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Lot A2 test, THC modelling of the bentonite buffer

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ABSTRACT

Finnish spent nuclear fuel is planned to be disposed of deep in the crystalline bedrock of the Olkiluoto island. In such a repository, the role of the bentonite buffer is considered to be central. The initially unsaturated bentonite emplaced around a spent-fuel canister will become fully saturated by the groundwater from the host rock. In order to assess the long-term safety of a deep repository, it is essential to determine how temperature influences the chemical stability of bentonite. The aim of this study was to achieve an improved understanding of the factors governing the thermo-hydro-chemical evolution of the bentonite buffer subject to heat generation from the disposed fuel and in contact with a highly permeable rock fracture intersecting a canister deposition hole.

TOUGHREACT was used to model a test known as the long-term test of buffer material adverse-2, which was conducted at the Äspö hard rock laboratory in Sweden. The results on the evolution of cation-exchange equilibria, bentonite porewater chemistry, mineralogy, and saturation of the buffer are presented and discussed. The calculated model results show similarity to the experimental results. In particular, the spatial differences in the saturation and porewater chemistry of the bentonite buffer were clearly visible in the model.

1. Introduction

Finnish spent nuclear fuel is planned to be disposed of according to the KBS-3 (KärnBränsle Säkerhet) concept in a deep repository planned to be constructed at a depth of 420 m in the crystalline bedrock of the Olkiluoto island (Fig. 1). In the KBS-3 concept, the spent nuclear fuel bundles are contained in copper-covered cast iron canisters, which are surrounded by a compacted bentonite buffer. Compacted bentonite clay is considered a suitable material for limiting the migration of radionuclides in case of canister breach, for providing a mechanical and chemical zone of protection around the canister and high enough thermal conductivity to efficiently dissipate heat emitted by the spent fuel.

Upon saturation with groundwater, bentonite swells and seals the deposition hole. However, thermal, hydrological, mechanical and chemical processes taking place in the bentonite buffer over thousands of years may change the properties of the bentonite to the extent that long-term safety is compromised. Therefore, sufficient long-term stability of this material must be demonstrated. Due to inaccessible time scales for relevant experiments, the assessment of material stability in a repository needs to be based on numerical modelling.

In this work, we concentrated on the modelling of the effects of temperature on the chemistry and hydrology of initially partially saturated bentonite using an integrated thermo-hydro-chemical (THC) model.

The Long Term Test of Buffer Materials (LOT) A2 parcel experiment at the Äspö hard rock laboratory (HRL) in Sweden was considered (Karnland et al., 2009) in this work. Thermal and hydraulic gradients are known to generally promote mineral dissolution/precipitation reactions in the bentonite. For example, anhydrite is found to precipitate at elevated temperatures. Also, the incoming groundwater affects the bentonite porewater, which may, in turn, influence the mechanical properties of the bentonite. Consequently, this has to be taken into consideration in a performance assessment of the buffer.

The expected thermal phase in a KBS-3 repository will last for a few thousand years. The most significant mineral alterations are expected during the first one thousand years (Pastina and Hellä, 2008). The A2 test was carried out under more extreme temperature conditions than to be expected in an actual KBS-3 repository to accelerate the kinetically controlled mineral reactions and to compare the thermal load of the test to the expected KBS-3 conditions over several thousand years.

The aim of this study was to investigate thermal, hydraulic and chemical processes affecting the bentonite buffer. For this purpose, a computational model was designed to simulate the THC processes in the A2 test.

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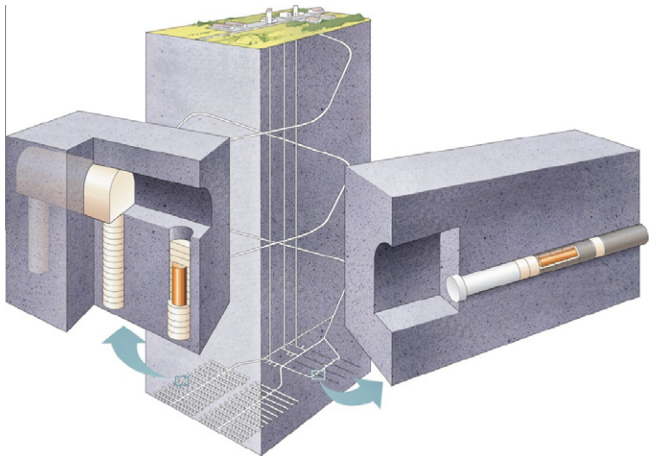

Fig. 1. The KBS-3 disposal concept displaying both the vertical (left) and horizontal (right) option (courtesy of Posiva Oy). The repository is located at a depth of 420 m. A deposition hole is 6–8 m deep depending on the type of spent fuel (Posiva, 2010).

