Nanosized CO₂ droplets injection for stable geological storage

Suguru UEMURA a,*, Yohei MATSUI a, Atsuto NODA a, Shohji TSUSHIMA a, Shuichiro HIRAI a

aTokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo, 152-8550, Japan

Abstract

Geological sequestration is an immediately available and technologically feasible method to achieve substantial reductions in carbon dioxide (CO₂) emissions to the atmosphere. To develop a stable geological storage technique, this study proposes a new method using nanosized CO₂ droplets in a porous structure. The buoyancy effect can be reduced by changing the CO₂ from a continuous phase to nanosized droplets before injection. In this study, the experiments focused on the formation of nanosized CO₂ droplets, their time evolution, and their behavior in porous media. The experimental results suggested the high potential of the nanosized CO₂ droplets for stable geological storage.

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1. Introduction

Geological storage is considered as an important key technology to mitigate CO₂ emissions into the atmosphere [1][2]. In recent years, CO₂ geological storage field tests have been performed in many parts of the world. However, the risk of CO₂ leakage from storage reservoirs remains a crucial problem. The injected CO₂ migrates upward because of the buoyancy effect, and caprock structures are therefore necessary to prevent CO₂ leakage [3].

Injected CO₂ generally forms a continuous plume in aquifers, and larger buoyancy effects are caused by the larger continuous phase of CO₂. To develop a stable geological storage technique, this study proposes a novel method that uses nanosized CO₂ droplets in a porous structure to allow stable geological storage (Fig.1). The buoyancy effect can be reduced by changing the CO₂ from a continuous phase to nanosized droplets before injection.

This technique can substantially improve the CO₂ storage stability. It is important that CCS achieves public acceptance. Nanosized CO₂ allows the possibility of realizing geological storage without

* Corresponding author. Tel.: +8-3-5734-3554; fax: +8-3-5734-3554.
E-mail address: uemura@mech.titech.ac.jp.
relying on caprock structures. It allows geological storage near large CO₂ emission sources, increases the CO₂ storage potential, and reduces the cost of transporting CO₂ [4]. In this study, experimental and study was performed to examine the stability of nanosized CO₂ droplets in the aquifer.

2. Experimental apparatus

The experimental study focused on the nanosizing process, the size distribution of the CO₂ droplets, and their behaviour in porous media. Figure 2 shows the experimental apparatus. The CO₂ nanosizing process was observed using a closed circulation channel that consisted of a static mixer, a circulation pump, and an observation section. The circuit pressure and temperature were controlled to give 6 to 9 MPa and approximately 22°C, and the CO₂ was therefore in a liquid state. The volume ratio of CO₂ to water was set to 1:1, and a surfactant was added to assist with the micronization of the CO₂. The concentration of surfactant used was kept as low as possible to reduce the storage costs.

The size distribution and time evolution of the nanosized CO₂ droplets were observed through windows made of sapphire glass. The droplet size distribution of the CO₂, and its time evolution, were measured using dynamic light scattering (DLS).

The nanosized CO₂ droplets and water were slowly aspirated using a syringe pump, and were injected into water-saturated porous media. The porous media was a packed silica sand bed (with grain diameters of 125 to 250 μm) in a stainless steel tube. The behaviour of the nanosized CO₂ in the porous media was investigated using X-ray computed tomography (CT).
3. Experimental results and discussion

Three observation windows made of sapphire glass were placed in the channel to enable observation of the nanosizing process with sufficient light intensity. As shown in Fig. 3, nanosized liquid CO$_2$ appears cloudy.

Figure 4 shows the average diameter of the CO$_2$ droplets immediately after the mixing was stopped. The initial diameter was approximately 40 to 70 nm. Nanosized CO$_2$ droplets were successfully generated.
The average diameter increased with time. It is considered that the change in the diameter distribution was caused by the coalescence and Ostwald ripening of the CO\(_2\) droplets. As the surfactant concentration \(C_s = \frac{V_{\text{surfactant}}}{(V_{\text{CO}_2} + V_{\text{H}_2\text{O}})}\) was increased, the speed of growth of the diameter of the CO\(_2\) droplets decreased.

Figure 5 shows the obtained CT images. Reconstructed three-dimensional CT images were obtained with spatial resolution 20 \(\mu\text{m}\) (i.e. pore-scale structure can be observed). The CT images cannot resolve the shape of nanosized CO\(_2\) droplets itself right after injection (Fig. 5. (a)). After a day, micro-scale CO\(_2\) droplets emerged in the pores because of coalescence of nanosized CO\(_2\) droplets (Fig. 5. (b)); however, the number of pore-scale CO\(_2\) droplets—and their positions—remained unchanged during an observation period of a few days (Fig. 5. (c)-(e)). It is considered that any increase in the CO\(_2\) droplet
diameter was prevented in the porous media, and the droplets were finally trapped in the pore-throat structure.

The lattice Boltzmann method—which is an optimal method for the simulation of immiscible two-phase flow in porous media, on the pore-scale—was also employed. The fundamental behaviour of the pore-scale CO2 droplets in a porous medium was simulated, and the results showed that the pore-scale CO2 droplets were stably trapped.

The experimental results also indicated that the nanosized CO2 permeated uniformly in the porous media, with no dependence on the pore-throat diameter. It show the potential that the storage efficiency as good as or better than that achieved using conventional storage methods, because the volume ratio of the nanosized CO2 to water was comparable to that observed under CO2 saturation (20 to 50%, CO2 without any change) in sandstone.

4. Conclusion

To develop a stable geological storage technique, a new method using nanosized CO2 droplets was proposed. In this study, the experiments focused on the formation of nanosized CO2 droplets, their time evolution, and their behavior in porous media. Nanosized CO2 droplets were successfully generated experimentally. The formation of nanosized CO2 droplets and their time evolution in the porous media were studied qualitatively and quantitatively. Nanosized CO2 permeated uniformly in the porous media with no dependence on the pore-throat diameter, and their time evolution was observed using X-ray CT. After a day, micro-scale CO2 droplets emerged, and their positions remained unchanged throughout an observation period of a few days. The experimental results suggested the high potential of the nanosized CO2 droplets for stable geological storage.

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