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## Impact of Vaporization on Mineral Changes and Salt Precipitation During CO<sub>2</sub> Storage

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### Abstract

The subsurface injection of CO<sub>2</sub> into deep saline aquifers in the San Juan Basin offers a promising way to reduce atmospheric CO<sub>2</sub> levels. Yet, it faces challenges like the vaporization of formation brine into the CO<sub>2</sub> stream, leading to halite deposition through a salting-out effect, potentially damaging the formation. This study explores the impacts of water vaporization and salt deposition on geochemistry and reservoir properties.

Using a compositional reservoir simulator, this research modeled reactive transport processes during supercritical CO<sub>2</sub> injection, focusing on mineral changes and salt precipitation due to water vaporization. A detailed, heterogeneous 3D model of the San Juan Basin was employed, considering the specific mineralogy and brine composition of the formation.

Results show that water vaporization in CO<sub>2</sub> sequestration models significantly affects CO<sub>2</sub> trapping mechanisms and mineral reactions. It increases residually trapped CO<sub>2</sub> by freeing up pore spaces and reduces dissolved CO<sub>2</sub> levels. This results in a lateral reduction of the plume size by over 350 feet in the topmost layer and approximately 800 feet in the bottom layer when vaporization is included in the model. Additionally, the dissolution of silica-bearing minerals is enhanced, promoting increased quartz precipitation. Salt deposition primarily occurs around well perforations, affecting reservoir properties.

This study underlines the importance of considering water vaporization on geological trapping mechanisms, mineral reactions and salt precipitation during CO<sub>2</sub> sequestration in saline aquifers. Findings stress the need to include vaporization effects in simulation models to enhance predictions for large-scale CO<sub>2</sub> operations, providing crucial insights into geochemical dynamics and highlighting the necessity for comprehensive sequestration strategies.

## 1.0 Introduction

Geologic CO<sub>2</sub> storage serves as an essential strategy in mitigating global CO<sub>2</sub> emissions from various sources, including gas flaring, coal plants, and other industrial activities that negatively affect our environment (Opoku Duarte et al., 2025; Ike et al., 2013). Saline aquifers offers significant CO<sub>2</sub> storage potential due to their large capacities and natural sealing properties. When supercritical CO<sub>2</sub> is injected, it displaces and evaporates the brine, leading to increased salt concentration and eventual precipitation which could affect reservoir properties (Bacci et al., 2011a, 2011b; Zettlitzer et al., 2010; Burton et al., 2008). This process establishes three distinct zones around the wellbore: the dry-out zone, where brine evaporation by the injected CO<sub>2</sub> increases salt concentration, causing salt precipitation; the two-phase zone, characterized by the coexistence of CO<sub>2</sub> and brine, allowing water and ions to mix across phases; and the initial brine zone, where the original brine is gradually pushed out by the advancing CO<sub>2</sub> (Ott et al., 2015; André et al., 2014; Peysson et al., 2014; Pruess, 2009).

Challenges arise, however, as these changes can impair reservoir injectivity by reducing porosity and permeability. To understand and mitigate these impacts, our study employs a compositional simulator to explore the effects of water vaporization within a heterogeneous 3D model of the San Juan Basin, focusing on how vaporization influences mineral dissolution and precipitation dynamics, aiming to improve predictions of CO<sub>2</sub> storage mechanisms and reservoir performance.

## 2.0 Methodology

A static model was constructed in Petrel and exported to the CMG-GEM compositional simulator (version 2024.20) to simulate CO<sub>2</sub> and brine interactions in a three-dimensional isothermal model configured in a 164 x 116 x 25 grid. The model, focusing on processes such as mineral dissolution, precipitation, and water vaporization, operates under initial conditions of 100% water saturation and a reservoir pressure gradient of 0.42 psi/ft at a reference depth, with an initial pressure of 3,200 psi. CO<sub>2</sub> was injected at a rate of 20 MMscf/day for 30 years through the SJB Carbon Safe Stratigraphic well with a bottom hole pressure of 4631.4 psi, followed by a 150-year post-injection monitoring phase.

