CO_2 Cushion Gas Effects on H_2–Brine Interfacial Dynamics in Underground Hydrogen Storage

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Abstract:

Hydrogen (H_2) is a key energy carrier for the energy transition, but large-scale surface storage presents technical and environmental challenges. Underground hydrogen storage (UHS) is a promising alternative, yet the physicochemical interactions governing gas mobility and trapping require further investigation. This study focuses on interfacial tension (IFT) variations in H_2-CO_2-brine systems, elucidating the impact of pressure, temperature, and salinity on gas-liquid and rock-fluid interactions critical for optimizing UHS.

Experimental approaches were employed to measure gas-water interfacial tension (γ_{max}-$_{xax}$), under reservoir conditions. The effects of temperature (20–80°C), pressure (10–100 bar), and gas composition (H_2 and CO_2 mixtures) were systematically analysed in distilled water and formation brine systems to assess their influence on gas storage efficiency and mobility. The study reveals that temperature, pressure, and salinity significantly influence IFT, with distinct trends observed based on

gas composition and aqueous phase properties. In pure H_2/distilled water systems, IFT increased with temperature, consistent with enhanced molecular kinetic energy reducing intermolecular cohesion. Conversely, in H_2/formation brine systems, IFT decreased with temperature due to the solubility effects of dissolved salts, which weaken intermolecular forces. Pressure effects were more pronounced in CO_2-containing mixtures, where increasing pressure reduced IFT due to enhanced gas solubility and molecular interactions. Salinity consistently lowered IFT, supporting the "salting-out effect," which reduces gas solubility and modifies gas-liquid interactions. Additionally, CO_2 as a cushion gas played a crucial role in improving hydrogen mobility and storage efficiency by reducing IFT, thereby minimizing capillary trapping and enhancing gas injectivity. The observed nonlinear pressure dependence at higher CO_2concentrations underscores the complexity of multiphase interactions in subsurface environments, emphasizing the need for accurate modelling in UHS.

This study provides novel insights into the interfacial behaviour of H_2 and CO_2 mixtures in geological formations, highlighting the critical role of CO_2 in optimizing UHS. The findings contribute to the fundamental understanding of gas-fluid interactions under reservoir conditions and support the development of more efficient hydrogen storage and carbon sequestration strategies.

Keywords:

H_2, CO_2, Interfacial tension (IFT), Underground Hydrogen Storage, Cushion gas.