Steady-State $scCO_2$–Brine and N_2–Brine Relative Permeability in Berea Sandstone

Introduction

Geological storage of CO_2 in deep saline aquifers and depleted reservoirs requires reliable two-phase flow functions to predict injectivity, plume migration, and residual trapping. Relative permeability (k_r) for $scCO_2$–brine systems is a key input to reservoir simulation, yet datasets that span full saturation paths (e.g., drainage → imbibition → secondary drainage) at reservoir conditions remain limited in the published literature (Faramarzi et al. 2025; Gao et al. 2024).

A recurring practical question is whether N_2–brine data can serve as a defensible analog for $scCO_2$–brine relative permeability (k_r) during screening and early-stage modeling. While controlled back-to-back coreflood studies show that replacing N_2 with $scCO_2$ can shift saturation endpoints and curve shapes in some rocks (Haghi and Chalaturnyk 2022; Reynolds and Krevor 2015), recent work on Berea sandstone reports that $scCO_2$–brine relative permeability is very similar to N_2–brine when tested on the same core at the same reservoir conditions, with both fluids exhibiting strongly water-wet behavior (Magzymov et al. 2024; Schembre-McCabe et al. 2024). These combined findings suggest that "N_2 as a surrogate" can be reasonable for Berea-type clean sandstones, but the validity remains rock- and flow-regime dependent and should be verified for other lithologies under consistent experimental design.

Here, we use Berea sandstone as a benchmark to (*i*) provide an independent comparison of N_2–brine and $scCO_2$–brine k_r under identical steady-state conditions and (*ii*) extend the comparison to saturation cycling including secondary drainage, which is directly relevant to reinjection and is rarely reported.

Method and/or Theory

Berea sandstone plugs were cleaned/dried and characterized (porosity and absolute permeability) before testing. Steady-state corefloods were then run with 4 wt% NaCl brine and either N_2 or $scCO_2$ at 30 MPa (4350 psi) and 77 °C in an HPHT system with backpressure control, temperature regulation, and differential-pressure monitoring across the core; produced phases were separated in a high-pressure separator, and the separator interface level was recorded.

Relative permeability was measured by a fractional-flow stepping approach. For each gas–brine pair, we imposed a sequence of gas fractional flows to establish primary drainage, reversed the sequence for imbibition, and repeated stepping for secondary drainage. At each step, data were recorded only after Δp and separator level met quantitative steady-state criteria. To diagnose and correct capillary end effects and the potential P_c contribution to Δp, selected multi-rate checks and pressure-history matching (interpretation-by-simulation) are recommended where feasible (Gupta et al. 2016; Farokhpoor et al. 2016; Lai and Brandt 1988).

k_r–S_w was computed from stabilized Δp and separator interface-level changes. Using the imposed phase injection rates and measured fluid properties, Δp provides the pressure gradient needed to compute k_r via Darcy's law, while stepwise interface-level changes were used to infer average S_w in the recirculating system (Gao et al. 2023). Results are presented in linear and log scale.

Results and Discussion

The resulting k_r curves (reported in both linear and log scale) indicate that $scCO_2$–brine and N_2–brine relative permeability behavior is very similar in Berea sandstone under matched conditions. As illustrated in Figs. 1–2, k_{rw} during imbibition and secondary drainage closely follows the primary drainage trend, whereas k_{rg} exhibits hysteresis: the imbibition and secondary-drainage curves overlap each other but differ from primary drainage. This hysteresis pattern is consistent with strongly water-wet gas–brine behavior, where wetting-phase k_r shows limited hysteresis and non-wetting k_r reflects trapping (Krevor et al. 2012; Ruprecht et al. 2014).

Residual trapping was assessed by plotting residual gas saturation versus maximum gas saturation (Fig. 3) and comparing the trend with Land's trapping framework (Land 1968) and published Berea datasets (Magzymov et al. 2024; Chen et al. 2017).

Core and test summary: Berea sandstone core Br4 was tested through drainage → imbibition → secondary drainage at 30 MPa (4350 psi) and 77°C (170°F), with net confining stress of 17.4 MPa (2525 psi). Core dimensions were 29.2 cm length with 11.46 cm^2 cross-sectional area, porosity 0.18, and brine absolute permeability $k_w(S_w=1)$ = 61 mD. Fluid viscosities at test conditions were 0.068 cP ($scCO_2$), 0.026 cP (N_2), and 0.5 cP (brine).

