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Sensitivity analysis of fault zone parametrization for an underground gas storage site

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Increasing renewable energy production can result in energy storage requirements on various scales given the fluctuating availability of renewable sources. Power-to-Gas in combination with underground gas storage in porous media is a viable option for mitigating offsets between energy demand and availability. Leakage of stored gas along fault zones could hinder or prohibit storage development, requiring a quantification of potential leakage scenarios. This study investigates the sensitivity of fault zone geometry, petrophysical parameters and capillary pressures on leakage rates during a gas storage operation using numerical scenario simulations.

A structural model of an anticline structure in the North German Basin is used for this analysis, which spans from Permian up to Quaternary horizons and includes several fault systems. For the sensitivity analysis, a 2D-slice perpendicular to the main N-S striking fault system is selected. In this model, the fault zone is represented as two independent units, namely a fault core and a damage zone. Literature analysis indicate that the highly fractured damage zone has high absolute permeability and thickness, while the fault core has a low permeability in is reasonably tight. East of the fault zone the storage reservoir is saturated with methane, with reservoir pressures set according to a gradient of 15 MPa/km, translating to an absolute pressure at the fault interface of around 86 bars. The remaining formations are set to hydrostatic pressure conditions. Petrophysical parameters, such as permeability and porosity are assumed homogeneous and isotropic. The leakage rates through the fault zone are determined for variable fault zone thicknesses (100; 50; 10; 1 m), damage zone permeabilities (10; 5; 1; 0.01 mD) and capillary entry pressures (varying from 0 to 9.6 bars).

Results of the simulation with varying fault zone parameters show a strong influence on the reservoir pressure decline and gas leakage rates. In the worst-case scenario, i.e. assuming a highly permeable damage zone, the gas leakage rate upwards through the damage zone quickly reaches 9000 sm^3/d and remains constant afterwards. After about 1 year, gas breakthrough is observed at the fault core, with leakage rates reaching 500 sm^3/d after 2 years. Leakage gas volume is 7879678 sm^3 after 2 years, which corresponds to 2.26 % of total gas in place. At a fault zone with thickness of 100 m, reservoir pressure declines by 14 bars compared to the initial condition. In comparison, reservoir pressure declines by around 5 bars due to pressure redistribution within the storage formation if the fault zone is assumed to be completely tight. Cases with different capillary entry pressure do not show a clear trend, but methane leakage volume can reach up to 6837049 sm^3 when capillary entry pressure is 3.2 bars. The results indicate that significant leakage rates can occur, showing the sensitivity of storage model to the fault zone parametrization.