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Evaluating the impact of Hysteresis and Heterogeneity on Hydrogen Storage Performance in Saline Aquifers

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The imperative to achieve net zero carbon emissions by 2050, aligned with global efforts to limit temperature rise, emphasizes the urgent shift to low-carbon energy sources. Hydrogen is identified as a key player in global decarbonisation however, concerns about the efficiency of hydrogen storage accompany its expanding production. This study investigates underground geological hydrogen storage in saline aquifers, emphasizing the impact of reservoir heterogeneity, flow function hysteresis, and injection/production flow rates on storage efficiency. The results show that hysteresis plays a crucial role in affecting storage efficiency, leading to significant entrapment and a lower recovery factor in initial production cycles. Reservoir heterogeneity leads to non-uniform gas movement in heterogeneous systems and as a result, the efficiency of hydrogen storage is greatly compromised. In addition, the optimal selection of production flow rates presents a challenge in balancing hydrogen recovery and water management. The study highlights the need for customized approaches, emphasizing the importance of aligning flow rates with specific reservoir characteristics for efficient large-scale hydrogen storage.

A set of simulations was conducted to investigate the influence of relative permeability hysteresis, injection/production rates, and reservoir heterogeneity (permeability) on large-scale hydrogen storage performance. The spatial continuity was established as omni-directional in the heterogeneous model and the simulation was conducted in a two-dimensional cartesian system (Figure 1). Both injectors and producers were controlled by the flow rate at reservoir conditions (0.015 PV/day), assuming the fracturing pressure would not be exceeded. The model's end simulated a large aquifer as a spill point, ensuring sufficient volume for input or output to maintain well flow rates in the gas injection and production cycles. The simulation was designed to terminate as soon as the gas reaches the spill point.

Both the homogeneous and omni-directional models exhibited similarities and differences in their hydrogen injection and production behaviour. The homogeneous system, with a consistent injection rate of 6.01305 m3/day, showed higher primary production recovery (72.56%) compared to the omni-directional system (56.60%), where high permeability in specific blocks led to rapid hydrogen advancement and more hydrogen trapping during production cycles. The second injection cycle demonstrated comparable trends in recovery factors for both systems, with the heterogeneous system achieving a slightly higher final recovery of secondary production (97.1%) compared to the omni-directional system (94%). In both systems, by decreasing the gas injection and production rates the final recovery of primary and secondary production was lowered.

Lowering the production flow rate consistently reduces the gas-water ratio in both models due to the decreased mobility difference between hydrogen and water. In the heterogeneous model, since water was displaced unevenly throughout the system (viscous fingering), the waterfront progressed faster towards the well during the production cycle. As shown in Figure 2, the waterfront eventually reaches the production well, causing a significant reduction in the gas-water ratio, particularly in the second production cycle since a smaller amount of hydrogen was injected during the second injection cycle. This dynamic transition holds substantial implications for storage operation efficiency and becomes a pivotal factor in operational decision-making.

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