# MIGRATION EXPERIMENT OF VOID AIR IN BUFFER MATERIAL DURING SEEPAGE

Naohiko TAKAMOTO*1, Ichizo KOBAYASHI*2, Masahiro KAWAKUBO*1, Masataka IMAI*1, Tomoko ISHII*1

*1 Radioactive Waste Management Funding and Research Center
Nichirei Akashicho Bldg. 12F, 6-4, Akashicho, Chuo-Ku, Tokyo, 104-0044, Japan

*2 Kajima Corporation
2-19-1, Tobitakyu, Chofu City, Tokyo, 182-0036, Japan

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**Abstract**

The buffer material composing the engineered barrier system for the geological disposal of high-level radioactive waste in Japan is expected to control migration of groundwater and radionuclides. The Radioactive Waste Management Funding and Research Center has been focusing on the re-saturation process of the buffer material with groundwater after emplacement, and researching mainly the behavior of buffer material based on long-term laboratory tests. The state transition of the buffer material is the most significant during this period, and the state after the period will affect the continual long-term behavior. Therefore, it is important to predict the state after the re-saturation process, for assessing the long-term performance of the buffer material. In this study, we conducted a one-dimensional long-term laboratory model test focusing on the migration of void air due to the seepage and swelling of buffer material during the re-saturation process, and obtained data for analytically evaluating the seepage process of the buffer material. The result showed the void air pressure increased very gradually. This implied that the pressure increase of void air was mitigated by dissolution of the void air into water in parallel with water seepage into the buffer material. Moreover, it was also noted that the seepage rate of the buffer material was slowed by trapped void air. In the future, it is necessary to consider the influence of heat from the waste; it is possible to predict the state of saturated buffer material and evaluate the breakthrough occurrence of the buffer material due to the pressure increase of the void air, by constructing an analytical method to reproduce the results of this model test and extrapolating the influence of heat and seepage behavior.

## 1. Introduction

There is a broad international consensus that passive safety of geological disposal of radioactive waste will be ensured by multiple safety functions such as combination of a natural barrier and an engineered barrier system (EBS). In the Japanese underground environment, a large amount of groundwater is expected in general, so the buffer material composing the EBS for geological disposal is required to ensure several functions, e.g., mechanical protection, hydraulic barrier, chemical buffer, and controlling migration of radionuclides.

It is assumed that long-term maintenance availability of functions expected of buffer materials is greatly affected by the initial state change in the re-saturation period after emplacement. Thus, it is important to predict the state of buffer materials after the re-saturation process, for assessing the long-term performance of the EBS and long-term safety assessment of the geological disposal system. The Radioactive Waste Management Funding and Research Center has been acquiring mainly long-term data on swelling behavior, chemical alteration, mechanical performance change, groundwater seepage, and gas migration, in order to understand the buffer material behaviors during the re-saturation process by groundwater after the installation of the buffer material. In this study, we focused on the migration of void air in the buffer material during the re-saturation process, and the void air pressure in a system in which void air is confined was measured by test equipment simulating one dimension. We also obtained data to analytically evaluate the possibility for breakthrough occurrence of buffer material due to the increase in void air pressure and the seepage / swelling behavior of buffer material up to saturation [1].

## 2. Methods for migration of void air experiment

Using test equipment simulating one dimension with 50 mm diameter and 1000 mm height as shown in Fig. 1, the swelling process associated with the groundwater seepage after setting the buffer material was simulated, and a long-term experimental laboratory scale test was conducted, to measure the behavior of pressure increase due to compression of void air during the seepage process. In the actual repository, groundwater seepage due to spring water from the bedrock occurs from around the buffer material toward the inside, so that void air may be trapped inside the buffer material, and uniform saturation of the buffer material may be inhibited. As a result, void air pressure may increase during re-saturation. Therefore, in this test, it is assumed that the void air was trapped inside the buffer material, and seepage water was fed from top and bottom in the test equipment. The void air pressure was measured at the center of the cell. Because migration of the void air indicates a change in degree of saturation, the saturation change of the buffer material was measured. Resistivity measurement was used as a method of measuring the saturation change in the buffer material without disturbing the specimen. In this resistivity measurement, a current is passed between electrodes in contact with the buffer material, and the degree of saturation is calculated from the resistance value between the electrodes. The correlation between the resistivity and the degree of saturation for buffer material was previously obtained by a preliminary laboratory test (Fig. 2) [2]. In the one-dimensional test equipment, 39 electrodes were installed at intervals of 25 mm, the resistivity value was measured, and the change in the degree of saturation for the buffer material was investigated. A mixture of bentonite (Kunigel V1) and sand was employed as a buffer material, with silica sand of 30 wt% against total weight. The buffer material was compacted and filled in an acrylic resin cell to avoid the occurrence of a gap at the interface between the acrylic resin cell and the specimen. The dry density of the specimens was 1.6 $Mg/m^3$. The volume of void air in the buffer material at this density will be approximately 20% to 40% under the pressure of one atmosphere. Table 1 shows the test conditions and measurement items.