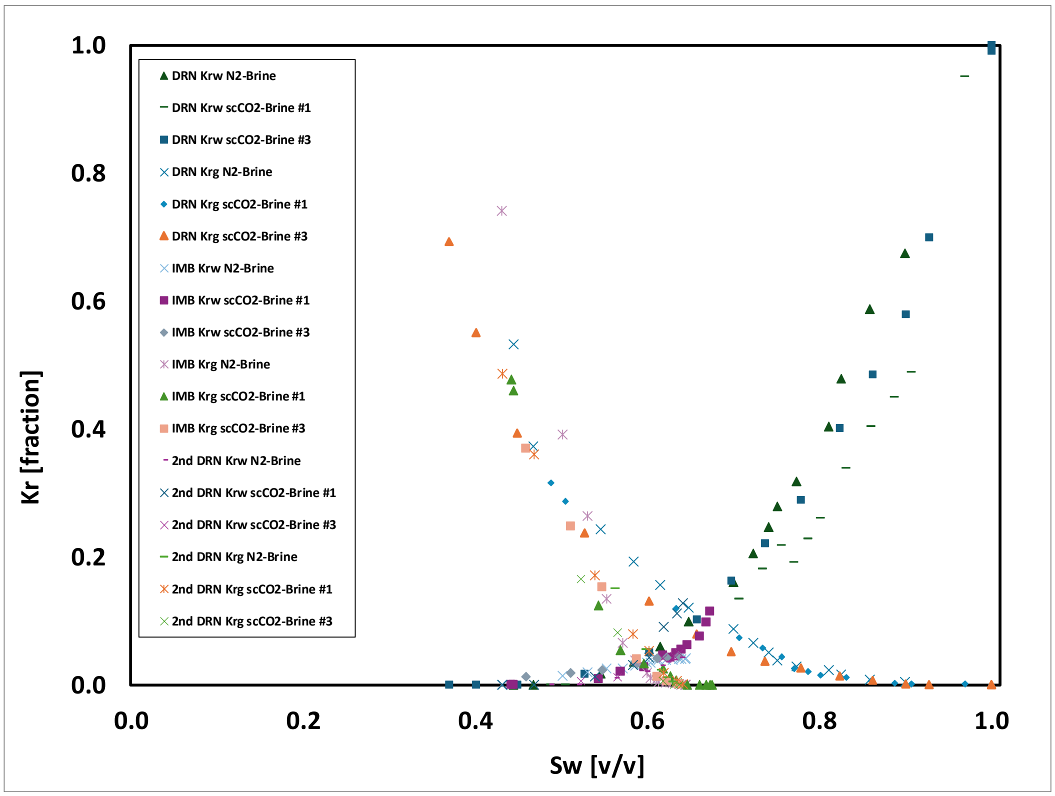

Figure 1 *Steady-state relative permeability results:* $k_{rg}(S_w)$ *and* $k_{rw}(S_w)$ *for* $scCO_2$*–brine vs* N_2*–brine during primary drainage, imbibition, and secondary drainage (linear scale).*

Conclusions

A steady-state HPHT workflow was adapted to generate comparable gas–brine k_r datasets for $scCO_2$ and N_2 in Berea sandstone. Under matched conditions, N_2–brine and $scCO_2$–brine k_r are very similar, and residual trapping follows Land's framework. For k_{rw}, imbibition and secondary drainage track the primary drainage trend, whereas for k_{rg} the imbibition and secondary-drainage curves overlap each other but differ from primary drainage.

These results support using N_2–brine k_r as a practical surrogate for $scCO_2$–brine in Berea-type clean sandstones under similar conditions; targeted $scCO_2$ measurements are recommended to confirm surrogate validity before extending to other lithologies or wettability states (e.g., tighter, clay-rich, or carbonate rocks).

