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Developing constitutive relationships for the properties of unsaturated bentonite buffers under high temperatures (Phase II)

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ABSTRACT:

The Phase II objectives are to apply the new knowledge gained from Phase I regarding the effects of high temperatures (up to 200 °C) on the mechanisms and material properties governing coupled heat transfer, water flow, and volume change in unsaturated, compacted granular bentonite to understand and simulate the multiphase hydration process of bentonite buffers in deep geological repositories with closely spaced waste packages or Dual Purpose Containers. The Phase II work plan includes a continuation of element-scale testing to further validate constitutive relationships for the bentonite thermo-hydro-mechanical material properties under high temperatures developed in Phase I, performing new tank-scale tests on mixtures of granular and pelletized bentonite representative of repository conditions to capture the coupled processes during hydration under high temperatures, enhancing numerical models to better consider transient density changes and vapor transport, and application of the enhanced numerical models to predict the behavior of the HotBENT field experiment. In the element-scale tests, three testing series will be continued from Phase I. These include measurement of the SWRC of bentonite specimens with different densities in a novel high-temperature, high-pressure relative humidity cell developed in Phase I, evaluation of the volume change response of as-compacted bentonite under different thermo-hydro-mechanical paths in a thermal triaxial cell, and evaluation of the swelling response of bentonite having different initial densities under high temperatures in a thermal oedometer. Results from these testing series will help validate the new nonisothermal SWRC for bentonite under different densities and calibrate thermo-elasto-plastic model parameters governing volume change during hydration/drying or heating/cooling. The new tank-scale test will focus on replicating the bentonite density, structure, and boundary conditions present in the HotBENT project and will measure temperature, relative humidity, and volumetric water content during central heating and hydration from the boundary. The tank-scale tests are critical for calibration and validation of the physics-based numerical simulations in TOUGH-FLAC, COMSOL, and the data-driven simulations with RKPM. These simulations will be updated in Phase II to consider the effects of local variations in bentonite density in constrained conditions due to heating and hydration, as well as to refine the techniques used to consider phase change and vapor transport. Finally, this project will simulate the performance of the bentonite buffer in the HotBENT project, which has now collected nearly 2 years of data. The simulations in this study will complement those being performed by international teams including LBNL by considering the effects of using nonisothermal material properties of bentonite under high temperatures. Deliverables from Phase II will include journal papers focused on further validation of the nonisothermal, coupled thermo-hydraulic relationships (SWRC, HCF, TCF, VHCF) for granular/pelletized bentonite under different densities, further validation of the thermo-elasto-plastic constitutive model for unsaturated soils under high temperatures, numerical modeling developments focused on consideration of transient volume change effects and new mechanisms for enhanced vapor diffusion and nonequilibrium phase change in unsaturated soils under high temperatures, and inter-code comparisons of long-term bentonite buffer hydration under high temperatures focused on both the new tank-scale test and the HotBENT project.