To measure void air pressure, as conditioning of the state in the cell, two water feeding methods of flow rate control and pressure control were used. In order to avoid breakthrough occurrence of the buffer material due to the initial sudden feeding of water under pressure control, distilled water was fed by flow rate control at the initial stage of the test until the buffer material swelled to a certain extent. Subsequently, the pressure control was switched when it was confirmed from the resistivity distribution that the seepage region was generated (50 days later). The resistivity distribution, the amount of feeding water, the void air pressure, and the feeding pressure were measured at regular intervals. The pressure was measured with an absolute pressure gauge to avoid the influence of atmospheric pressure. The feeding water pressure was gradually increased to avoid breakthrough occurrence of buffer material due to sudden feeding of water; the behavior of void air pressure was measured at 876 kPa (corresponding to 1 MPa of a general gauge pressure gauge). As for the seepage rate in the situation where the void air was not trapped, the test was separately carried out under the water feeding condition from the lower part using the same shaped test equipment (the setting for which the air escapes to the top part) [1, 3].

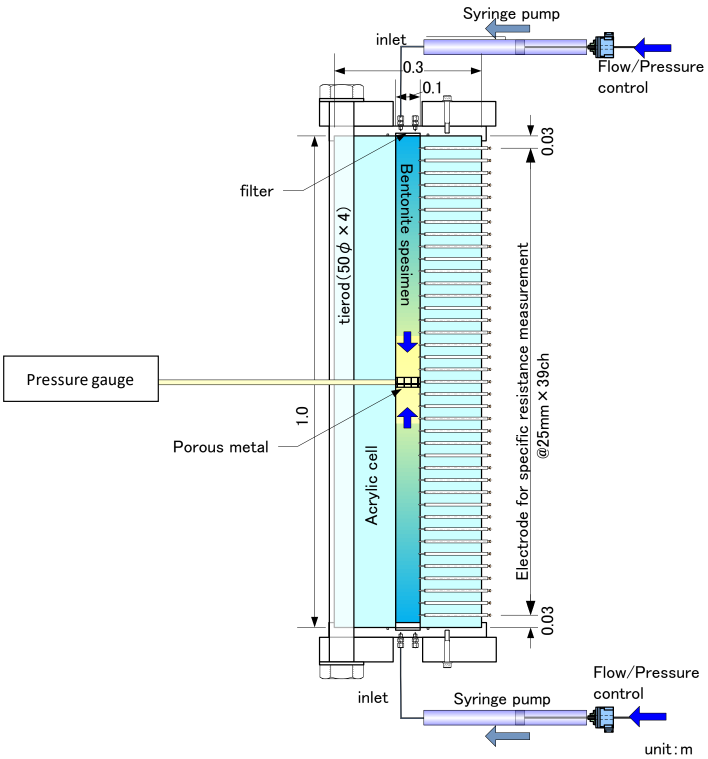


Fig. 1 Test equipment for migration of void air in the saturating buffer material

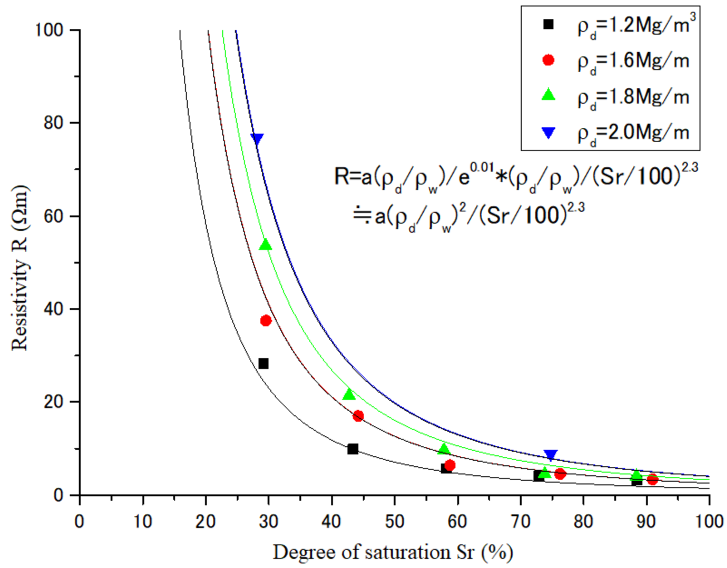


Fig. 2 Relationships between resistivity and degree of saturation of buffer material with various dry densities [2]