The simulation excludes geomechanical effects and impurities in primary minerals, adhering to methodologies described by Nghiem et al. (2004) and Norouzi et al. (2021). Two scenarios were simulated:

1. **Case 1 (Base Case):** Excludes water vaporization to model standard geochemical interactions.
2. **Case 2 (Water Vaporization Case):** Introduces conditions of extreme dryness using parameters like Aqueous Phase Saturation Cutoff (SATWCUTOFF) and Residual Aqueous Phase Saturation for H<sub>2</sub>O Vaporization (SWR-H2OVAP).

For geochemical modeling, analysis of a core sample from the Entrada Sandstone identified minerals such as quartz, Illite, calcite, chlorite, smectite, and various feldspars. The ion profile, including sodium, chloride, sulfate, bicarbonate, and carbonate concentrations, was consistent with the data used in Boison et al. (2024)

## 3.0 Results and Discussion

### 3.1 Effect on CO<sub>2</sub> trapping mechanisms

Figure 1 shows the comparison of the CO<sub>2</sub> trapping mechanisms under scenarios with and without the influence of water vaporization (Case 1 and Case 2). Initially, CO<sub>2</sub> dissolution rates are approximately 24% in the base case and slightly lower at 23.4% in the vaporization case, due to reduced water saturation. As the brine approaches saturation, the dissolution percentages decrease to 14.8% and 14.08%, respectively, eventually stabilizing at 9.6% and 8.6% after injection ends. This reduction is attributed to re-equilibration caused by phase redistribution and ongoing geochemical interactions.

The pH changes during the monitoring period, indicating a stabilization at a less acidic pH of 5.6 in the vaporization scenario, compared to 4.3 in the base case as seen in Figure 2. This suggests that the vaporization effect may mitigate acidification by altering the chemical equilibria within the system.

The results show a gradual decrease in supercritical CO<sub>2</sub> trapping, settling at 53% for the base case and 52% for the vaporization case, post-injection. The vaporization scenario exhibits more pronounced residual trapping at

39%, compared to 37% in the base case, attributed to the availability of additional pore space from water vaporization, which facilitates greater CO<sub>2</sub> retention.

Mineral trapping is modeled by the behavior of calcite since it is the only carbonate in our model. In Case 1, some CO<sub>2</sub> is trapped in calcite through precipitation processes. However, as conditions change due to vaporization, calcite primarily dissolves during the monitoring period, with precipitation expected to commence only once the conditions become favorable for mineral formation.

