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Predicting the CO_2 footprint in saline aquifers: a numerical-analytical hybrid model

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Abstract

Sequestration of carbon dioxide (CO_2) in geological formations is considered to be one of the most promising solutions for mitigating carbon emissions and, hence, global warming. Injection of CO_2 into deep saline aquifers is known to be the most feasible option for carbon storage because these aquifers have the largest accessibility and highest storage capacity. An understanding of the behaviour of CO_2 in saline reservoirs is thus required for a better assessment of the efficiency of geo–sequestration projects and optimization of subsurface flow management. After completion of the CO_2 injection process, brine imbibes back into the pore space to displace drained CO_2, resulting in CO_2 being residually trapped as isolated blobs or ganglia. To evaluate the security of storage process, an accurate understanding of the migration and trapping of CO_2 plume during and after injection is essential. Mathematical models offer insight into the physics of CO_2 migration and allow for the estimation of long-term evolution of CO_2 and assurance of having a safe and permanent storage. Since residual trapping is a key process contributing to the majority of the CO_2 trapping during the post-injection stage, it is required to be incorporated in the mathematical models while predicting the CO_2 plume migration. While residual trapping affects CO_2 migration over large scales, it is inherently a pore-scale process. So, our main goal of this study is to develop a framework, which is capable of capturing both the large-scale CO_2 plume migration and the pore-scale characteristics of the process, which highly affect the residual trapping efficiency of CO_2 plume.

In this study, we present an integrated framework including a sharp-interface analytical method and a pore-scale simulation to model subsurface migration of CO_2 plume subjecting to the gravity current and residual trapping. These integrated methods combine the flexibility of a pore-scale simulation method, allowing for implementing the pore-scale properties such as wettability, with the efficiency of an analytical method, for a quick estimation of the CO_2 plume extension and its residual trapping during the injection and post-injection stages. According to the formulation, the prediction of the model basically depends on two parameters including mobility ratio and capillary trapping coefficient. The capillary trapping coefficient, which depends on the residual CO_2 saturation and the connate brine saturation, is estimated using the pore-scale simulation. We have applied a pore-scale two-phase flow tool using the lattice Boltzmann (LB) method to simulate drainage and imbibition processes in CO_2/brine systems and subsequently calculate the capillary trapping coefficient. The LB model is adopted to simulate CO_2/brine two-phase flow in rock samples, by employing three-dimensional micro-CT images of those samples. To gain a better insight into the effect of wettability on the footprint of CO_2 and its trapping, we run pore-sale simulations in different samples with various wetting conditions and calculate the capillary trapping coefficient as a function of wettability. Thus, incorporating the

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pore-scale simulation results into the analytical model help us evaluate the effect of pore-scale properties such as wettability on the storage efficiency. We believe that this approach provides an appropriate tool for applications of storage efficiency estimation in CO_2 sequestration projects.

Keywords: Analytical model; Pore-scale simulation; CO_2 plume migration