Performance of Czech Bentonite Material in the Plug in Geological Disposal Demonstrations.

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The EPSP laboratory tests of bentonite B75_2013 got concentrated on determining a basic description of the material and the confirmation of its properties against the requirements that were set out in the beginning of the project. A set of experiments and expertises were performed in order to determine firstly basic chemical and geotechnical properties, being followed by test focused on manufacturing bentonite pellets for successful plug construction. Other test complemented the mentioned ones, starting with hydraulic conductivity and retention curves, being followed by construction of physical models. Those simulated partly the performance of the plug as the EPSP itself is not going to be dismantled during the course of DOPAS project. Firstly, the physical hydraulic model (PHM) got focused into bentonite saturation; on the other hand physical interaction model (PIM) aimed to observe into plug component material interactions. Those model were after defined time period dismantled and evaluated providing data for plug performance modelling.

1. Introduction

The Czech deep geological repository (DGR) concept assumes that waste packages containing spent nuclear fuel (SNF) assemblies will be enclosed in steel-based canisters placed in vertical or horizontal boreholes at a depth of ~ 500m below the surface. The void between the canisters and the host crystalline rock will be backfilled with compacted bentonite which will make up the final engineered barrier. It is presumed that the buffer material will originate from Czech Republic bentonite deposits. DGR safety will be enhanced by the efficient performance of the plugs and sealing systems which will make up an important part of the overall disposal system.
Several types of sealing plugs will be required, the function of which will be to provide for the sealing and closure of individual waste packages not only throughout the period of repository operation, but also following the permanent closure of the facility. Such plugs will have to provide a high level of resistance to the considerable pressure which will be exerted by hydrostatic forces and volumetric changes within the engineered barriers (Dvořáková et al., 2014).
The objective of the DOPAS international project is to design a sealing plug system for DGR use, provide detailed plans for the design of such plugs, test both the characteristics of the materials to be used and the construction technology and to install four experimental in-situ plugs. Four in-situ plugs have been constructed within this project. One of them is the plug within the frame of EPSP (Experimental Pressure and Sealing Plug) (Svoboda et al., 2016b), built at Underground Laboratory Josef, operated by Czech Technical University in Prague (CTU) - see Figure 1-1.

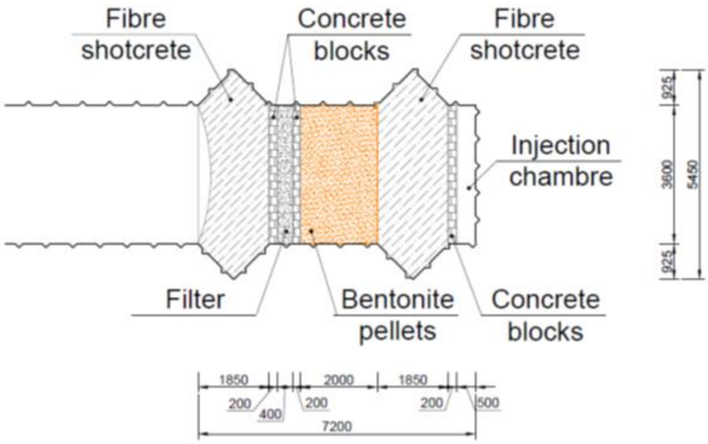

Figure 1-1- Scheme of the conceptual design of the EPSP. Dimensions in mm. (White, et al., 2013)

2. Scope and objectives

The main requirements toward using bentonite material for future Czech DGR repository plug were following:

- Local material (Czech origin)
- Non-activated bentonite
- Fulfilment of the various sealing requirements (see deliverable D2.1, White et al., 2013)
- Homogenous material
- Availability in sufficient quantity
- Availability in reasonable time

Commercially available “Bentonit 75” (B75) bentonite was found to be the only material readily available and able to fulfil all the above criteria. Non-activated Ca-Mg bentonite (Bentonit 75) is extracted from the Černý vrch deposit and is produced by Keramost, a. s. Therefore, the scope of activities presented was to assess properties and performance of bentonite and bentonite pellets, made from B75 toward DGR sealing plug safety performance. The B75 material for the EPSP construction was delivered in 2013, thus marked as B75_2013.

