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Bentonite buffer under high temperature: laboratory experiments and coupled process modeling

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Abstract. Bentonite buffer in a geological repository will be simultaneously heated from decaying radioactive waste and hydrated from the surrounding host rock, triggering complex and coupled THMC (thermal–hydrological–mechanical–chemical) processes. Understanding the THMC behavior of bentonite-based engineered barrier system (EBS) is key to the evaluation and prediction of its long-term performance. Studies on the THMC process have been focused on conditions under 100 °C, as most design concepts impose a thermal limit of 100 °C in bentonite. Recently, studies under high-temperature conditions have been conducted to evaluate the possibility of raising the thermal limit and expanding the data/knowledge base to increase the confidence level. In this abstract, we present a series of bench-scale laboratory experiments at high temperatures (up to 200 °C) and the corresponding modeling work. Two sets of column tests were conducted, and each set consisted of two test columns: a control column undergoing only hydration (non-heated) and an experiment column experiencing both heating and hydration (heated). During the experiment, frequent X-ray computed tomography (CT) images were collected to provide a 3D visualization of the density distribution and present the spatiotemporal evolution of (1) hydration/dehydration, (2) clay swelling/shrinkage, (3) displacement, and (4) mineral precipitation. The two sets of tests differ with respect to several experimental conditions, such as bentonite type, compacted density and water content, water chemistry, and hydration pressure, but the important difference is that the first set used bentonite powder with a dry density of 1.28 $g\,cm^{-3}$, whereas the second set used granulated bentonite (mixture of pellets and powder) with a dry density of 1.45–1.5 $g\,cm^{-3}$. In both sets of experiments, a comprehensive post-dismantling characterization of bentonite samples was carried out after the column tests had been running for 1.5 years. Comparing non-heated and heated columns, the temperature gradient led to lower degree of homogenization of bentonite after bentonite became fully saturated; comparing the first and second sets, granulated and powdered bentonite exhibited drastically different hydration behavior. A THM model with a 2D axisymmetric grid system was used to interpret the data from the first set of tests. The model considers the combined impact of saturation, fluid pressure, and porosity change due to swelling/compression on the spatiotemporal distribution of bulk density and movement of the thermocouple modules. Observations from the tests help us understand the early perturbation of bentonite buffer under high temperature, and data from these tests improve the calibration of key constitutive hydrological and mechanical models and, therefore, enhance the modeling capability with respect to calculating the long-term evolution of bentonite buffer.

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