Large Scale Borehole Leakage Experiments under Cyclic Loading & Fluid Flow Modelling

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The exit from nuclear and fossil-fuel energy and the increase in renewable energy conversion lead to a higher fluctuation in energy supply. To meet demand in times of energy shortages, this effect can be compensated by extracting and using gas from underground gas storages. As long as enough renewable energy is available, storages can be filled again. However, this results in increasing injection and extraction frequencies, leading to faster occurring pressure and stress changes and therefore posing an additional challenge for reservoir rock, cap rock and technical components.

With the objective to evaluate the effects of this additional cyclic loading on the rock-cement-steel-compound, we used an autoclave system on a realistic scale to simulate abandoned wells. It consists of a 2 m long cemented steel casing with a pressure chamber at each end and heating mats surrounding the system. In order to simulate injection and extraction, gas pressure (N_2) was applied and released on both ends. Additionally, temperature was raised up to 70 °C. Between loading cycles, permeability was measured to determine the effect of pressure and temperature variation on the tightness of the system.

We present our results from the analysis of three cemented casings by means of numerical models. Since the hardened cement was not connected to the steel casing after the experiments, we assume an annular gap as main gas path in most cases. This gap was modelled and fitted to the experimental data. After pressure variations between 0 bar and 60 bar, the tightness of the system decreased in every experiment, leading to an increased modelled annular gap width. Temperature variations between 30 °C and 70 °C did not have an effect on the first two casings, but increased tightness and therefore decreased the modelled gap width in the third casing.

Additionally, we observed an anomaly in the second casing, which was extraordinarily tight before the first pressure drop. However, when small amounts of pressure (around 3 bar) were released from the upper chamber, around 30% of the released pressure built up again within a few minutes, while the rest took several hours. We assume an almost closed annular gap for the slow pressure buildup and a highly permeable and porous area at the top of the cement for the fast buildup. The results of a finite difference model with this approach seem plausible and are compared to the results of independent permeability and porosity measurements.

These results are in agreement with older CO_2 experiments of the autoclave system that were modelled by a 1D numerical approach. Three conceptual models were tested: Fluid flow through the entire pore space of the cement, through the annular gap or through a highly permeable area at the cement–steel interface. The last two provided the best fits, which is in agreement with the results of the more recent N_2 experiments.