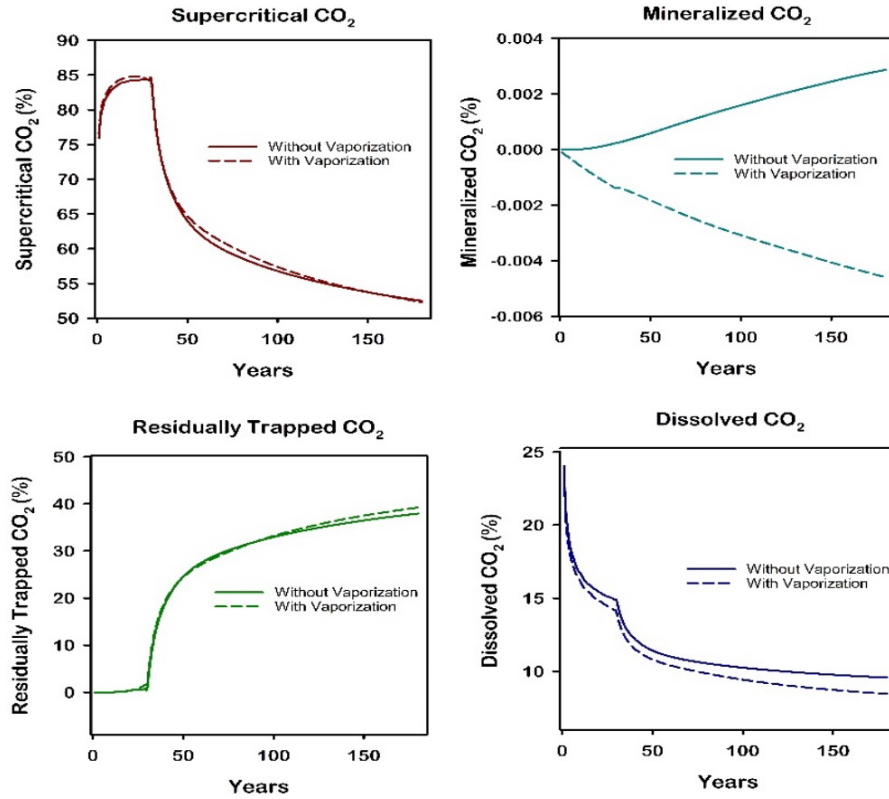


Figure 1: Comparison of CO<sub>2</sub> trapping mechanisms with and without water vaporization

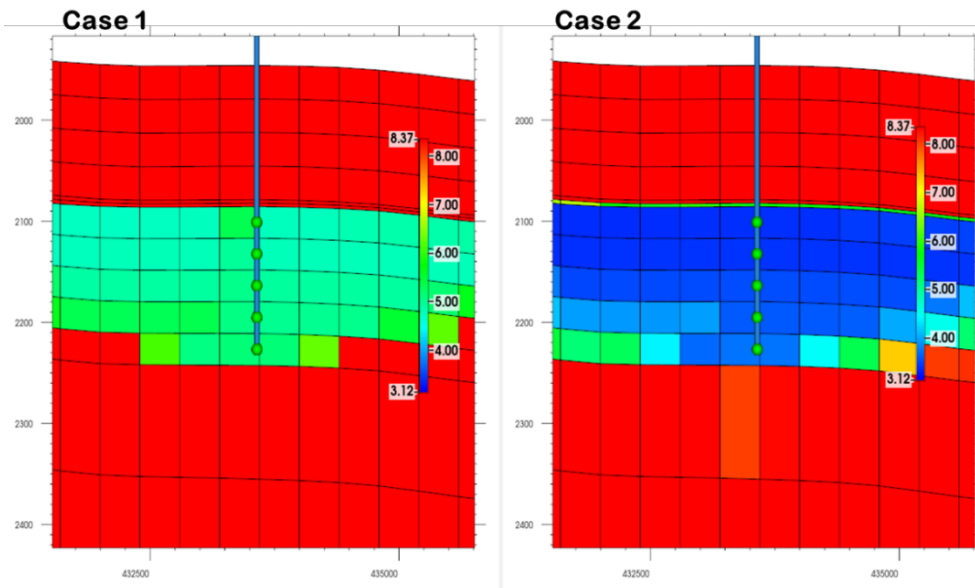


Figure 2: pH distribution for the vaporization and base case after monitoring period

### 3.2 Impact on Plume size

As water near the perforation region vaporizes during CO<sub>2</sub> injection, previously water-filled pore spaces are liberated, facilitating increased residual trapping of CO<sub>2</sub>. The vaporization process frees up more pore space, allowing CO<sub>2</sub> to occupy these voids, thereby reducing the mobility of free-phase CO<sub>2</sub>. This mechanism of increased residual CO<sub>2</sub> trapping, particularly around the injection area, contributes to a notable reduction in the size of the CO<sub>2</sub> plume. As observed in Figure 3, In the base case scenario, the topmost layer was approximately 9,557 ft, while the vaporization case reached 9,179 ft, reflecting a reduction of about 4%. Similarly, the plume at the base measured 1,994 ft in the base case and 1,200 ft in the vaporization case, indicating a significant reduction of approximately 40%. This reduction was consistently observed across all layers in the k-direction. These results enhance our ability to accurately predict the area of review, thereby facilitating the precise placement of monitoring wells.