Table 1 Test conditions and measurement items

| Bentonite dry density | Initial water content | Liquid | Measurement items |
|---|---|---|---|
| 1.6 Mg/m$^3$ (mixture of bentonite and silica sand) Kunigel V1: 70 wt% Silica sand: 30 wt% | 10 % | Distilled water | Resistivity<br>Amount of feeding water<br>Void air pressure<br>Feeding pressure<br>Swelling pressure |

**3. Results and Discussion**

After 50 days from the start of the test, regions with decreased resistivity were formed at the upper and lower ends of the specimen. This means that a certain degree of seepage area due to feeding water was formed. Therefore, it was switched to pressure control on the 53rd day after starting the test. Fig. 3 shows the temporal change in the void air pressure and inflow rate after switching to pressure control. To avoid breakthrough due to water feeding through the

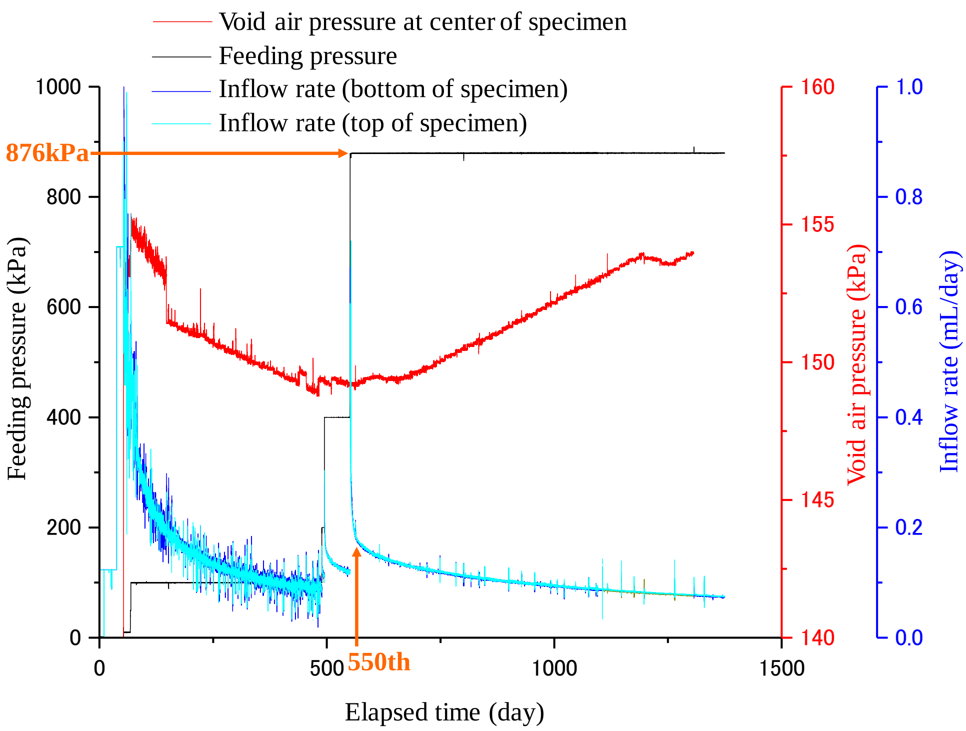


Fig. 3 Temporal change in the void air pressure and inflow rate

buffer material, the feeding pressure was increased step by step with the initial pressure of 10 kPa. Finally, the feeding pressure was increased to 876 kPa on the 550th day. At the stage where the feeding pressure was low, the void air pressure decreased. Because this implied that the seepage rate due to the capillary phenomenon of the pore water was faster than the feeding rate, negative pressure seems to have been reached in this state. In addition to the above, there is a possibility that the void air pressure decreased due to dissolution of void air into pore water. However, at this time, the surface area and amount of pore water were small, so the influence for increase of void air pressure due to dissolution of void air in pore water was presumed to be small. When the feeding pressure was set to 876 kPa, the void air pressure was increased. At this time, it was implied that a saturated region confining void air was formed. Subsequently, as the seepage of the central unsaturated region progressed, the void air pressure increased with a constant gradient: the increase was about 3 kPa in about 2 years and was a very slow rate. After setting