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Air and hydrogen injection tests on saturated compacted bentonite

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The concept of the Czech deep geological repository for radioactive waste, as in most other countries that are planning such projects, currently envisages the use of compacted bentonite for the sealing layer around the waste disposal package emplaced in the disposal borehole. The concept considered involves the use of steel-based waste disposal packages. It is expected that gases (mostly hydrogen) will form as a result of the corrosion of the waste disposal package, via the radiolysis of water or due to the development of microbial activity; therefore, a knowledge of the gas transport mechanisms in bentonite is fundamental in terms of the safety assessment of the deep geological repository. It is known that gas flow in water-saturated bentonite occurs mostly via networks of pressure-induced dilatant pathways, a fact that has been supported by the results of numerous laboratory tests involving indirect observations as well as direct detection methods. The current state of the art with concern to gas transport processes was established via the EURAD project [1].

This article presents the work carried out by the CTU in Prague and ÚJV Řež as part of Task 2 of the GAS Work Package of the EURAD project. Since the Czech deep geological repository concept is considering the use of local bentonites, the research programme is focusing on Czech Ca-Mg bentonite (BCV) and its benchmarking comparison with foreign materials such as MX-80 sodium bentonite. Both the CTU and ÚJV laboratory testing programmes involve the performance of gas breakthrough tests on water-saturated compacted bentonite samples using similar methodologies and equipment. The objective of the research is to compare the gas breakthrough behaviour of Czech bentonite with other materials. Moreover, the key contribution of the research concerns the direct use of hydrogen as the gas injection medium for some of the tests, thus providing unique data for comparison with other gases that are typically used as a surrogate for hydrogen.

The basic component of the CTU test equipment comprises a constant volume steel cell which can be used for the determination of the hydraulic conductivity and swelling pressure of bentonite samples when connected to a water permeameter [2], as well as for gas injection testing purposes [3]. Homogeneous samples of the material are prepared via the direct compaction of powdered bentonite in a cylindrical steel chamber of 30 mm in diameter and 20 mm in height. The testing cell, which has been specially modified for the purposes of this project, consists of two pistons and two total pressure sensors positioned between the sample surfaces and the cell flanges measuring axial pressure hereinafter called as total pressure. Initial testing was performed via the injection of the gas into the centre of the sample using an injection needle with the aim of simulating a gas point source. However, due to gas leakage issues, a standard procedure was adopted for the rest of the tests consisting of injection into the base of the cylindrical sample through sintered steel plates. A total of 5 samples of BCV bentonite with dry densities that varied between 1300 and 1500 kg/m^3 were prepared for the purposes of the project. All the samples were firstly connected to the water permeameter to ensure their saturation under a constant water injection pressure. The saturation level is checked by the monitoring of the water flow and the total (swelling) pressure. It usually takes several weeks to months to attain full saturation, which is confirmed by the attainment of stable water flow and total pressure values. The samples are then subjected to air injection tests involving incremental increases in pressure at the sample inlet applying small increments of, in most cases, 0.05 MPa until gas breakthrough (detected by gas outflow

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and decreasing injection pressure) is detected. The pressure at the outlet of the sample is maintained at the atmospheric level and the outflow is measured using a flow meter.

The ÚJV experimental apparatus is equipped with a similar constant volume cell that contains samples of 30 mm in diameter and 15 mm in height. The apparatus enables the use of both air and hydrogen as the injection media. One of the most important components comprises a GDS ELDPC pump that is connected to the outlet from the sample, which is used for the precise measurement of the volume of the fluid which passes through the sample. The pressure in the outflow pump is maintained at the atmospheric level. The procedure for the gas injection testing of fully water-saturated samples involves incremental pressure increases with increments of 0.2 to 0.3 MPa until gas breakthrough is achieved. The pressure is always increased at the moment at which the flow through the sample has stabilised. The initial injection pressure is, in all cases, set at a lower value than the expected swelling pressure of the sample. Following the completion of the gas injection test, the sample is dismantled and its porosity and water content are determined in order to verify whether the sample has been partially de-saturated by the injection of gas. Three different materials are being subjected to testing. In addition to a series of samples of BCV bentonite, samples of MX-80 bentonite have been tested and it is planned that Kunipia bentonite will also be tested so as to complete the data set. Three samples with a dry density of 1400 kg/m^3 and three samples with a dry density of 1600 kg/m^3 are prepared for each of the materials. One sample is used for air injection testing, the second for hydrogen injection testing and the third is used as the control sample for the determination of the water content and porosity directly following the saturation process.

The results of the CTU testing programme revealed that the time period necessary for the saturation phase for the BCV samples may be in excess of 5 months before the conditions stabilise. The gas injection test on the 1300 kg/m^3 sample lasted 3 months, with gas breakthrough occurring at slightly below the measured total pressure. The gas injection tests on the 1400 kg/m^3 and 1450 kg/m^3 samples have been underway for several months and, in both cases, the injection pressure level has exceeded the total pressures without the detection of gas breakthrough.

The results of the ÚJV tests on the BCV and MX-80 series of samples demonstrated that the breakthrough events in all cases occurred at pressure levels that corresponded to the theoretical swelling pressure values for both air and hydrogen. The breakthrough events for the 1400 kg/m^3 and 1600 kg/m^3 samples were observed to be very close, with a maximum difference of 0.2 MPa. With concern to the 1400 kg/m^3 MX-80 samples, breakthrough was registered at exactly same pressure level (3.9 MPa) as the theoretical swelling pressure as determined by Karnland et al. [4]. The difference between the breakthrough pressures for the 1600 kg/m^3 MX-80 samples was more noticeable; the breakthrough with hydrogen occurred at 8.5 MPa and with air at 7.2 MPa. However, it must be noted that, based on known correlations between dry density and swelling pressure, the theoretical swelling pressure for higher dry densities lies in a broader interval and a large range of variability of material properties exists for different material batches. The results of the determination of the water content for the samples subjected to gas injection testing did not reveal any major deviations from the non-loaded samples and the theoretical full saturation values. This result corresponds to the general observation that gas flow through dilatant pathways does not result in the significant de-saturation of the samples, or the de-saturation is so minor that it cannot be detected by means of standard methods.

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