Gas Mixing Behavior and Flow Processes in Porous Media During the Conversion of Natural Gas Storage Facilities to Hydrogen Storage

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Long-term storage of hydrogen, as a promising alternative to fossil fuels, in underground gas storage (UGS) facilities has significantly attracted research interest. Nevertheless, the complexity of the gas mixing and flow processes and the interactions between hydrogen, cushion gas, and reservoir water are currently insufficiently known and must be explicitly investigated for porous UGS facilities. The present work intends to provide initial analysis and assessment of these mechanisms by means of reservoir simulation.

Two generic reservoir models (2D and 3D homogenous) are generated according to the average reservoir properties of German UGS facilities. By employing compositional numerical simulation (CMG GEM), the main mechanisms involved in hydrogen storage in UGS (except for geochemical reactions) are successfully modeled. Furthermore, a comprehensive sensitivity analysis is conducted aiming to elaborate on the parameters influencing the gas mixing behavior. The hydrogen-cushion gas mixing degree and the hydrogen production efficiency are monitored over the entire simulation scenarios. In general, simulation results illustrated strong gravity segregation due to the extreme density difference between the hydrogen gas and the cushion gas (mainly methane). Sensitivity analysis showed that the mixing extent and the gravity segregation are strongly sensitive to porosity/permeability and reservoir dip-angle. Higher porosity/permeability and up-dip injection in general can significantly control gravity segregation and reduce gas mixing.

Furthermore, investigations on the impact of hydrodynamic dispersion on gas mixing revealed that mechanical dispersion is the dominant mechanism at high flow rates. Nevertheless, the share of molecular diffusion in overall hydrodynamic dispersion and gas mixing increases considerably at low flow rates.

In order to correctly analyze the hydrodynamic parameters, numerical dispersion minimization is carried out using mainly two methods: 1. reducing the grid block size and time-step size. 2. Implementing the higher-order upstream weighting scheme calculation method.

Simulation results pointed out the effectiveness of the second method on numerical dispersion control is similar to the first method. Nonetheless, the second method resulted in a considerably lower run time.

This work has primarily developed the assessment of the undergoing processes in the porous media to convert UGS to hydrogen storage. For the first time, this work provides a comprehensive analysis of the influence of the various reservoir parameters and -effects regarding the hydrogen storage process and their impact on the quality of the withdrawn gas. The geological parameters and uncertainties are based on the available data from German UGS facilities. The conclusions based on the generic models can serve as a basis for future research on the topic.