the feeding pressure to 876 kPa, the feeding rate stabilized and gradually decreased compared to the period before the feeding pressure was set to 876 kPa. This implied that irregular void air migration had not occurred and void air pressure changed by compression of the void air volume due to water seepage. At this time, the balance of mass transfer to the specimen seems to have been dominated by feeding and dissolution of the void air into the pore water. Therefore, the pressure increases of the void air caused by the groundwater seepage from the surroundings of the buffer material were expected to be mitigated by the dissolution of the void air into the pore water, and it was considered that breakthrough of the buffer material due to pressure increase in void air did not occur.

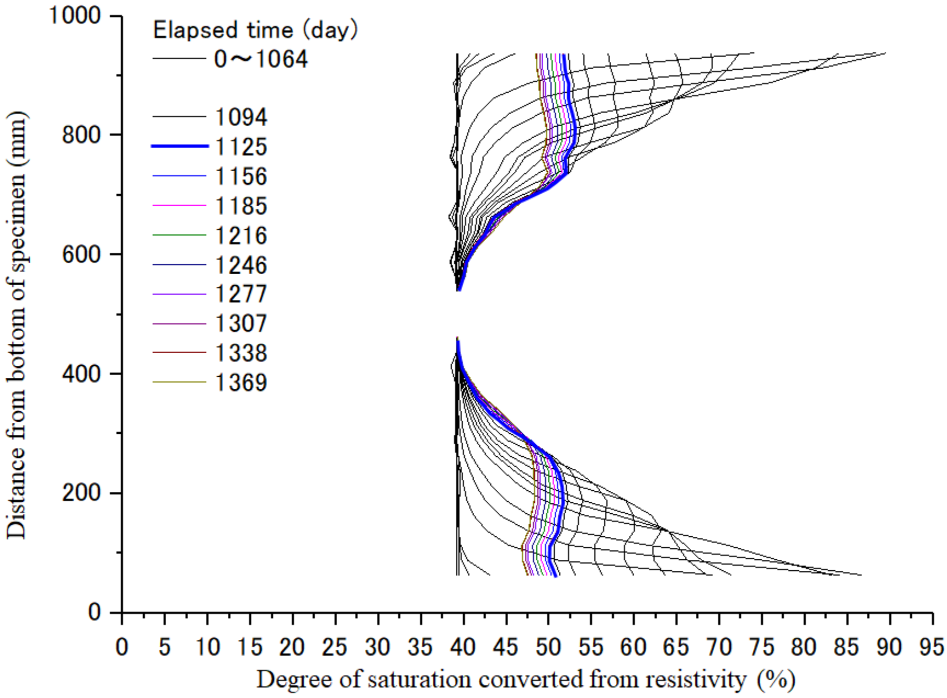


Fig. 4 Temporal transition of the saturation distribution converted from the resistivity (pressure control process)

Fig. 4 shows the temporal transition of the saturation distribution converted from the resistivity during the pressure control process. Under the condition that the initial water content was 10%, the degree of saturation of the buffer material was about 40%. As shown in Fig. 4, the degree of saturation gradually changed from the top and the bottom toward the center of the specimen, and the degree of saturation reached to about 90% at the top and bottom. However, from the 400th day, the s resistivity of the upper and lower parts tended to decrease. These decreases in resistivity mean decreases in the degree of saturation when the dry density is constant. On the other hand, when the density changes, it does not necessarily mean a change in the degree of saturation. As the swelling proceeds, the upper and lower end faces of the specimen may be compressed by the specimen swelling and the dry density may increase. In this case, assuming that the degree of saturation is constant at 100% and calculating the density from the change in resistivity by Fig.2, the dry density has increased from 1.76 to 1.79 Mg/m$^3$. From the complete saturation line shown in Kobayashi et al.

