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# Engineered Precipitation Geo-barriers via Transverse Mixing for CO2 Storage

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## Abstract

The success of geologic carbon storage mostly relies on the sealing capacity and integrity of the caprock, which acts as a barrier to prevent leakage. However, selecting appropriate sites presents significant challenges and costs, where there may exist pre-existing faults, fractures, and fissures that could pose potential leakage risks. Given the limitations and risks associated with geologic carbon storage, we propose an innovative method to create an engineered barrier for subsurface storage by intentionally inducing precipitation. Incompatible ionic solutes in parallel flows can diffuse transversely, forming an insoluble precipitation layer that significantly alters the local permeability of the rock, which can eventually act as engineered barriers for subsurface storage.

In this study, we generated geo-barriers in a core-scale experimental setup. We used a special core flooding setup which allowed injecting two separate brines to create geo-barriers. By implementing parallel dual injection from the inlet – injecting two separate brines containing $Ba^{2+}$ and $SO_4^{2-}$ ions respectfully, we generated a precipitation layer by filling the pores with barite ($BaSO_4$). While the injection pressures of the two fluids were carefully monitored, we used X-ray Computed Tomography (CT) to scan the rock and observed the formation of the geo-barrier. Subsequently, we cored small cylindrical specimens perpendicular to the geo-barrier layer, and measured their permeability to evaluate the sealing capacity.

The X-ray CT results demonstrated that a geo-barrier layer was generated along the specimen length, with the barite layer being denser and thinner closer to the inlet. Moreover, analysis of the CT images allowed us to determine how the porosity-permeability relationship was altered due to the precipitation layer. The permeability measurements of the small cores indicated a significant decrease, down to a permeability of $10^{-19}$ m² in a week, approaching that of caprock permeability.

The significance of this study lies in its innovative approach, intentionally inducing precipitation to generate engineered geo-barriers. Unlike conventional reliance on natural caprock formations, this method expands

the number of potential storage sites by mitigating risks associated with caprock integrity. The creation of engineered barriers offers a novel, scalable solution for improving $CO_2$ sequestration reliability and site selection flexibility.

## Introduction

$CO_2$ sequestration has proven to be one of the most effective ways of storing large volumes of atmospheric $CO_2$ (Iglauer et al., 2015a). This process requires a sufficient storage volume and an impermeable caprock that can impede the gas leakage to the atmosphere (Iglauer et al., 2015b). Seal integrity is a vital factor for determining whether the reservoir is suitable for $CO_2$ injection. However, the presence of pre-existing faults, fractures, or fissures in sealing layers poses potential leakage risks, disqualifying suitable sites. Thus, there is a need for a novel method to efficiently isolate the injected $CO_2$ and address the challenges due to the pre-existing fractures.

Precipitation has been shown to reduce the permeability of porous media (He et al., 2024). A commonly observed process in petroleum engineering and geology involves barium sulfate ($BaSO_4$) precipitation. This occurs when barium chloride ($BaCl_2$) and sodium sulfate ($Na_2SO_4$) mix to form precipitates that fill in the pores and reduce the permeability. This study proposes an innovative method to create an engineered barrier for subsurface storage by intentionally inducing this precipitation. Incompatible ionic solutes in parallel flows (Katz et al., 2011) can diffuse transversely, forming an insoluble precipitation layer that significantly alters the local permeability of the rock, which can eventually act as engineered barriers for subsurface storage. We conduct laboratory experiments to utilize intentional precipitation via transverse mixing to create barriers and validate the feasibility of these geo-barriers for efficient geologic carbon storage.

## Methods

A 1.5-inch diameter Bentheimer sandstone specimen was selected for this experiment. The experiment begins by injecting deionized water into the sample, saturating the specimen and measuring the intrinsic permeability (Geoffrey Mason & Norman R. Morrow, 2013). The injection pressure and volume are constantly recorded with time. Next, the dual injection is replaced with two ionic solutions; $BaCl_2$ and $Na_2SO_4$, to begin the geo-barrier generation via precipitation. The x-ray computer tomography (CT) scan technique is used to monitor the geo-barrier formation. Then, 1-inch diameter cores are extracted in the perpendicular direction to the Barite layer formation to measure the change in permeability due to the geo-barrier formation.

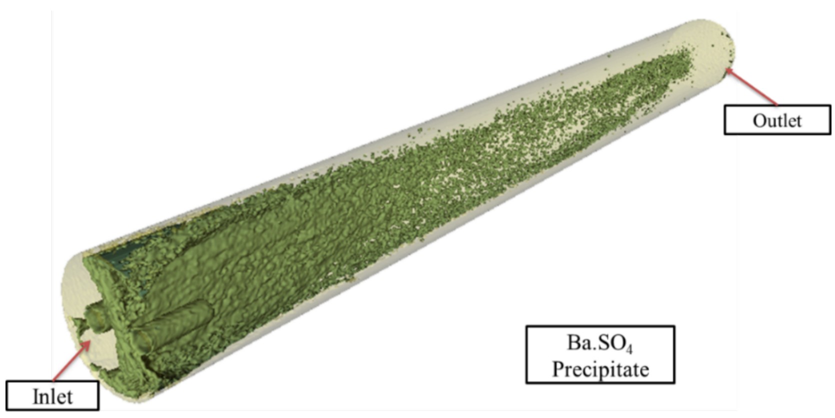


**Figure 1.** X-ray image of the barite geo-barrier formation

## Results and Discussion

After dual injection, X-ray CT images showed a well-defined geo-barrier formed at the center of the dual injection zone (Figure 1). Permeability measurements from small cores indicated that the barrier achieved extremely low permeability values, comparable to those of shale ($10^{-19}$ $m^2$). The permeability gradually increased with distance from the inlet. The thickness of the barrier increased with distance, indicating a decrease in barite concentration. The experiments successfully demonstrated the formation of a geo-barrier extending along a plane within the porous media. The permeability of the precipitant layer was measured to be equal to or lower than that of shale, confirming the feasibility of using Barite as a precipitant for barrier generation.

**Conclusions**

This study highlights the effect of transverse mixing combined with chemical precipitation through a laboratory-scale proof-of-concept experiment. Parallel injection of two ionic solutions at the same rate resulted in the formation of a mineral-based solid barrier within the porous media. However, the results indicate that permeability increases as the distance from the injection point grows. Moving forward, the objective is to develop methods to control permeability variations in the formed barrier. Future experiments will explore different concentrations, flow rates, temperatures, and other parameters that may influence the geo-barrier's formation.

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