Laboratory Gas Injection Test Considering Disposal Environment

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1. Introduction

Deep geological disposal is one of the disposal methods for spent nuclear fuel. It consists of engineered and natural barriers. An engineered barrier system (EBS) comprises a canister, buffer (compacted bentonite), and backfill. In the disposal environment, gases can be generated in a disposal environment for several reasons, including canister corrosion, radiolysis, etc. If the gas generation rate is much faster than the diffusion rate in compacted bentonite, gases may become trapped and increase pore pressure. Pore pressure can increase by more than 10 MPa depending on the type of radioactive waste and disposal environment (Diomidis, N. et al., 2016). This increase in pore pressure can cause mechanical damage to the buffer, forming internal cracks and accelerating the migration of leaked nuclides. Horseman et al. (1999) described that in saturated compressed bentonite, gas could only migrate rapidly through a preferential path caused by mechanical cracking and defined this phenomenon as a gas breakthrough. Additionally, it was experimentally observed that a preferential path occurs when the gas pressure (breakthrough pressure) increases beyond the sum of the swelling and pore water pressures. The breakthrough pressure and swelling pressure depend on the raw material and its dry density. Thus, building a database through the gas injection test is essential to design appropriate buffer density for the Korean Disposal System. The Korean Disposal System concept considers building an underground disposal site of approximately 500 m. Therefore, in this study, the pore water pressure that can be applied in the disposal environment was set as the experimental condition, a gas injection experiment was performed, and the resulting gas migration was observed.

2. Experimental Setup

2.1. Test Setup

The British Geological Survey (BGS) is an organization with experience in various gas injection experiments to analyze gas migration phenomena in buffer materials. The experimental apparatus used in this study was constructed referring to Harrington and Horseman (2003). The test system primarily consists of an interface vessel for gas stabilization and injection and a high-pressure cell with a sample. In particular, the high-pressure cell has sensors to observe pore water pressure and total stress at each location, as shown in Fig. 1.

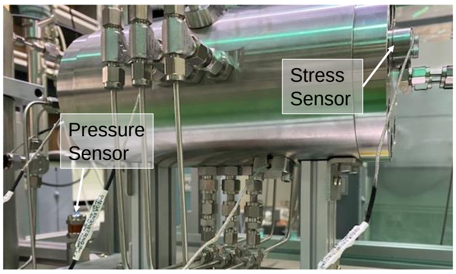

Fig. 1. High-pressure cell with stress and pressure sensors.

2.2. Specimen preparation

The swelling pressure and permeability of compacted bentonite depend on the raw material's properties and the compacted bentonite's dry density. In this study, Bentonile WRK powder (Ca-type), one of the candidate materials for the buffer, was used and compressed to a dry density of 1,550 kg/m^3 by the CIP method.

3. Methods

The experimental procedure consists of sample preparation, hydration, gas stabilization, and gas injection and cessation stages. In the hydration stage, it is possible to estimate the swelling pressure generated as the buffer material saturates. The critical pore pressure associated with gas breakthrough can be observed during the gas injection stage. In this case, the observed critical pore pressure can be considered as the gas inflow pressure for the compressed bentonite sample. Detailed experimental procedures are described in Tamayo-Mas et al., (2021). While the BGS experiment set the initial pore water pressure to 1 MPa, this study put it to 5 MPa, considering the water pressure at the expected depth of 500 m for the Korean disposal system.

4. Results

Fig. 2 shows the results of the gas injection experiment performed at BGS. When the pressure of the gas injection filter reaches the critical pressure, a rapid increase trend is observed in stress and pore water pressure sensors at all locations. This trend observation makes it possible to predict the gas breakthrough phenomenon in the buffer. Harrington and Horseman

(2003) stated that the critical pressure at which gas breakthrough occurs is closely related to the swelling and pore water pressures. In other words, it was observed that when the gas injection pressure became greater than the sum of the swelling and the pore water pressures, the gas flowed into the buffer abruptly.

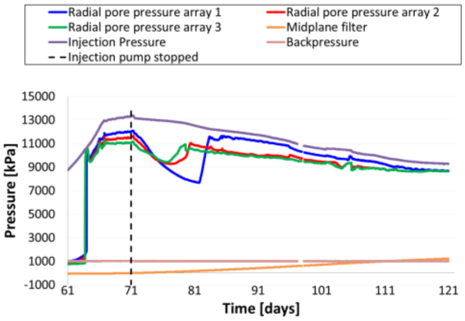

Fig. 2. Total stress and pore pressure evolution during gas injection test, initial pore pressure = 1 MPa (Tamayo-Mas et al., 2021).

Fig. 3 shows the pressure evolution observed in this study. Unlike the pressure trend of BGS, a gradual increase in pore pressure was observed, while an abrupt increase was not observed before peak pore pressure. However, a rapid increase in pore pressure was observed in the pressure decay stage after the peak pressure (i.e., after cessation of gas injection). Additional research is currently being conducted to analyze this phenomenon.

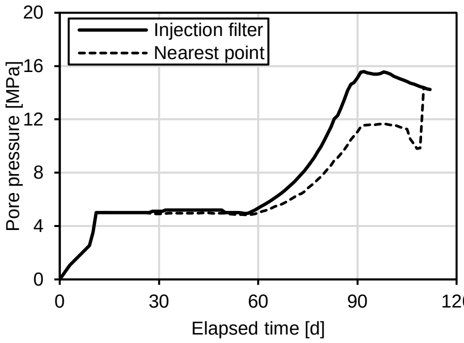

Fig. 3. Pore pressure evolution during gas injection test, initial pore pressure = 5 MPa (this study).

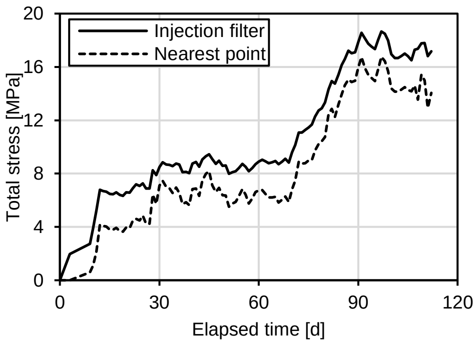

Fig. 4. Total stress evolution during gas injection test, initial pore pressure = 5 MPa (this study).

Fig. 4 shows the total stress evolution observed during the test performed in this study. The hydration process to saturate the block was carried out for about 65 days, and the swelling pressure derived from the measured total stress was about 1.5 to 3.7 MPa.

Using the relationship between swelling and pore water pressures, the critical pressure at which the gas breakthrough occurs is approximately 6.5 to 8.7 MPa. This suggests that the injection pressure, 5 MPa, was already close enough to form a preferential pathway in the early stages of gas injection. For this reason, it is inferred that the rapid increase in the pore pressure trend seen in the previous experiment was not observed.

5. Conclusions

This study performed a gas injection experiment with a bentonite block compressed with Bentonile WRK powder, a candidate material for buffer in the Korean disposal system. As a result of the experiment, the swelling pressure was about 1.5 to 3.7 MPa, and no rapid gas breakthrough was observed due to the gas injection pressure being relatively high compared to the critical pressure. However, considering that a gradual increase in the gas injection filter and the stress and pressure sensors closest to the filter was observed, a local path was believed to have occurred, although a preferential path penetrating the sample was not formed. As a further study, it is necessary to identify the mechanism of gas migration within the buffer under relatively high pore water pressure conditions.

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