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Numerical Simulation of CO₂ Storage in Aquifers without Trapping Structures

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Abstract

The numerical simulations for the CO₂ storage using a conceptual, generic, simple 3D aquifer model without trapping structures were carried out in this study. They showed that the mudstone barriers, which have relatively poor sealing efficiency, prevent the upward migration of CO₂ and help its lateral distribution. This suggests that the heterogeneities in the formation, particularly the distribution and properties of low permeability rocks, are very important to predict the movement of the injected CO₂. Even the gently dipping structures lead to increased updip migration of injected CO₂ due to buoyancy effect. When CO₂ comes in contact with fresh unsaturated formation water, its dissolution into water phase occurs. If injected CO₂ is not large in quantity the dissolution can still store the injected CO₂. When a large amount of CO₂ is injected into the aquifer the gas relative permeability hysteresis is a key for the long-term CO₂ storage. The trapping of CO₂ as a residual phase in the post-injection period strongly reduces the distance of updip migration, though it subsequently leads to decreased dissolution into the formation water. The simulation study suggests that heterogeneous formations that do not have structural closures and mudstones with relatively poor sealing efficiency can be a target for long-term CO₂ geological storage, if these effects are understood precisely and utilized appropriately.

Introduction

Storage of CO₂ in oil and gas reservoirs and aquifers with trapping structures and proven seal has been considered for reducing greenhouse effects. However, the potential capacity for CO₂ storage in those structures is not large^{1,2}. Aquifers in the formations that are composed of weakly consolidated sandstone and mudstone are possible attractive candidates for CO₂ storage because they are widely distributed in the vicinity of common industrial sources of CO₂. These formations usually dip at low angles. The movement of the injected CO₂ may be affected by the properties of mudstone³. The dissolution of CO₂ into formation water is one of the important trapping mechanisms. The trapping mechanism of CO₂ as residual phase due to gas relative permeability hysteresis may occur in those formations^{4, 5, 6, 7}. We conduct 3D numerical simulations to know how they work in the aquifers without trapping structures.

Simulation model

The study was carried out using a compositional simulator, GEM-GHG⁸. A simple aquifer model 13,250 m long, 7,100 m wide and with a total thickness of 390 m was used. The formation consists of 30 m thick high

permeability sand layers (100 md) and alternate 20 m thick low permeability mud layers (0.01 md) with dips of 0° and 3° (Figure 1). In addition, the cases of higher permeability and poor capillary-sealing efficiency of mud layers (0.1 and 1 md) are tested. The vertical to horizontal permeability ratio (K_v/K_h) is 0.1 for sandstone, while that for mudstone is unity. The porosity of the sandstone and mudstone is 0.30.

The number of fundamental grid blocks is 80×41×52. The grid block size near injection well is 50 m × 50 m × 5 m, and becomes coarser with increasing distance from the well. Large pore volumes were assigned to the top boundary and the lateral boundary blocks to represent an aquifer that extends beyond the simulation grid. The injection completions are located at a depth between 1,500 and 1,525 m in 6 grid blocks. These well blocks were refined into 5×5×1 grid blocks to improve accuracy on CO₂ injection behavior. CO₂ was injected for 25 years with a target injection rate of 500,000 or 100,000 tons/year. The maximum bottom hole pressure allowed is 20 MPa in order to maintain the mechanical integrity of the formation, at the top of the completion, where the initial pressure was set to 15 MPa. The simulation was run for 1,000 years to monitor its long-time migration. The geothermal gradient is