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Tritium sorption behavior on the percolation of tritiated water into a soil packed bed

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HIGHLIGHTS

- We establish the permeation model of tritiated water in the soil layer.
- Saturated hydraulic conductivity of water in soil was gained by using the model.
- The isotope exchange reaction coefficient was good agreement with experimental data.

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ABSTRACT

Development of tritium transport model in natural soil is an important issue from a viewpoint of safety of fusion reactors. The spill of a large amount of tritiated water to the environment is a concern accident because huge tritiated water is handled in a fusion plant. In this work, a simple tritium transport model was proposed based on the tritium transport model in porous materials. The overall mass transfer coefficient representing isotope exchange reaction between tritiated water and structural water in soil particles was obtained by numerically analyzing the result of the percolation experiment of tritiated water into the soil packed bed. Saturated hydraulic conductivity in the natural soil packed bed was obtained to be 0.033 mm/s. By using this value, the overall mass transfer capacity coefficients representing the isotope exchange reaction between tritiated water percolating through the packed bed and overall structural water on soil particles was determined to be 6.0×10^{-4} 1/s. This value is much smaller than the mass transfer capacity coefficient between tritiated water vapor and water on concrete material and metals.

1. Introduction

To secure the tritium safety of the commercial plant of a nuclear fusion reactor, it is important to understand tritium behavior in not only fusion reactor materials but also construction materials and natural materials. A concern accident is the spill of a large amount of tritiated water to the environment. The detail study on tritium behavior in the environment and the impact analysis of safety has to be performed. The porous hydrophilic materials such as concrete and soil have a possibility of a large tritium sorption capacity by adsorption and isotope heat exchange reaction because of large surface area. There are some reports on the behavior of tritiated water and tritiated water vapor in concrete materials [1–4]. However studies on the behavior of tritiated water in soil has been hardly performed. In our previous work, tritiated water was poured in the natural soil packed bed and effluent tritium behavior was observed [5,6]. Tritium retention ratio (effluent *T*/input *T*) was slightly larger than water retention ratio (effluent water/input water). This indicates that tritium was trapped in the soil not only by water absorption but also by isotope exchange reaction between *T* in water and *H* in soil. In this work, tritium transport model in concrete materials, which was proposed by the present authors [8], were applied to the analysis of tritium sorption in the natural soil packed bed. Tritium behavior in the soil packed bed was simply assumed to consist of the water percolation by the gravity and the isotope exchange reaction. The overall mass transfer coefficient representing isotope exchange reaction in soil particle was obtained by the curve fitting method.

2. Theory

The percolation behavior of tritiated water in a soil packed bed can be considered by the present authors that the following transfer