(2007) [4], the swelling pressure of Kunigel V1 alone with a dry density of 1.8 Mg/m$^3$ is about 1.42 MPa. In this test, because the pressure acting on the upper and lower end faces was 1.6 MPa, an increase in dry density due to consolidation may have occurred. On the other hand, as compared with the temporal change of the saturation distribution under the condition that the air escapes to the upper part tested separately (Fig. 5) [1,3], for example, the increase range in saturation after about 1100 days reached about 400 mm from the upper and lower end faces of this test result, whereas in the test result of the condition that air escapes to the upper part, it reached the increase range of saturation of about 600 mm or more (blue bold line in Fig. 4 and Fig. 5). Therefore, it was found that the seepage rate of the buffer material was slowed by the void air trapped inside the buffer material. Also, as shown in Fig. 5, there was no decrease in resistivity on the lower face side as shown in Fig. 4. Therefore, it is evident that the propagation of pressure is different in the state where the void air has escaped, and the density difference of the buffer material hardly occurs.

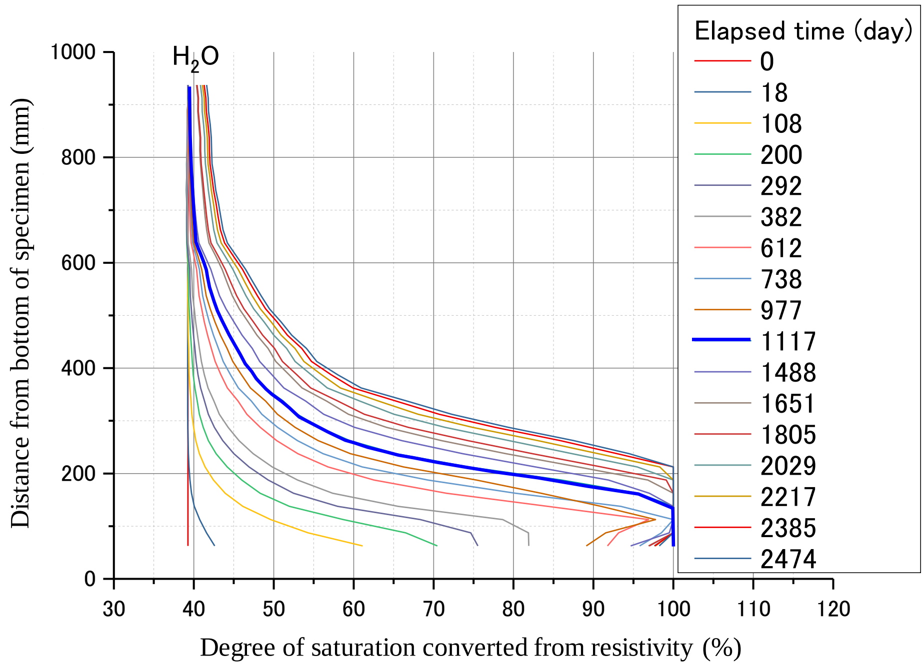


Fig.5 Temporal transition of the saturation distribution under the condition that the air escapes to the top part [1, 3]

## 4. Conclusion

In this study, in order to evaluate the seepage process of buffer material during the re-saturation process, focusing on the migration of void air accompanying swelling, we conducted a long-term laboratory experimental model test simulating one dimension in a system in which void air is confined. As a result of this model test, the pressure of void air increased very gradually; it was learned that the pressure increasing of void air was mitigated by dissolution of the void air to water in parallel with water seepage into the buffer material. As the void air was trapped, it was revealed that the seepage rate of the buffer material slowed down.

In the actual disposal pit, because the void air pressure increases by the heat from the waste and the solubility of air decreases due to the temperature increase of the pore water, it is expected that the void air pressure increases. Therefore, it is necessary to consider the influence of heat generated during the seepage period. This model test was a test at room temperature; in the future, based on the separately obtained seepage rate [1, 3], it is expected that the behavior of the void air pressure at the repository can be evaluated by simulating in consideration of the influence of heat and dissolved amount of air. It is assumed that the behavior of the void air pressure at the repository can be evaluated by simulating the influence of the dissolved amount of heat and air. Furthermore, it is expected that a method showing the state after saturation of the buffer material can be constructed by studying a three-dimensional mechanical simulation which combines various behaviors during the re-saturation process. Indicating the state of the buffer material after saturation leads to the initial state of safety assessment, which is important information for the evaluation of the long-term safety of the repository.

In this test, it was suggested that the seepage rate is slowed by trapped void air and there is a possibility that density nonuniformity may be promoted. As a countermeasure for keeping the performance of the buffer material against such a phenomenon, it is possible to assume, for example, a constructional countermeasure which allows escape of the void air in the buffer material.

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