

The Impact of Physiochemical Conditions on Hydrogen Stability and Storage in Depleted Carbonate Hydrocarbon Reservoirs

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Abstract

Hydrogen fuel derived from renewable energy and low-CO₂ fossil sources has an immense decarbonization role in electricity generation, energy storage, transportation, and heavy industry. However, its lightweight nature necessitates a large storage capacity to enable its instrumental utilization. Underground hydrogen storage (UHS), particularly within readily accessible depleted hydrocarbon reservoirs (DHR), emerges as a promising solution, offering substantial, cost-effective, and secure storage capabilities. Yet, the risk of hydrogen loss due to both biotic and abiotic phenomena poses a challenge to the safety and integrity of these storage sites. In this study, we investigated the effects of mineralogy, salinity, pressure, and temperature on the interactions of hydrogen/brine/mineral and the rate of hydrogen loss within carbonate DHRs. Utilizing three distinct brine and limestone rock samples, we conducted static batch simulations across temperatures of 50-130°C and pressures ranging from 15 MPa to 30 MPa over a year-long storage cycle period, using PHREEQC and MATLAB. The results show that the dissolution of H₂ and formation of CH₄ and H₂S increased with the increase in reservoir temperature and pressure at a rate of 1:2, respectively. In the various brine and mineral compositions studied, the lowest risk of H₂ loss rate (<20%) was shown to be 115-130°C (at 17MPa); meanwhile pressure above 18 MPa (at 50°C) indicated the highest risk of loss (>50%)—with even much loss percentage >85% above 19 MPa. Moreover, the mineral sample with the highest reactive mineral composition (25 wt%), had 80% H₂ loss within the initial 50 days of the storage period across all pressure and temperature conditions, indicating a potential one-month risk of 50% loss within such mineralogy. However, in rock samples with over 90 wt% calcite and a 2 wt% reactive composition, H₂ molality increased 4-fold on average across the storage period, salinity, temperature, and pressure condition, highlighting the dominant influence of mineralogy, particularly the reactive component, over temperature and pressure considerations in carbonate mineral systems. The findings, in summary, indicate that high temperature (~120°C), low pressure (~17 MPa), and reactive rock mineral (<2 wt%) may be appropriate physiochemical conditions to limit H₂ loss risk below 20% during its storage in carbonate DHR.

Keywords: Underground hydrogen storage; Hydrogen loss; Carbonate reservoir; Geochemistry; PHREEQC; MATLAB