Dear Anonymous Referee #2,

We sincerely thank the reviewer for the positive assessment of our work and for recognizing the relevance of the proposed numerical framework to long-term $CO_2$ sequestration in saline aquifers. We also appreciate the constructive comments, which have helped us clarify several important assumptions and improve the technical rigor of the manuscript. Our point-by-point responses are provided below.

**Comment 1:**

(Section 2.1) How is the phase partitioning of $CO_2$ between the liquid and gas phase determined? While Equation 4 is provided, it is not clear to me if it is derived based on the thermodynamic principles.

**Response:** We thank the reviewer for this expert comment. Here, we indeed adopted a simplified mass transfer model based on Reference (Martinez, M. J., & Hesse, M. A. (2016). Two-phase convective $CO_2$ dissolution in saline aquifers. Water Resources Research, 52(1). https://doi.org/10.1002/2015WR017085). We did not provide a detailed explanation of this point. We assumed that dissolution occurs only in the two-phase region; therefore, the source term in the brine-saturated region is zero. In this simplified model, $CO_2$ dissolution is incorporated as a source term in the mass conservation equation. Mass transfer of $CO_2$ from the $CO_2$ phase to the brine phase can only take place when $S_g > 0$ and $c < c_{\mathrm{eq}}$, i.e., when the brine phase is undersaturated with respect to $CO_2$. The mass transfer coefficient $\kappa$ is the inverse time constant for dissolution and diffusion of gaseous $CO_2$ into fresh brine. This formulation allows us to simulate compositional two-phase flow problems without resorting to the computationally expensive compositional reservoir formulation.

We have added an explanation for adopting this simplified treatment in lines 87–89:” The dissolution of the $CO_2$ phase into the brine phase is assumed to occur only in the two-phase region. Treating the dissolution mass as a source term in this way simplifies the simulation of multi-component two-phase flow problems and improves computational efficiency.”

**Comment 2:**

(Section 2.2) The authors mentioned that the precipitation is neglected, yet this is a primary mechanism for mineral trapping. How is mineral trapping quantified in the following sections (e.g., the results shown in Figure 7) if precipitation is excluded?

**Response:** We thank the reviewer for the comment. We agree that precipitation significantly affects mineral trapping in the reservoir. However, the current model is not yet capable of accounting for mineral precipitation, and this remains a direction for our future research. In this study, we adopted a simplification in which only calcite is reactive in the reservoir, and the total amount of mineral trapping is quantified by the mass change of calcite. Since the timescale of multi-component chemical reactions is 1–2 orders of magnitude greater than that of convective mixing, we selected calcite—which has a relatively fast reaction rate—to focus on the coupling between reaction and convection. This approach is common in similar studies (10.1016/j.ijggc.2016.12.005, 10.1016/j.ijggc.2021.103365 and 10.1016/j.jclepro.2025.145948 ).

**Comment 3:**

- (Section 2.3)

(Line 141) Please justify why 500 years is considered reasonable for gas distribution to stabilize.

**Response:** Thank you for the comment. Our simulation results indicate that the average $CO_2$ saturation in the reservoir is nearly identical to the residual saturation, and in the region where the $CO_2$ phase is present, the brine has already reached the maximum concentration at 500 years. As shown by Eq. (4), dissolution will not proceed.

The coexistence of $CO_2$-saturated brine and residually trapped $CO_2$ is in fact an important assumption underlying gravity-induced Ostwald ripening. We therefore consider that the gas plume has stabilized after 500 years. We have supplemented this assumption with a clarifying statement in lines 143–146:" The gas distribution stabilizes and attains the initial ripening state under the assumption that the maximum concentration has been achieved throughout the domain. Our simulation results show that after 500 years, the average $CO_2$ saturation in the reservoir approaches the residual saturation, and according to Eq. (4), dissolution no longer occurs. Therefore, the simulation results at 500 years were selected as the initial condition for the gravity-induced Ostwald ripening process."

**Comment 4:**

(Line 143) Residual saturation appears to be a critical parameter for the ripening process. Have the authors considered incorporating hysteresis effect to give a more accurate evaluation of residual saturation?

**Response:** We fully agree with your perspective. We agree that hysteresis can improve the estimation of residual $CO_2$ saturation, particularly during drainage–imbibition transitions. In the present model, residual saturation was prescribed as an effective parameter to keep the full-cycle simulation tractable. We have now clarified this limitation and noted that incorporating hysteretic relative permeability and capillary pressure functions would be an important extension for more accurately distinguishing mobile, residual, and dissolved $CO_2$. The work by Wang et al. (2022) provides a detailed description of how to address the issue you raised, and we will consider adopting a similar approach in future work to distinguish residually trapped $CO_2$. This would greatly facilitate the characterization of transitions among different $CO_2$ trapping states.

Wang, Y., Vuik, C., & Hajibeygi, H. (2022). Analysis of hydrodynamic trapping interactions during full-cycle injection and migration of $CO_2$ in deep saline aquifers. *Advances in Water Resources*, *159*(July 2021), 104073. https://doi.org/10.1016/j.advwatres.2021.104073

**Comment 5:**

(Section 4.1) Ostwald ripening analysis is decoupled from the flow and transport simulation. Given that it takes quite a long time to reach equilibrium, is it physically consistent to incorporate it into the model, as $CO_2$ may have dissolved completely during this equilibrium stage?

**Response:** We thank the reviewer for this constructive comment. This assumption stems from the fact that the timescale of gravity-induced Ostwald ripening is far longer than those of dissolution and geochemical reactions in our model. The timescales of convective mixing and geochemical reactions considered here are on the order of 100–1000 years, whereas previous theoretical studies indicate that ripening-induced $CO_2$ redistribution in a 50-m-thick formation requires timescales 2–3 orders of magnitude longer. Directly incorporating this process into the finite element simulation would significantly reduce computational efficiency; moreover, the vertical mass transfer resulting from ripening is extremely small. Given these considerations, we have implemented a post-processing interface for this long-timescale process: the finite element simulation results are used as input for a subsequent secondary calculation of ripening-induced mass transfer.

We have added an explanation of the reasons for adopting this approach in Section 2.4 of the revised manuscript (lines 172-174): "Since the timescale of gravity-induced Ostwald ripening is 2–3 orders of magnitude larger than that of convective mixing and mineralization, the mass transfer term associated with ripening is very limited. To balance computational efficiency and convergence, we used the final results of the finite element computation as the initial condition for the ripening post-processing calculation."

**Comment 6:**

(Section 4.2) Based on the results presented in Figure 9, changes in porosity may not be significant and the reaction has limited impact on the density-driven convective transport. Is this case representative of typical $CO_2$ storage in saline aquifers? Can the authors comment on this?

**Response:** We agree with the reviewer on this point. In the present model, the effect of geochemical reactions on the convective process is indeed not significant. The reservoir parameters we selected are primarily representative of typical high-permeability sandstone saline aquifers, and we simplified the system by considering calcite as the only reactive mineral component. Because formation properties and mineral assemblages vary across different reservoirs, the contribution of geochemical reactions to convective flow might not be necessarily as limited as in the case presented here (https://doi.org/10.1016/j.jclepro.2025.145948). In our previous study (https://doi.org/10.1007/s12665-025-12367-1), we have non-dimensionalized this coupled process by introducing the Rayleigh number (Ra) to characterize the intensity of convection and the Damköhler number (Da) to characterize the intensity of reaction, allowing us to systematically evaluate the impact of density-driven reactive flow under a wide range of geological conditions.