3. Laboratory tests

3.1 Bentonite and pellet characterisation

The initial EPSP laboratory tests got concentrated on determining a basic description of the material and the confirmation of its properties against the requirements set out in Deliverable D2.1 (White et. al., 2013).

3.1.1. Bentonite characterisation

The processing technology has been identified as the main factor affecting the properties of B75 produced in recent years. The resulting bentonite B75_2013 chemical composition is presented in Table 3-1. (Vašíček et al., 2016). Table 3-2 provides a summary of the basic geotechnical properties of B75_2013 (Vašíček et. al., 2016)

Table 3-1 Chemical analysis of bentonite B75

wt%	**B75_2013**		
SiO_2	49.83	**MgO**	2.88
Al_2O_3	15.35	**CaO**	2.01
TiO_2	2.82	**Na_2O**	0.67
Fe_2O_3	10.9	**K_2O**	1.05
FeO	3.74	**P_2O_5**	0.63
MnO	0.09	**CO_2**	3.66

Table 3-2 Basic geotechnical properties of B75_2013 bentonite material

Water content on liquid limit	171%
Specific density	2860kg/m^3
Hydraulic conductivity at dry density 1400kg/m^3	$4{\cdot}10^{-13}$ m/s
Swelling pressure at dry density 1400kg/m^3	2MPa
Thermal conductivity at 1400kg/m^3 and water content 6 and 20%	0.3 and 1W/mK

3.1.2. Pellet characterisation

A number of tests were conducted by CTU with respect to manufacturing the bentonite pellet. The main aim was to determine under which conditions the best bentonite compaction can be achieved resulting in the best possible dry density. Two most promising manufacturing technologies resulted into two types of "pellets" (B75PEL12 and B75_REC – see Figure 3-1 and 3-2). Influence of water content during pressing on final dry density of B75PEL12 is shown on Figure 3-3, comparison of final dry densities of both products is on Figure 3-4.
The B75PEL12 with a maximum dry density value of around 1800kg/m^3 was selected for further experimental purposes. The pellets have a diameter of 12mm, a length of up to 40mm.

Figure 3-1 B75 PEL12 material

Figure 3-2 B75 REC material

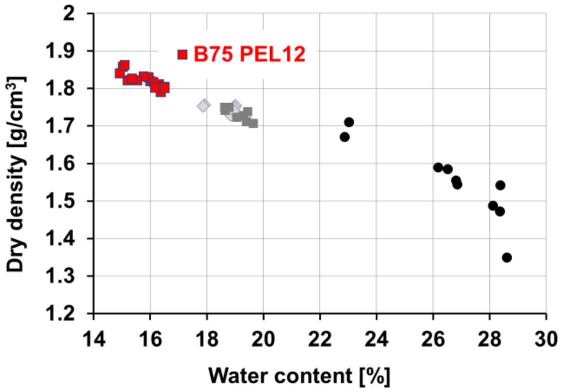

Figure 3-3 Influence of water content on B75PEL12 final dry density

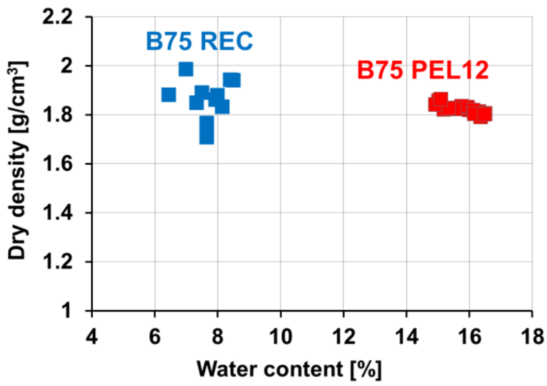

Figure 3-4 - Comparison of dry densities of both final products.