2. Experimental

The A2 test at Äspö was carried out in crystalline rock at the depth of approximately 450 m from the ground surface. The water pressure was kept higher than the vapour pressure and the water inflow rate low enough to prevent piping erosion. However, the rate of water inflow was found too low and, consequently, it was decided to introduce external water via a supply hole to accelerate the progress of the experiment. The water pressure in the hole was about 1.2 MPa and the water supply was connected to the borehole through titanium tubes. The water pressure was kept constant throughout the test period (Karnland et al., 2009). The dimensions of the parcel test, illustrated in Fig. 2, are presented in Table 1. An internal heater was placed inside the lower parts of the copper tube with a maximum power of 2 kW (Fig. 2).

Table 1
Dimensions in LOT A2 parcel test (Karnland et al., 2009).

Borehole depth	4 m
Borehole diameter (nominal)	0.3 m
Emplaced parcel diameter	0.28 m
Copper tube height	4.7 m
Heater diameter	0.108 m

The results from the parcel test were used as reference data for comparison with model results (Karnland et al., 2009). In the test, relatively small parcels (see Table 1 for the dimensions) were exposed to field conditions at Äspö HRL. The test series included three parcels with similar conditions to those expected in a vertical variant of the KBS-3 repository (KBS-3 V) and additional four parcels, which were exposed to more extreme temperature conditions. For the horizontal disposal option (KBS-3H), see Fig. 1.

The A2 parcel was placed in a vertical borehole, which was drilled into excavated, horizontal tunnels in granitic bedrock. In the parcel, MX-80 bentonite, considered by Posiva as the reference buffer material, was exposed to elevated temperatures (120–150 °C) and very high temperature gradients (4.5–5.0 °C/

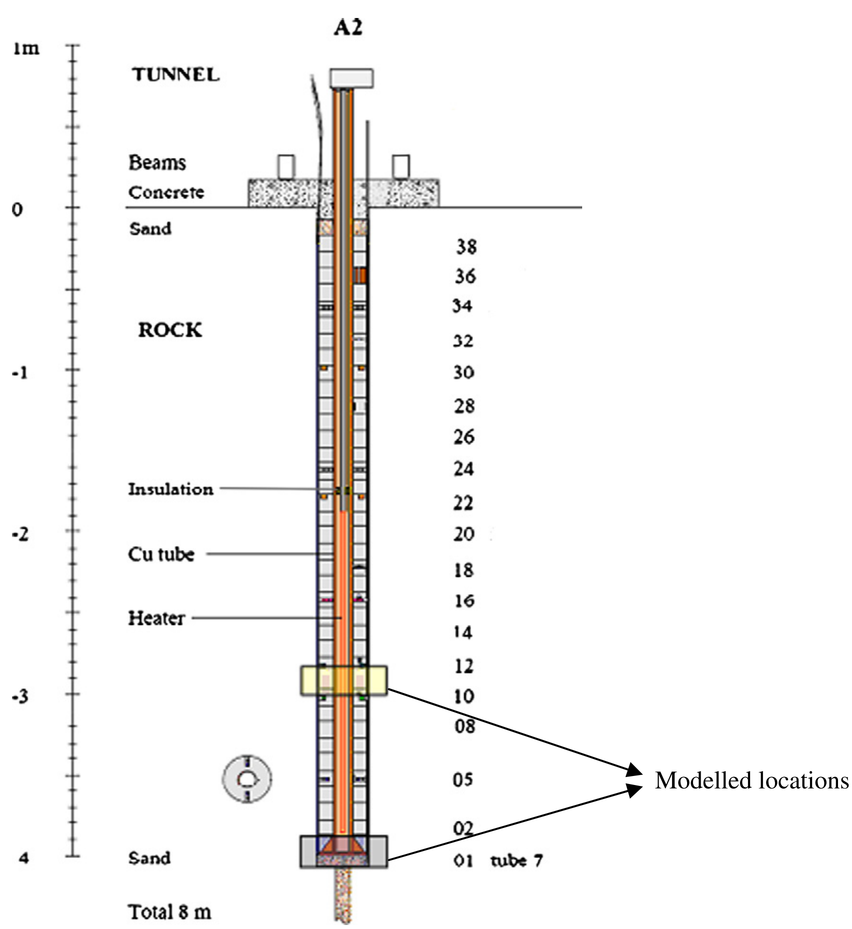

Fig. 2. Schematic drawing of the A2 test parcel (Karnland et al., 2009). Modelled locations are indicated by rectangles (the lower denotes the fracture and the upper is 1.1 m above the fracture). The numbers refer to the respective bentonite blocks. The water-supply hole was situated at the position "01".