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Microfluidic study for investigating migration and residual phenomena of supercritical CO_2 in porous media

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Abstract

This study aims to observe the displacement pattern and to estimate storage efficiency by using micromodels. A series of $scCO_2$ injection experiments is conducted for visualization of distribution of injecting $scCO_2$ and residual porewater in transparent micromodels under reservoir conditions. To analyze the porewater displacement by $scCO_2$ injection quantitatively, the images of invasion patterns and distribution of CO_2 in pore networks are acquired through an microscopic imaging system. The results are applied in investigating the effects of major environmental factors such as CO_2 phase and pressure on porewater displacement by $scCO_2$ and storage efficiency in terms of areal displacement efficiency.

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Keywords: geological CO_2 storage; micromodel; CO_2; porewater; image analysis; areal displacement efficiency

1. Introduction

Geological carbon sequestration is widely considered as a promising technology to stabilize the atmospheric concentration of carbon dioxide. In successful sequestration, anthropogenic CO_2 captured on a large scale and injected

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in deep geological formations should be safely stored for hundreds and thousands of years through natural trapping mechanisms such as structural trapping, dissolution trapping, residual trapping, mineral trapping, etc. These mechanisms are governed by various physical and chemical factors such as wettability, surface tension, solubility, capillarity, mass transfer, etc. in CO_2-porewater-rock systems. The changes in these factors have direct effects on the imbibition and drainage processes of CO_2 and porewater and storage efficiency in geological carbon sequestration [1]. Therefore, various researches have been performed and reported to reveal the effects of geochemical factors such as temperature, pressure, salinity, etc. on the surface and interfacial characteristics and their interactions in CO_2-porewater-rock systems [2, 3, 4]. Among these, experimental studies using micromodels, artificial pore networks fabricated with transparent materials, have been conducted for investigating the CO_2 migration at pore scale through close observations and image analysis.

Since Chatenever and Calhoun (1952) used in experimental observations on fluid movement in porous media [5], glass-etching micromodels have been utilized as effective tools for scrutinizing the migration and distribution of multiphase flow at pore level. Recently, especially in the subject of geological carbon storage, micromodel studies have played a significant role in investigating various phenomena in CO_2-porewater-rock systems. Naderi and Babadagli (2011) identified the effects of wave frequency and power, initial water saturation, wettability and injection rates on multiphase flow in porous media using homogeneous and heterogeneous micromodels [6]. Zuo et al. (2013) directly observed carbon dioxide exsolution from carbonated water in silicon-wafer micromodel under reservoir conditions [7]. Kim and Santamarina (2014) applied surfactants in CO_2 injection to improve displacement efficiency and closely observed interfacial interactions in artificial pore network [8].

This study aims to conduct a series of experiments on the injection of supercritical CO_2 ($scCO_2$) for visualization of distribution of injected $scCO_2$ and residual porewater using transparent microfluidic chips. Among experimental results, the binary images from image analysis are quantitatively examined in order to illuminate the effects of CO_2 phase and neighboring pressure on the imbibition process of CO_2 in terms of displacement efficiency.

2. Materials and methods

2.1. Micromodels

The transparent glass micromodels (Micronit Microfluidics BV) are applied in order to visualize the migration and distribution of injecting $scCO_2$ in this study. The micromodels are fabricated by symmetrically etching uniform channel networks representing porous media or rock structures on two silica plates (a patterned area of 20 × 10mm) and by fusing them together with hydrofluoric acid (Fig. 1). Calculated pore volume and porosity of the micromodel are 2.1μL and 0.31, respectively.

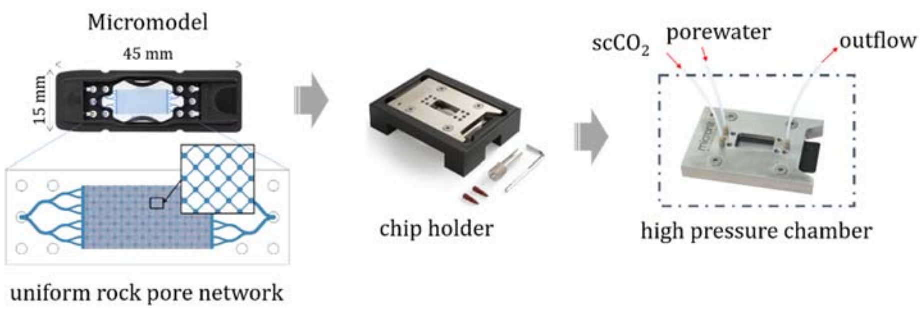

Fig. 1. A micromodel and assembled chip holder used in this study