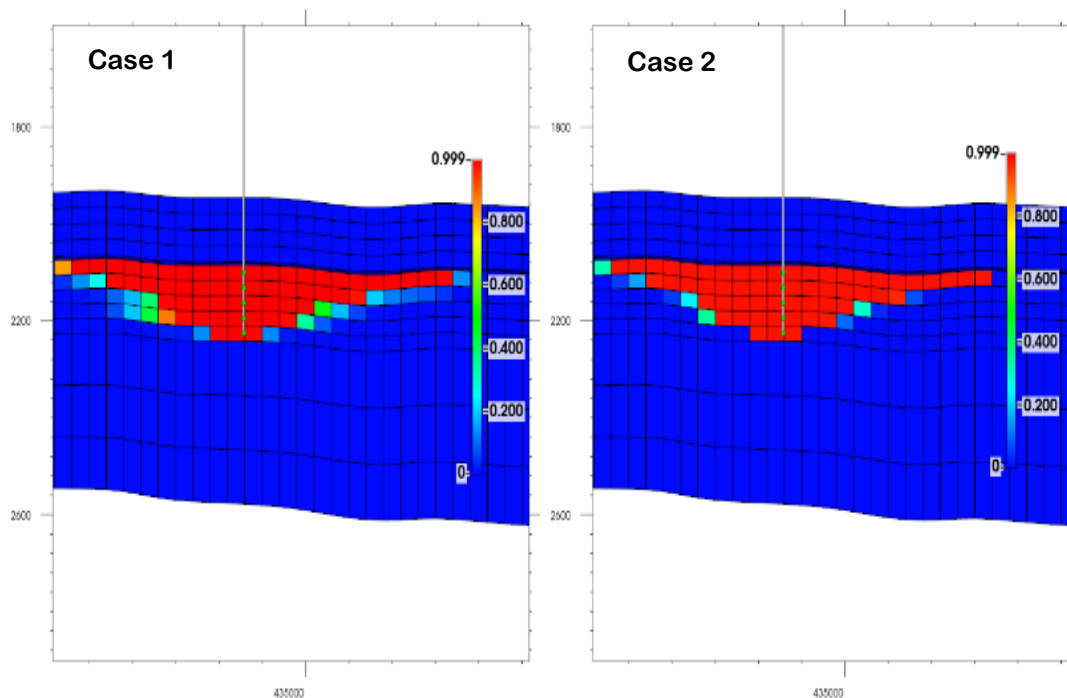


Figure 3: Gas Saturation and Plume for the two scenarios

### 3.3 Effect of Vaporization on Mineral Dissolution/Precipitation

Figure 4 demonstrates the impact of water vaporization on mineral behavior during CO<sub>2</sub> injection over a 175-year timeline, illustrating significant geochemical alterations within the subsurface. The diagram shows enhanced dissolution of minerals like feldspars (albite, plagioclase, and orthoclase) and continuous dissolution of calcite in scenarios with vaporization. Unlike non-vaporization conditions where calcite initially precipitates, vaporization leads to its sustained dissolution. Similarly, chlorite and Illite, both silica-bearing minerals, experience significantly increased dissolution rates, up to 20 times more than in the base case without vaporization.

In contrast, quartz sees a notable increase in precipitation, about 15 times higher under vaporization conditions, driven by the surplus silica from the dissolution of other minerals. This substantial quartz formation plays a key role in stabilizing the geochemical environment as it adjusts to the changes induced by vaporization. Smectite exhibits variable behavior, indicating its responsiveness to shifting chemical contexts. These observations show the influence of water vaporization on the geochemical dynamics and mineral transformations during CO<sub>2</sub> injection.

