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MOCK-UP EXPERIMENT FOR BENTONITE BARRIER TESTING***

1. Introduction

There are different concepts for taking care of the spent nuclear fuel. For the final disposal, geological repositories are the only feasible solution for the moment. The spent nuclear fuel will be prevented from spreading radioactivity into the biosphere by a system of the independent multiple barriers. In many concepts bentonite will be used as one barrier, due to its plasticity and very low hydraulic conductivity and also due to the cation retardation capacity resulting from the cation sorption to the negatively charged surfaces.

Bentonite, especially its main mineral phase — smectite is the most sensitive component of the buffer material. There are various physico–chemical conditions which may occure in the potential geological repositories and affect negatively the properties of bentonite. The most important will be the influence of high temperature, water solutions and radioactivity. The interactions with the host rock and construction elements of the repository have to be considered as well.

A number of laboratory tests, made by different research groups, have resulted in various buffer alteration models. The most popular are large laboratory and in-situ tests, lead by radioactive waste management agencies as ANDRA (France; [4]); ENRESA (Spain; [6, 7]), NAGRA (Switzerland; [14]); ONDRAF/NIRAS (Belgium; [10]); SKB (Sweden; [8]) in Europe, and many others in the world. The main objective of these studies is to identify the processes occurring in the mock–up tests during the heating and water saturation of bentonites. The quantitative analyses of the changes are instrumental for understanding the nature and potential consequences for future repositories. Belgian mock–up experiment OPHELIE [12, 13] and

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Spanish experiment FEBEX [6, 7] are very good examples of large scale projects based on several heating tests simulating the conditions of a radioactive waste repository, and reproducing the thermohydro–mechanical processes that could eventually occur in the repositories using the bentonitic barriers.

2. Experimental setup

Bentonite barrier, composed of highly compacted bentonite blocks, was placed in the cylindrical vessel designed to withstand the high pressure (up to 5 MPa) anticipated from the swelling bentonite. The experimental setup (fig. 1) was inspired by another mock–up tests and adapted for our purposes. Similar experiment — Mock–Up–CZ was built by the team of the Czech University of Technology in Prague [11]. Designing of our experimental setup was sporadically consulted with the Czech team. The mock–up experiment simulates vertical placement of radioactive waste in the underground repository. Relatively small model (in comparison with any international mock–up experiments) was basically a stainless steel cylinder (400 mm diameter and 600 mm height), simulating a section of gallery in which the radioactive waste will be disposed. The cylinder was equipped with a 140 mm diameter central tube, in which heating elements — simulating the heat produced by the waste — were placed. The temperature produced by the radioactive waste should not exceed 90°C in the real repository, however mock–up is relatively short term experiment in consideration of real conditions, therefore heating temperature was 120°C. Temperature was controlled and measured by 9 sensors located in different parts of the bentonite barrier.

Electronic device of the system was operated by Control Web 2000 software in MS Windows environment. Changes in temperature, pressure and relative humidity were continuously measured and recorded in order by the PC to be in the position to assess long–term stability of bentonites used in the experiment (fig. 1 and 2).

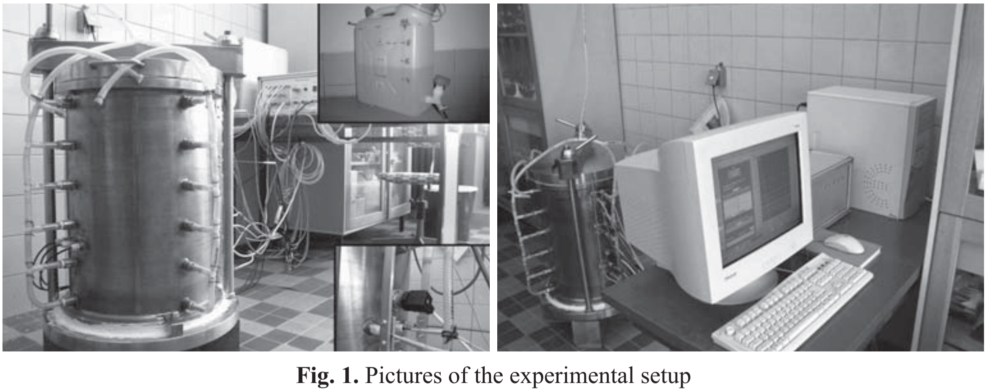

Fig. 1. Pictures of the experimental setup

The annular gap between the central tube and the outer lining was backfilled with precompacted bentonite blocks. 24 bentonite blocks and one bentonite cylinder (filling the space under the heater) were made by compaction in isostatic (triaxial) press to prevent a preferred orientation of platy clay particles. Dry density of the blocks varied between 1.6 and 1.8 g/cm^3.

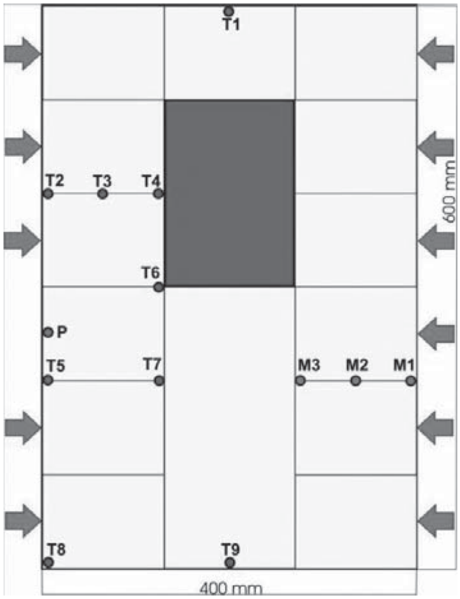

Fig. 2. Illustrative cross–section of the experimental vessel with localization of sensors (*T* — temperature, *M* — humidity, *P* — pressure)

3. Material

Major part of compacted blocks (16) was made of pure bentonite from Jelšový Potok deposit and the next 4 from Lieskovec deposit, both milled into < 250 μm fraction. Mineral composition of used bentonites is shown in table 1.

