CO₂ Plume Migration with Gravitational, Viscous, and Capillary Forces in Saline Aquifers

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ABSTRACT

When injecting CO₂ in saline aquifers, in order to investigate realistic flow, this study proposes a dimensionless group in the form of combination of Capillary number and Bond number to consider three forces of gravitational, viscous and capillary forces, simultaneously. Using of each dimensionless group individually is insufficient to obtain a satisfactory correlation with flow behavior of injected CO₂. With the proposed dimensionless group, the universal profile of CO₂ saturation was obtained in describing CO₂ flow behaviors for CO₂ injection rate, CO₂-water interfacial tension, and density difference between CO₂ and water. Thus, more realistic CO₂ flow behavior was analyzed.

KEY WORDS: CO₂ sequestration; saline aquifers; CO₂ flow behavior; Capillary number; Bond number; dimensionless group.

INTRODUCTION

Geological sequestration of CO₂ is one of the practical technologies for mitigating anthropogenic CO₂ in atmosphere which is caused by the use of fossil fuels. Among the geological formations for CO₂ sequestration, saline aquifers are considered as a promising option because saline aquifers have larger storage capacity of CO₂ than other formations and accessibility from CO₂ sources. In terms of storage safety, saline aquifers are more effective storage sites since structural, residual, solubility and mineralization trapping mechanisms by physical and geochemical interactions of CO₂-water-rock occur actively than depleted oil and gas reservoirs including mainly structural trap. When two immiscible fluids flow in porous media, viscous force quantified by mobility ratio and gravitational force by density difference of the fluids are important factors affecting flow regimes which mean behaviors of fluids flow. In order to analyze and describe the fluids flow, dimensionless groups defined by using the viscous and gravitational forces have been studied. Crane et al. (1963) classified flow regimes based on range of the dimensionless groups defined as viscous to gravity ratio and estimated sweep efficiency of oil by water flooding in porous media. One of virtues for using the dimensionless groups is that they allow scaling from field conditions to the laboratory conditions, so that the flow regimes analyzed in the laboratory are similar to those in the field. The other is that using dimensionless groups reduces the number of parameters affecting immiscible fluids displacement in porous media to be studied effectively. Majority of previous studies investigated the effect of dimensionless groups on oil recovery performance during gravity drainage process (Kulkarni and Rao, 2006; Wood et al., 2008; Jadhawar and Sarma, 2008, Rostami et al., 2010). They mainly investigated the effects of viscous force affected by rate of gas or CO₂ flooding and gravitational force by upward and downward direction of injection, and density change by oil components. In an aspect of CO₂ storage, plume shape of injected CO₂ and ratio of trapping mechanisms were analyzed under the various CO₂ injection rate condition using Gravity number which is the ratio of viscous force to gravitational force of CO₂-water system (Ide et al., 2007). Kuo et al. (2010) conducted experiments and simulation studies to investigate the effect of gravity and viscous force by changing CO₂ injection rate on flow behavior of injected CO₂ in saline aquifers using Capillary number and Gravity number in homogeneous and heterogeneous systems. However, most of previous studies investigated effect of viscous and gravitational forces independently using dimensionless groups defined by ratio of two forces. Furthermore most of them considered capillary force as constant, and it means characteristics of CO₂ and water, and interaction of the fluids could not be fully analyzed. In this study, we attempt to consider three forces of gravitational, viscous, and capillary forces, simultaneously, with the proposed dimensionless group to examine more realistic flow behavior of CO₂, when CO₂ is injected in saline aquifers. By the analysis of the acquired each trapping mechanism from flow behavior as flow regimes, optimum CO₂ injection scheme can be designed for maximizing the solubility and residual trappings as stable mechanisms. Mineralization trapping mechanism is neglected in this study due to its slow process for CO₂ sequestration.

MODEL DESCRIPTION

CO₂ plume migration was analyzed using GEM-GHG which is a compositional simulator developed by Computer Modeling Group. The simulation model of two-dimensional vertical cross-sectional system was created to consider gravitational, viscous, and capillary forces. The system is for CO₂ storage with closed boundaries on three sides and