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Evaluation of specific surface area of bentonite-engineered barriers for Kozeny-Carman law ☆

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Abstract

The impermeability of bentonite is dependent on montmorillonite microstructures and varies with chemical alteration caused by related changes. The Kozeny-Carman equation is viewed as a rational hydraulic model for bentonite because it incorporates microstructure parameters such as specific surface area in addition to macrostructure parameters such as the void ratio. In the study reported here, a technique for measuring the specific surface area of compacted bentonite under constant volume conditions using X-ray diffraction was developed, and the hydraulic conductivity of various bentonite materials was evaluated based on the measurements thus obtained. The applicability of the Kozeny-Carman hydraulic model for evaluation of impermeability of bentonite was clarified.

Keywords: Bentonite; Montmorillonite; Hydraulic conductivity; Specific surface area; Kozeny-Carman law

1. Introduction

Finding methods for the final disposal of radioactive waste is a pressing issue in Japan, and ongoing studies have been conducted on the feasibility of disposal projects from a scientific perspective. The country's planned disposal methods include encasing trans-uranium (TRU) and other high-level radioactive waste in facilities built under stable bedrock at least 300 m below the ground surface. This technique is referred to as geological disposal; it involves the use of a system comprised of both natural and engineered barriers. The system is expected to retard contact between the groundwater and the radionuclides and to slow the migration of the radionuclides into the biosphere even if the groundwater becomes contaminated (JAEA, 2000).

Fig. 1 shows a conceptual model of a geological disposal facility for TRU waste in Japan. The facility has engineered barriers, including cementitious types to reduce diffusion and bentonite types to minimize hydraulic conductivity (FEPC and JAEA, 2005).

An engineered bentonite barrier is a compacted soil mixture of bentonite and silica sand. Its low hydraulic conductivity comes from montmorillonite (the principal mineral in bentonite clay), and therefore, depends on the type and content of the montmorillonite used.

The primary particles of montmorillonite have a sheet-like form, a permanent electric charge and a capacity for cation exchange. Various interlayer cations are adsorbed between the primary particles. Montmorillonite with Na interlayer cations is known as Na-montmorillonite, and bentonite whose principal mineral is Na-montmorillonite

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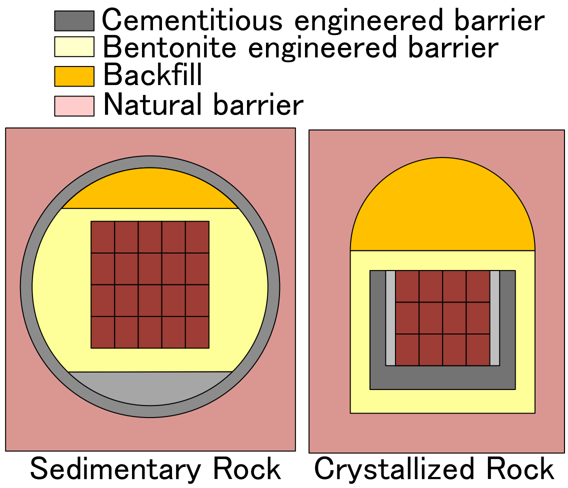

Fig. 1. Basic concept of TRU geological disposal (FEPC and JAEA, 2005).

is known as Na-bentonite. The hydraulic conductivity of montmorillonite depends on the type of cations, as its microstructure also differs with the interlayer cations. Na-montmorillonite exhibits lower hydraulic conductivity than other types of montmorillonite because it retains many water molecules among its primary particles (known as hydration or swelling), resulting in the absence of large voids under saturated conditions. Accordingly, Na-bentonite is used as a reference material for engineered bentonite barriers in Japan.

However, interlayer cations are readily displaced depending on the type and the ionic strength of the cations contained in the pore water due to cation exchange reactions. As a result, the use of Na-bentonite for building engineered barriers in geological disposal facilities may increase the hydraulic conductivity due to these cation exchange reactions depending on the subsequent compositional changes in the pore water. For example, after passing through an engineered cementitious barrier, the groundwater (cement leachate) becomes highly alkaline and Ca ion-rich. As cement leachate permeates bentonite, the interlayer cations in the montmorillonite (in this case, Na ions) are displaced by the Ca ions. This results in the alteration of the bentonite to Ca-bentonite, which swells less than Na-bentonite. Thus, large voids can be expected in Ca-bentonite even under saturated conditions unless the material is compacted to a high dry density, which could increase the hydraulic conductivity. Additionally, the reaction of highly alkaline pore water (such as cement leachate) with montmorillonite over an extended period may cause the montmorillonite to dissolve and create a non-swelling mineral. Similarly, the hydraulic conductivity of engineered bentonite barriers may increase due to the reduced montmorillonite content caused by such an alteration and the resultant increased presence of large voids.

Against such a background, an assessment to determine the feasibility of radioactive-waste geological disposal facilities with a lifespan of tens of thousands of years must involve a prediction of the temporal changes in the performance of the engineered barriers in consideration of the related chemical interaction. Therefore, this study was conducted to examine a hydrologic model for engineered barriers that enables an analysis of the microstructural changes caused by the chemical interaction.

A typical approach to the development of hydrologic models for engineered bentonite barriers involves the experimental determination of the relationship between the dry density and the hydraulic conductivity of the barrier material as well as the establishment of a fitting

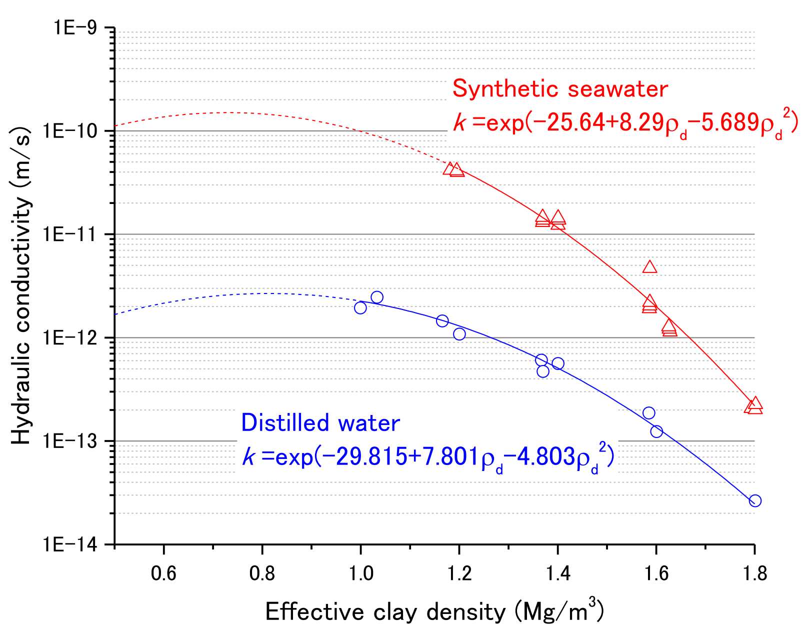

Fig. 2. Modeling based on fitting experiment results (adapted from Kikuchi et al., 2003).

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