TABLE 1
Quantitative mineral composition of pure bentonites

wt %	smectite	quartz	feldspars	kaolinite	micas	volcanic glass	cristoba-lite	SUM
Jelšový Potok	68	3	9	3	3	13	1	100
Lieskovec	49	11	10	11	3	13	3	100

Two bentonite deposits in Central Slovakia underwent different alteration processes. The bentonite from Stará Kremnička — Jelšový Potok (J) developed from rhyolitic tuffs in a lacustrine environment; the main component is an Al–rich montmorillonite [9]. The deposit is located in the SW part of the Kremnické Vrchy Mountains in the Western Carpathians and belongs to the Jastrabá Formation. Bentonite from Lieskovec (L) has andesitic pyroclastics as parent rocks and the main mineral is an iron–rich smectite [2]. The Lieskovec deposit, belonging to Abčina Formation, is located in Zvolenská kotlina Basin, only about 25 km east of the J deposit. In spite of close occurrence of the two bentonites, they differ in mineralogical compositions. Both bentonites are well characterized and commonly used. Andrejkovičová et al. [3] reported recently that the blend containing 65 mass % of Na^+–Lieskovec and 35 mass % of Na^+–Jelšový Potok bentonites meets all the requirements on bentonites used in geosynthetic clay liners.

4 another blocks were a mixtures (fig. 3). Two blocks (1 with J bentonite and 1 with L bentonite) contained either 5% of pyrite concentrate to simulate pyrite presence in a galery host rock. Pyrite is a negative component because of its tendency to oxidize during the undergound repository excavation. The next two blocks contain 5% of powdered elementary iron to determine iron–bentonite interactions (iron components in gallery).

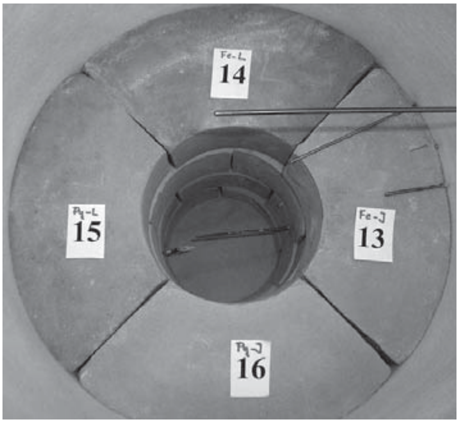

Fig. 3. Position of segments in the experimental vessel

Mineral composition of bentonite material was characterized by the X–ray diffraction analyses of oriented (clay fraction) and random specimens (bulk fraction) carried out using Philips PW 1710 (Cu–Kα radiation with graphite monochromator) diffractometer.

Samples for quantitative analyses were milled in McCrone Micronising Mill with internal standard ZnO to < 20 μm size. The XRD data were converted into wt % minerals using the RockJock software [5]. The program fits the sum of stored XRD patterns of standard, pure minerals and amorphous phases (the calculated pattern) to the measured pattern by varying the fraction of each standard pattern, by using the Solver function in Microsoft Excel to minimize the degree of fit parameter between the calculated and measured pattern. Data were normalized to 100% at the end of analysis.

4. Saturation

In the host rock the bentonite water saturation occurs naturally. In the experimental mock–up the hydration was ensured from the external water source. Water was distributed using 23 hydration holes placed outside of the backfill block. Holes and bentonite were separated by permeable geotextile membrane. The water chemistry (tab. 2) was based on the composition of the original water present in the most perspective area for geological radioactive waste repository in Slovakia. From the geological point of view, the Szécsény Schlier from the Lučenec Formation is a geological area with favourable properties. It is a friable calcareous siltstone with intercalations of silty clay and fine–grained sandstone, of low hydraulic conductivity and acceptable uniaxial compessive strength [1].

TABLE 2
Chemical composition of synthetic water used in the experiment [mg/l]

Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO^{3-}	Cl^-	SO_4^{2-}	pH
4509	136.6	251.5	151.5	896.9	6542.0	223.5	7.3

5. Conclusion

After approximately one year of saturation and heating, the experiment was dismantled and more than 30 samples were extracted with regard to they position in the experimental vessel. The detail mineralogical analyses of the bentonite based material used in the mock-up revealed stability of the mineral composition and the crystallochemical characteristics of smectite which is the main barrier component. Smectite content was similar for all bentonite samples from Jelšový Potok (approximately 70 wt %) and in Lieskovec bentonite varied around 50 wt %. One year lasting experiment has no impact on general properties of bentonites, required for barrier material. This mock–up can be considered as a pilot experiment and it was intermittent due to some technical complications (especially sealing problems and corrosion of humidity sensors). Experiment should be run again for longer period of time in order to verify the long term stability of engineering bentonite barrier.

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