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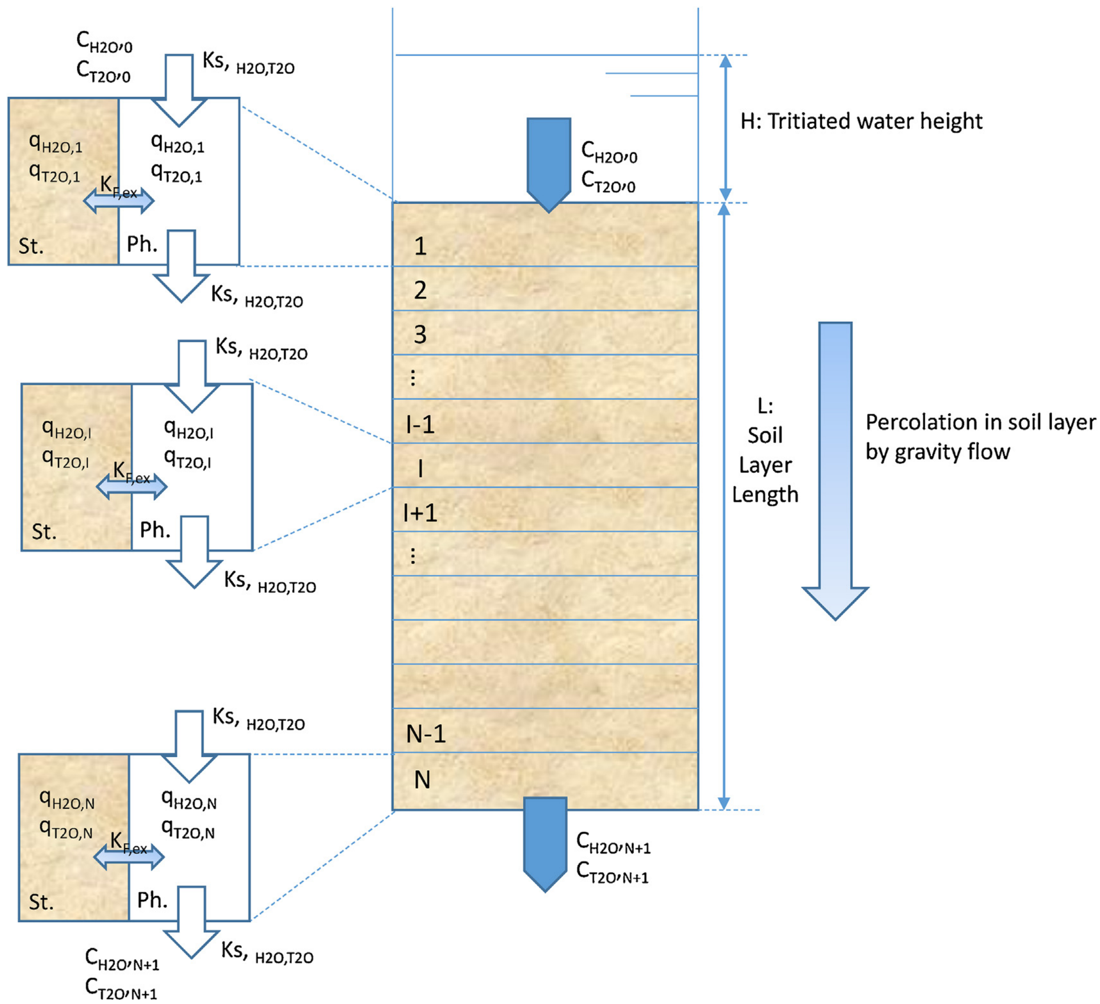

Fig. 1. Tritium transport model in a soil packed bed.

processes. It has been confirmed that similar model can be applied to the permeation behavior of tritiated water in concrete [1].

(a) Percolation of water and tritiated water from Darcy's law.
(b) Isotope exchange reaction between tritium in water and hydrogen in soil particles.

Diffusion rate of water in side particle and adsorption rate of water on the soil surface can be ignored when the soil packed bed is quickly filled with water.

The physically adsorbed water, chemically adsorbed water and structural water in various metal surface were defined by Nishikawa et al. [7]. In this study, chemically adsorbed water and structural water in soil particles are defined as overall structural water because the percolation experiment of tritiated water was carried out at room temperature in atmospheric condition. In this condition, chemically adsorbed water and structural water cannot be distinguished.

Fig. 1 shows the tritium transport model proposed in this study. Tritiated water percolates through the soil packed bed with decreasing tritium concentration by isotope exchange reaction and finally effluents to a tray. Per. and St. in Fig. 1 mean percolated water and structural water in the soil packed bed, respectively. The symbols shown in Fig. 1 were used in the mass balance equations described below.

The water flow in the saturated soil packed bed conforms to the Darcy's law. The analytical model of water flow in the percolation experiment is shown in Fig. 2. The following equations were shown in previous study [6] for processing listed above as (a).

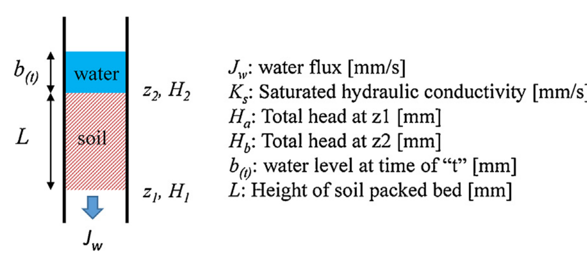

Fig. 2. Analytical model of water flow in the percolation experiment.

$$J_w = -K_s \frac{H_2 - H_1}{z_1 - z_2}, \tag{1}$$

and K_s is given as follows:

$$K_s = -\frac{L}{(t_1 - t_0)} \ln \frac{b_0 + L}{b_1 + L}, \tag{2}$$

where t is time (s), b_0 and b_1 are water level (mm) at time t_0 and time t_1. The following equation is derived from Eq. (2). The change of water level with time can be measured experimentally.

$$b_{(t)} = (b_0 + L)\exp\left(-\frac{K_s}{L}t\right) - L, \tag{3}$$

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