The CTU was also responsible for the construction of the bentonite seal of EPSP. Various emplacement tests were performed with the aim to achieve average dry density at least 1400kg/m^3 after installation. Tests included free fall pouring, pouring with vibration, using of dynamic compaction plates and spraying. As a result, the bentonite pellets (B75PEL12) were emplaced into the EPSP sealing section in horizontal layers with a maximum thickness of 3cm which were subsequently vibration compacted. Sprayed clay technology was used for the backfilling of the upper part of the drift. Approximately 5% (1.5m^3) was backfilled; with B75 REC (fraction 0.8-5). In-situ sampling during the construction phase confirmed achievement of the required dry density of the pellet layer (1400kg/m^3). More details are available in D3.20: EPSP plug test installation report (Svoboda et. al., 2016a) and in the contribution Svoboda et al. (2016b).

3.1.3. Bentonite pellet saturation and homogenisation

The homogenization of bentonite pellets was monitored during measurement of hydraulic conductivity. The Figure 3-5 shows the state before and after its saturation. Pellet homogenization is clearly visible.

Figure 3-5 State of bentonite pellets before (left) and after 3 days of its saturation (right). Picture in the middle shows the point of water entrance into the sample, the right one the material from the middle of the sample.

3.1.4 Bentonite and pellet hydraulic conductivity measurements

The values of the permeability/hydraulic conductivity of the bentonite materials will influence the nature and functionality of the EPSP experimental plug. Experiments were conducted on two types of experimental sample hereinafter referred to as "small cell/small samples" and "large cell/large samples" in the text. The interior dimensions of the experimental cells consisted of:

- small cell: diameter 30mm and length 15mm (permeability of compacted powdered bentonite B75)
- large cell: diameter 80mm and length 50mm (pellets compacted into the large cells; dry bulk density value of 1400kg/m^3)

The maximum pressure applied in the experiments was 2.0MPa (Vašíček et al., 2016).
Hydraulic conductivity varied for powdered B75 (dry bulk density 1400kg/m^3) varied between $4.78 \cdot 10^{-13}$ - $5.70 \cdot 10^{-13}$m/s (for input water pressure 1.6 - 2.0MPa) and for bentonite pellets $3.12 \cdot 10^{-13}$ - $3.23 \cdot 10^{-13}$m/s (for input water pressure 1.6 - 2.0MPa; Vašíček et al. 2016).

3.2 Retention curves (Block tests)

The moisture retention curve was determined using two methods. The first method was a block method (Villar, 2007), the second one was saturation measurement in the physical hydraulic model (PHM, see chapter 4). In the PHM the moisture retention curve was determined using the measured relative humidity values (after conversion to suction pressure) and the corresponding water content. The comparison of both methods is shown on Figure 3-6. The results indicate that, despite the difference in scale of the samples, they well compatible.

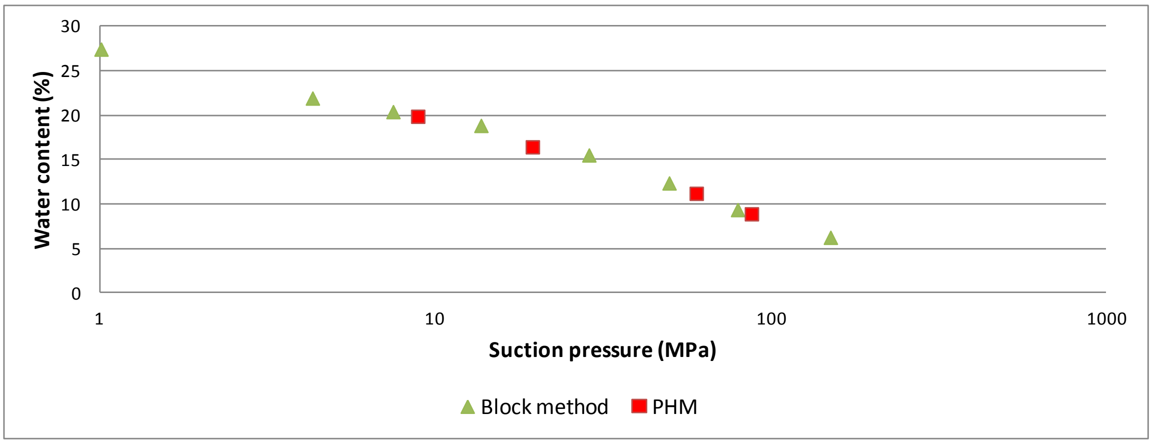

Figure 3-6 Comparison of the retention curves of bentonite B75 obtained by the block method and following the dismantling of the physical hydraulic model (PHM)

