Skerbisch, Lukas[1]; Misch, David[1]; Sari, Mustafa[2]; Sarout, Joel[2]

Comprehensive characterization of rock salt from the Haselgebirge Formation: Insights for cavern storage of hydrogen

[1]Montanuniversität Leoben, Österreich;
[2]CSIRO, Energy, Australien;
lukas.skerbisch@stud.unileoben.ac.at

Underground hydrogen storage (UHS) is currently broadly discussed as an efficient way to store renewable energy in the subsurface. Besides long-term, high-volume storage in depleted gas fields and low-volume and short-term storage in surface facilities, UHS in salt caverns could fill the intermediate gap. In Austria caverns from salt mining exist in the Haselgebirge Formation, an evaporitic succession that has been tectonically deformed, resulting in a complex deposit structure. This study aims at a comprehensive characterization of the variable rock salt types with respect to geomechanical behaviour and hydrogen permeability under confinement. These data can be used in future cavern assessment for UHS.
Five different lithologies from a depth range of 477 – 755 m have been tested (red salt with mudstone clasts – RS 477 m, two types of grey salt with anhydrite – GS1, GS2 from 649 m and 755 m depth, anhydrite with dolomite – AD 555 m, dolomite with vein-type salt – DVS 540 m). Porosity, permeability, bulk mineralogy via X-ray diffraction (XRD), as well as ultrasonic velocities (v_p, v_s) have been measured for baseline characterization, and computed tomography (CT) and scanning electron microscopy (SEM) imaging were used to visualize sample textures. Plugs from each sample (2.54 cm diameter, 1:2 aspect ratio, 70% relative humidity) were then tested in an autonomous triaxial cell with a multiple failure state procedure, setting pressure stages at 1 MPa, in-situ pressure (11, 12.5, 15, 17.5 MPa), and 25 MPa. To test for permeability, additional single stage tests have been conducted with low confinement (1 MPa), and high confinement (25 MPa) pressure with 0.5 and 3 MPa nitrogen (N_2) pore pressure at the downstream side respectively. The upstream pressure and corresponding ultrasonic velocities were monitored during the testing procedure.
RS has the lowest porosity and permeability (0.14-0.38%, 0-0.0027 mD) while GS1 & GS2 (0.15-2.53%, 0-0.24 mD) exhibit the highest. Intermediate porosity and permeability values (0.04-0.84%, 0-0.20 mD) are observed for samples dominated by anhydrite and dolomite (AD, DVS). Young's moduli range from 5 to 10 GPa in RS, are slightly higher (8-12 GPa) in GS1 & GS2 and reach 23-40 GPa in AD & DVS. Gas permeability is generally higher at lower initial confinement (1 MPa). The permeability of softer salt types (RS, GS1 & GS2) increases during loading, indicating the progressing formation of microfractures before the maximum load is reached. Stiffer salt types containing more dolomite (AD, DVS) fail with a rupture and an immediate gas breakthrough at the maximum load. In contrast, no gas breakthrough could be observed at high confinement pressure conditions for all tested formations, supporting the more ductile behaviour at high confinement. In general, the investigated salts can be considered effective seals for gas storage. While a locally elevated gas permeability related to microfractures could occur at cavern walls under high storage gas pressure, the increased confinement within the intact salt formation would likely impede gas leakage.

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