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Pore-Scale Modeling of Hydrogen and Cushion Gas Relative Permeability to Brine in geological hydrogen storage

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Hydrogen is poised to become one of the most promising alternative clean sources of. energy for climate mitigation. The development of a sustainable hydrogen economy depends on the global implementation of safe and economically feasible inter-seasonal hydrogen storage and recovery. However, the current body of literature lacks a comprehensive numerical characterization of the multiphase flow of hydrogen-brine and hydrogen-cushion gas in porous media. It is crucial to study the essential parameters that impact hydrogen storage and withdrawal at the pore scale.

This study introduces a pore network model designed to replicate the underlying mechanisms of hydrogen interaction with in-situ fluids, such as brine and cushion gases. Initially, the developed pore network model is validated against laboratory measurements of hydrogen-brine drainage and imbibition curves using the precise fluid properties and the measured petrophysical properties of the core sample. Additionally, a comprehensive sensitivity analysis was conducted to quantify the effects of fluid and rock properties on the relative permeabilities of the hydrogen phase.

The model was adapted to replicate the results of drainage and imbibition observed in the laboratory experiment of hydrogen-brine drainage and imbibition curves. Furthermore, a sensitivity analysis of the model was conducted under various conditions, including injection pressure, initial reservoir pressure, reservoir temperature, salinity of brine, and the presence of cushion gas. The results indicate that capillary pressure and the relative permeability of the hydrogen-brine system are sensitive to surface wettability. Moreover, the relative permeability endpoint (residual saturation) is significantly influenced by pore distribution and pore connectivity. A higher ratio of smaller pores correlates with a higher residual saturation of hydrogen. Conversely, the presence of a third phase (cushion gas) reduces the residual saturation of the non-wetting phase (hydrogen). Additional analysis of different cushion gases revealed that CH4 performs better as a cushion gas compared to CO2 and N2 under the simulated conditions.

This research offers a comprehensive pore-scale prediction of the relative permeability of hydrogen and brine systems, both with and without cushion gases. The analysis provides crucial quantifications of the effects of various parameters on hydrogen production. These findings contribute to the improved selection of optimal storage sites and operational parameters for the geological storage of hydrogen and its production.

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