4. Physical models of plug performance

The EPSP experiment will not be dismantled during the course of the DOPAS project, therefore plug physical models at the laboratory scale were proposed. The aim of these experiments was to collect data for the subsequent calibration of numerical models of the bentonite material saturation.
Two types of physical model were constructed in the ÚJV's laboratories:

- **Physical hydraulic model - PHM**
- **Physical interaction model - PIM**

Detailed description is presented in Trpkošová et al. (2016) and Večerník et al. (2016).

4.1. Physical hydraulic model (PHM)

The aim of PHM was to describe the hydraulic and mechanical processes during saturation of bentonite. Two PHM tests were constructed, one with bentonite powder and the other with bentonite pellets. The both physical hydraulic models consist of nine stainless steel chambers of cylindrical shape with approximate dimensions 0.05m in length and 0.08m in diameter (total length of bentonite in PHM is 45 cm) and will be equipped with RH sensors to record the distribution of water content within the bentonite material.

The sample of compacted bentonite and pellets (the intentical materials as that used in EPSP) was fitted with measurement sensors and the sample was gradually saturated with water under pressure 2MPa. The results of the testing of the physical hydraulic models consisted of curves describing the development of:

- the volume of water which infiltrated into the sample
- the pressure under which the water infiltrated
- the development of RH at 9 observation points
- the development of swelling pressure at the end of the sample

The result examples for PHM with bentonite powder are shown on Figure 4-1 and Figure 4-2

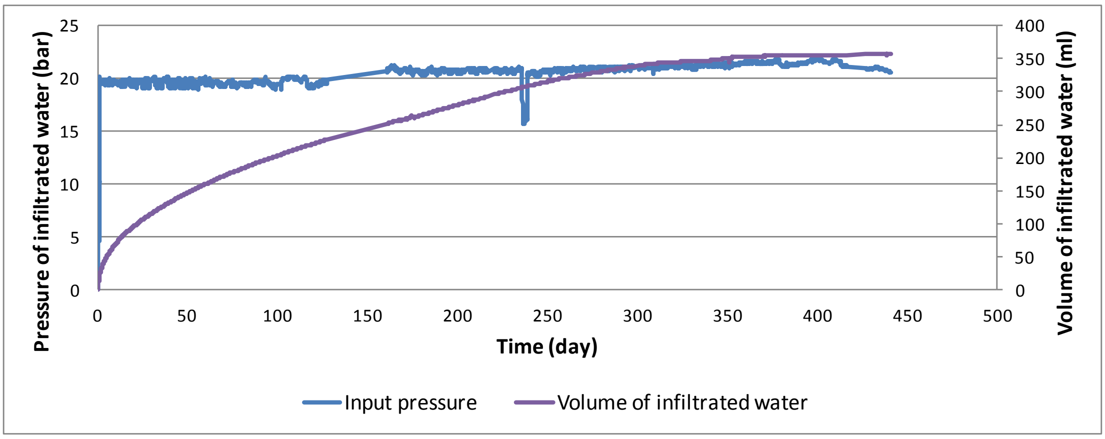

Figure 4-1 The pressure and water volume infiltrating the sample. Pressure drop around 230 days was caused by the failure of a pressure reducing valve (Trpkosova et al., 2016).

