth pattern are very different for the two proposed clogging models. The reactive transport based clogging model gives much more uneven precipitate consequently destroys the homogeneity, as a result, both the absolute and relative permeability decreased greatly. Nevertheless, there are also some common phenomena found from the two clogging models that is the carbonate precipitation induced pore structure evolution influences the absolute permeability significantly, while for the relative permeability, pore space reduction has much more impact on non-wetting phase than the wetting phase.