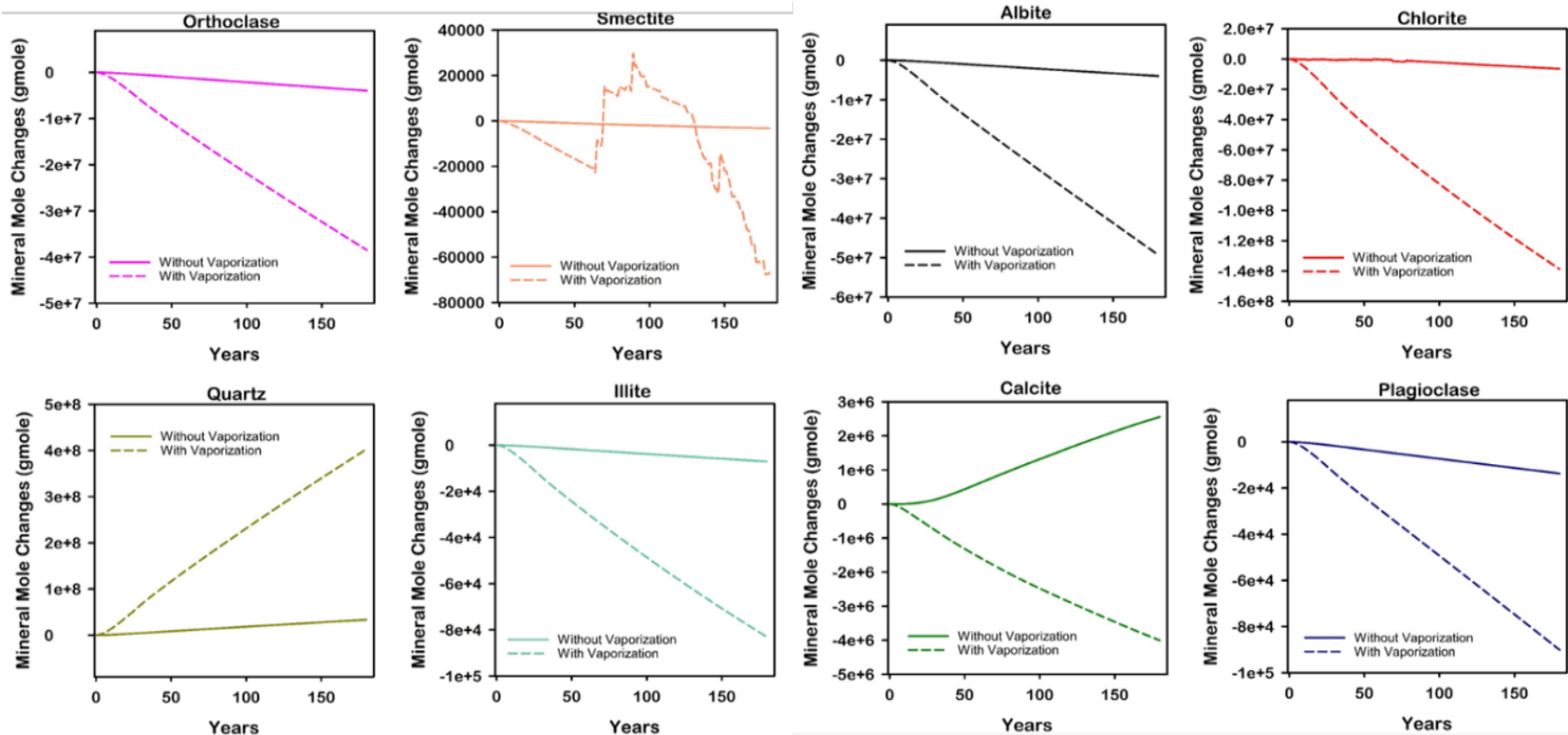
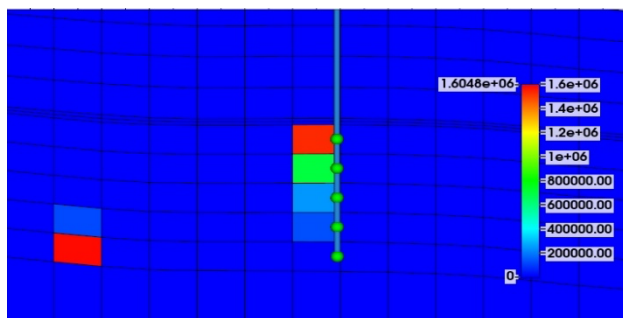