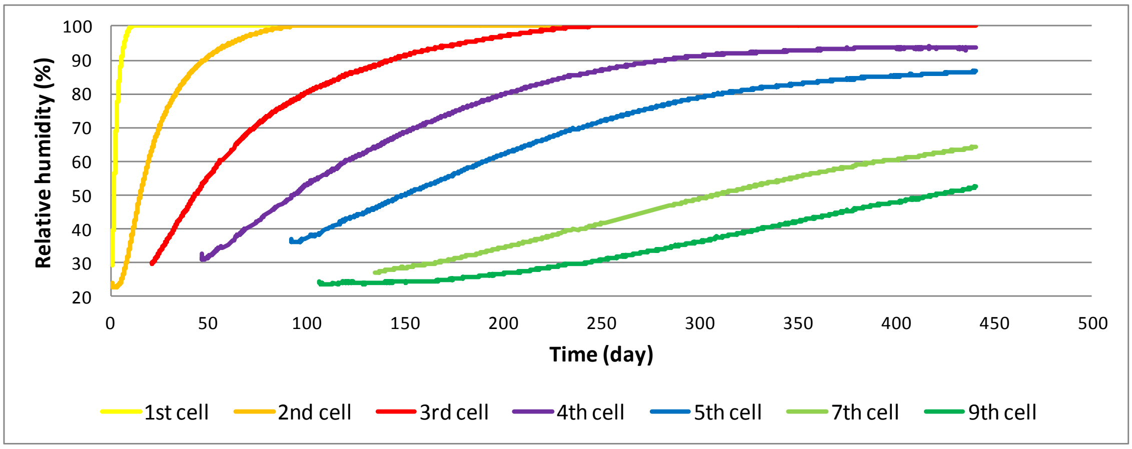

Figure 4-2 Development of the relative humidity in different observation points (Trpkosova et al., 2016).

4.2. Physical interaction model (PIM)

A physical interaction model (PIM) was dedicated to verification of anticipated interaction processes between the materials being used for the EPSP construction (e.g. changes in material properties, the formation of new phases, interaction of water with phases etc). The identical materials (concrete and bentonite) were used to those in the EPSP plug. Synthetic granitic water (SGW), under input 2 MPa pressure (as in Trpkosova et al., 2016), was used as the liquid phase.

The quantity of PIM water outflow was continuously monitored following the attainment of the steady state. The water was sampled for chemical analyses. The outflow exhibited significant enrichment in all major cations and anions in comparison to entrancing synthetic granitic water. A similar degree and enrichment content was observed in the output of the bentonite hydraulic permeability tests (PROP), see Figure 4-3. PIM dismantling focused on the determination of interaction products and so as to comparing the physical and chemical properties of the materials prior and after the experiment (i.e. mineralogy, porosity, CEC, pH of the leachate, chemical composition, etc.). The concrete part of the PIM acted as calcium source, exchanging for Na^+ and Mg^{2+} in bentonite (determined using cation exchange capacity, CEC). Bentonite material was also analyzed for the specific surface area (SSA) using EGME method (Carter et al., 1986). Although some minor difference in specific surface area along PIM bentonite samples were observed, generally the SSA values are close to the original bentonite B75_2013.
The results proved that some of the interaction processes occur. However, interaction experiment duration was not sufficient to observe or confirm expected changes (e.g. in mineralogy and physical properties etc.). All details of laboratory testing will be reported in final version of Deliverable D3.21 (Vašíček et al. 2016).

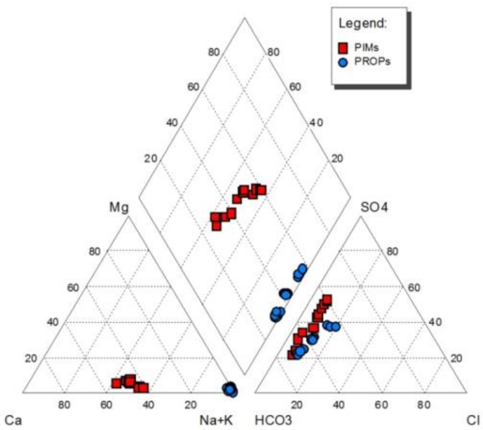

Figure 4-3 Piper diagram of PIM and PROP water samples (Vašíček et al., 2016).

5. Conclusions

The extensive laboratory research has supported bentonite material characterisation and property description in order to prove the ability for this material to be used for plug construction, even concerning pellet manufactured for this purpose. Eventhough the plug will not be dismantled during the course of DOPAS project, important data could be gained using laboratory models.

6. Acknowledgement

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