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Capillary trapping and flow dynamics in CO2-Brine systems: A Microfluidic experimental study near the critical point

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Efficient carbon capture and sequestration (CCS) in deep saline aquifers relies on understanding the complex interactions between CO_2 and brine under varying conditions. Previous studies have provided critical insights into the mechanisms driving CO_2 storage. For instance, Wildenschild et al. [1] quantified the effects of interfacial tension, viscosity, and flow rate on capillary trapping, while Pentland et al [2]. measured the residual non-wetting phase saturations of supercritical CO_2, emphasizing capillary trapping as an effective immobilization mechanism. Furthermore, Peichung et al [3]. demonstrated how high-pressure microfluidic experiments enhance mass transfer rates, offering key insights into multiphase flow dynamics.

Considering relevant factors on these studies, we investigate the injection of CO_2 into a porous media micromodel, alternating with brine flooding, as a promising strategy to better understand carbon sequestration. This study examines the impact of pressure conditions—above and below the critical point of CO_2—on multiphase flow dynamics and CO_2 storage efficiency in saline aquifers. Using the Sapphire Lab microfluidic platform, we conduct controlled experiments that allow precise regulation of flow rate, pressure, and temperature, while simultaneously visualizing fluid behavior in the micromodel.

This approach enables real-time monitoring of aqueous phase saturation throughout the injection process, capturing the interplay between CO_2 and brine phases under diverse thermodynamic conditions. Key phenomena such as saturation, displacement patterns and capillary trapping are analyzed to understand the influence of sub- and supercritical pressures on fluid distribution and storage mechanisms.

Preliminary results reveal distinct behaviors at pressures above and below the critical point, with significant implications for optimizing injection strategies. High-resolution microfluidic techniques enhance the accuracy of multiphase flow observations, providing valuable insights for designing more efficient and sustainable carbon storage operations.

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References

[1] D. Wildenschild, R. T. Armstrong, A. L. Herring, I. M. Young, and J. W. Carey, "Exploring capillary trapping efficiency as a function of interfacial tension, viscosity, and flow rate,"Energy Procedia, vol. 4, pp. 4945–4952, 2011. [2] C. H. Pentland, R. El-Maghraby, A. Georgiadis, S. Iglauer, and M. J. Blunt, "Immiscible displacements and capillary trapping in CO2 storage,"Energy Procedia, vol. 4, pp. 4969–4976, 2011. [3] T. H. M. Ho, J. Yang, and P. A. Tsai, "Microfluidic mass transfer of CO2at elevated pressures: implications for carbon storage in deep saline aquifers,"Lab Chip, vol. 21, no. 20, pp. 3942–3951, 2021.

Primary authors: DE CASTRO COSTA, Brenda Maria (PUC-Rio); AVENDAÑO, Jorge (Pontifical Catholic University of Rio de Janeiro PUC-Rio); SALEMA DE MEDEIROS, Yan (PUC-RIO)

Co-authors: Ms HARTMANN, Daniela (CNPC Brasil); CARVALHO, Marcio (PUC-Rio)

Presenter: DE CASTRO COSTA, Brenda Maria (PUC-Rio)

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