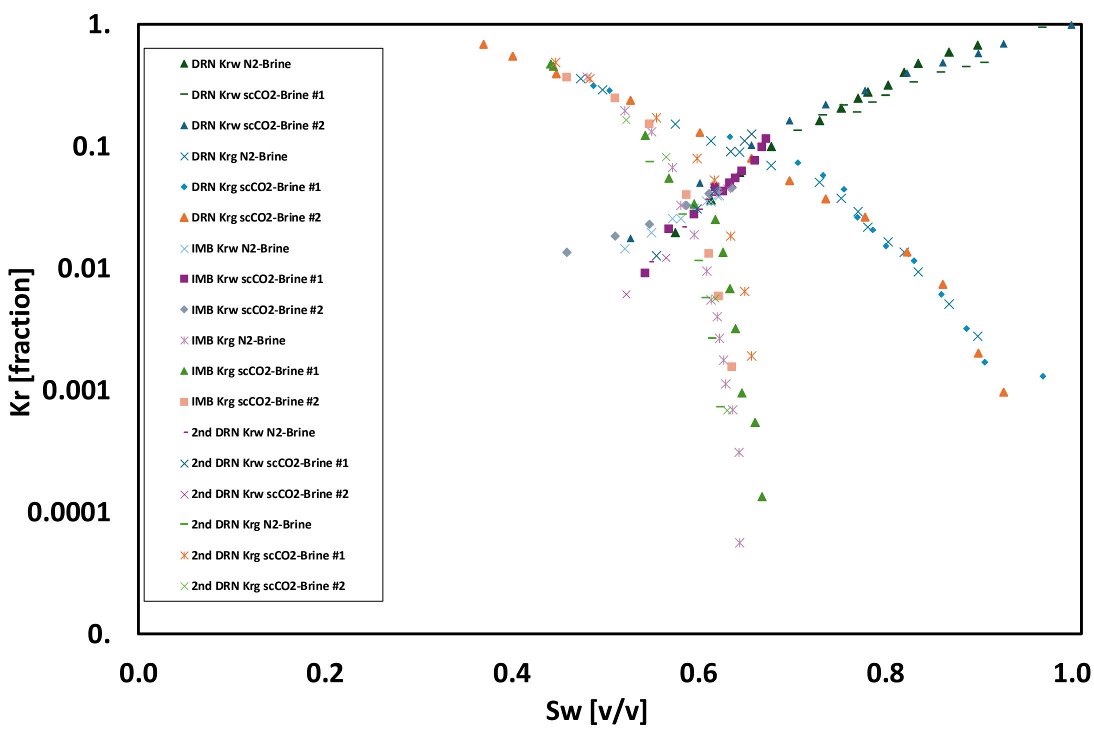

Figure 2 *Steady-state relative permeability results: $k_{rg}(S_w)$ and $k_{rw}(S_w)$ for $scCO_2$–brine vs N_2–brine during (a) primary drainage, (b) imbibition, and (c) secondary drainage (log scale).*

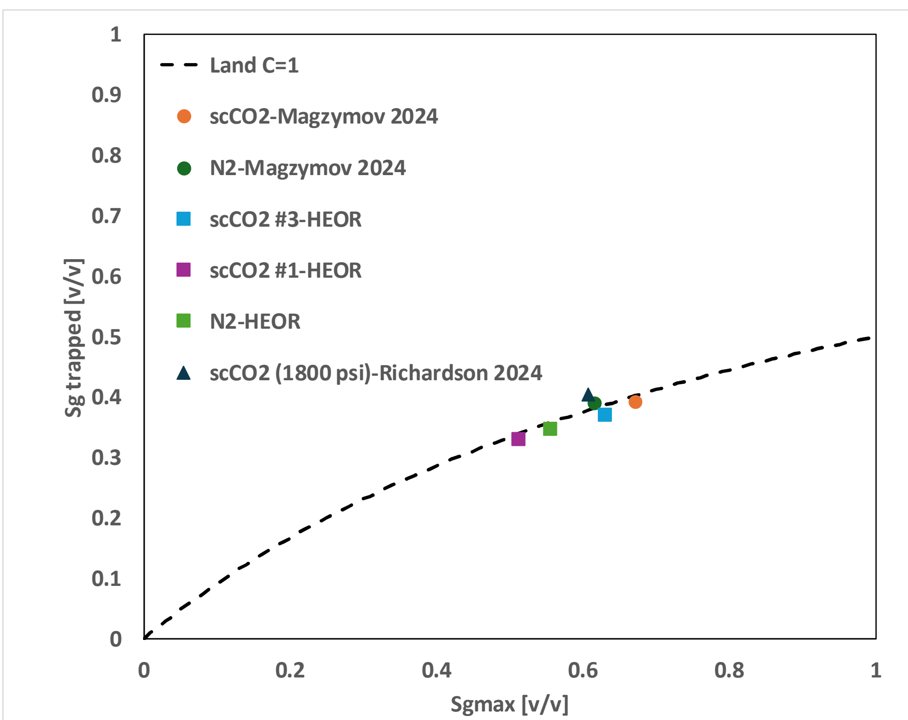

Figure 3 *Residual trapping: Initial-residual gas plot for $scCO_2$-brine at 4350 psi, nitrogen-brine at 4350 psi, $scCO_2$-brine at 1800 psi (Magzymov et al. 2024), $scCO_2$-brine and N_2-brine at 4350 psi (Magzymov et al. 2024), and Land's correlation fit.*

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