Figure 4: Comparison of Mineral Mole Changes for both scenarios

### 3.4 Impact of Vaporization on Salt Precipitation

Given the high initial composition of Sodium (Na<sup>+</sup>) and Chlorine (Cl<sup>-</sup>) ions, halite precipitation is a significant process during CO<sub>2</sub> injection, especially near the wellbore. Figure 5(a) shows that halite primarily precipitates in regions close to the wellbore. Figure 5(b) contrasts halite precipitation between two scenarios: Case 1, with minimal precipitation, and Case 2, which includes water vaporization and shows notable halite precipitation. The marked increase in halite formation in Case 2 is attributed to the creation of a dry-out zone around the wellbore. This zone, characterized by reduced water content, leads to elevated salt concentrations, thereby promoting the formation and accumulation of halite crystals. This distinction underscores the impact of water vaporization on mineral dynamics during CO<sub>2</sub> sequestration processes.

(a)



(b)

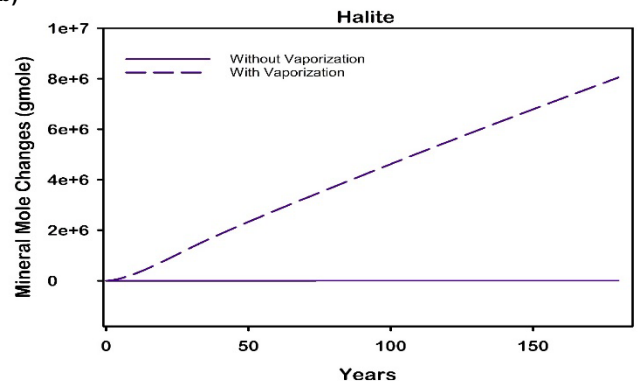


Figure 5: Comparative Analysis of Halite Precipitation: (a) Spatial Distribution near the Wellbore, (b) Mineral Mole Changes with and without Water Vaporization

### 4.0 Conclusion

This study has investigated the effects of water vaporization on CO<sub>2</sub> trapping, plume dynamics, mineral behavior, and salt precipitation during CO<sub>2</sub> injection into geological formations. The findings highlight the significant

impact of vaporization on these processes, emphasizing its role in enhancing CO<sub>2</sub> retention and altering geochemical dynamics.

Water vaporization lowers water saturation in the reservoir, which initially reduces CO<sub>2</sub> dissolution but significantly increases residual trapping, allowing more CO<sub>2</sub> to be securely held within the formation. This process also leads to a smaller and more localized CO<sub>2</sub> plume, which reduces the area of review and facilitates more efficient placement of monitoring wells, thereby improving plume monitoring and long-term management.

Additionally, water vaporization induces changes in mineral dissolution and precipitation, helping to stabilize the geochemical environment. These shifts are critical for ensuring the long-term stability and integrity of the storage formation. However, vaporization also creates a dry-out zone near the wellbore, resulting in significant halite precipitation. This salt deposition can alter formation permeability, posing potential operational challenges that require careful monitoring and management.

The results of this study underscore the importance of accounting for water vaporization in simulation models to enhance predictions and optimize strategies for large-scale CO<sub>2</sub> sequestration projects.

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