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# Long-term Simulation of THM coupled behavior in the Heater Emplacement Experiment at Mont-Terri Underground Research Laboratory

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## 1. Introduction

Especially in the engineered barrier system in the high-level radioactive waste (HLW) disposal system, complex thermo-hydro-mechanical (T-H-M) coupled behavior affects the performance of buffer material and host rock. Numerical simulation is an effective method to predict the long-term behavior of the complex coupled behavior, but validation and verification are essential for ensuring the simulator's reliability.

As a part of the DECOVALEX (DEvelopment of COupled models and their VALidation against EXperiments) Project, an international joint research for developing a numerical model for thermo-hydro-mechanical-chemical coupled behavior in the high-level radioactive waste disposal system, we performed a series of T-H-M coupled numerical simulation based on the full-scale heater emplacement experiment performed at Mont-Terri underground research laboratory in Switzerland[1]. The T-H-M simulation results in the bentonite and host rock are presented in this study.

## 2. Numerical model and results

*2.1 Numerical Model*

In this study, the OGS-FLAC simulator, based on an open-source code, was utilized to simulate the thermo-hydro-mechanical coupled behavior within the disposal system. The OGS-FLAC simulator conducts analyses by sequentially exchanging result files between OpenGeoSys, which is responsible for thermal-hydraulic analysis, and FLAC3D, which handles mechanical analysis. In the full-scale heater test at the Mont Terri underground research facility, three heaters were horizontally installed, with bentonite blocks positioned beneath them and the remaining space filled with granular bentonite. The analyzed section was designed to be (150×100×150) m to consider boundary effects. The initial principal stresses are 2.5, 4.5, and 6.5 MPa in the x, y, and z directions, respectively, and constant stress boundary conditions were maintained during the simulation. Considering the hydrostatic pressure and ventilation tests before the heating process, the initial pressure was also applied.

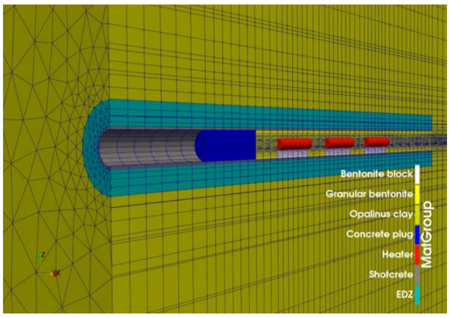


Fig. 1. A cross-section view of numerical model for the heater emplacement experiment at Mont-Terri URL.

*2.2 Simulation results*

In the heater experiment, the heater power simulated the decay heat, and the experiment is planned to continue for 18 years. The heater power was scheduled to increase gradually up to 1350 watts and maintained for eight years. Furthermore, the heater power was increased to 1485 watts to investigate the high-temperature effect on the buffer material.

Fig. 2 compares and predicts the experiment (dots) and simulation results (solid line). The temperature on the heater surface matched well with the experimental results during the experimental period. The highest temperature monitored at the heater surface was 135°C before heater power increased to 1485 watts. After the heater power increase, the highest temperature is predicted to be 144°C. The relative humidity in the bentonite increased first due to the vaporization and decreased due to temperature increase. Pore pressure, temperature, and displacement observed in the host rock also agreed well (Fig. 3). In the near field from the disposal tunnel, the drainage effect was dominant due to the capillarity of the unsaturated bentonite (blue line in Fig. 3). In contrast, in the far field, the thermal expansion was the dominant factor for the pressure distribution (black line in Fig. 3). Anisotropic distribution of T-H-M results was also observed in the host rock due to the bedding plane. Along the parallel direction, the pore pressure and temperature gradient increased more than the results in the perpendicular direction, reflecting the anisotropic characteristics. The displacement in the host rock expanded along the bedding plane direction due to the heat transfer from the heater, while simulation results showed a slight discrepancy compared to the field data. The mechanical anisotropy amount of the host rock might affect the difference between the results.

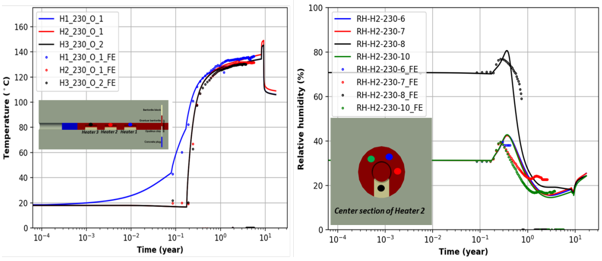


Fig. 2. Comparison between experimental data and simulation results. Temperature on the heater surface(left) and RH change in the bentonite(right).

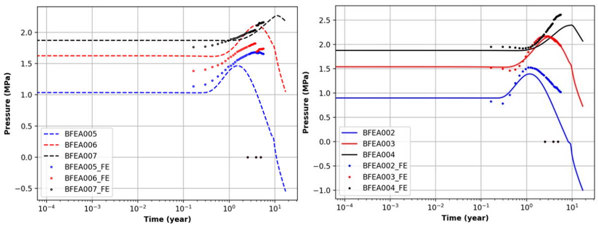


Fig. 3. Comparison of the pressure in the Opalinus clay host rock between experimental data and simulation results. Pressure monitored along the direction perpendicular (left) and parallel (right) to the bedding plane.

## 3. Conclusions

This research used the self-developed OGS-FLAC simulator to model the full-scale heater disposal experiment to analyze thermo-hydro-mechanical coupled behavior. Various thermo-hydro-mechanical behaviors within the disposal system were simulated, and the analysis results matched well with the experimental results. The multiphase flow was well captured, including saturation change due to temperature variation. Depending on the distance from the disposal tunnel, the dominant factor affecting the pressure gradient in the host rock was varied. Capillarity was the main parameter at the near field, while thermal expansion influenced more at the far field distance. Based on the simulation results, the OGS-FLAC simulator showed the possibility of meaningful application in the field of the HLW disposal-related research.

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