



Multi-target identification for emission parameters of building materials by unsteady concentration measurement in airtight micro-cell-type chamber

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ABSTRACT

The purpose of this study is to develop a concurrent determination method that can estimate multiple emission parameters, that is, the emission rate, initial concentration and effective diffusion coefficient D_c in building materials, by a single unsteady concentration measurement. This study focused on the time history of VOC concentration in the gas phase that occurred when the target building material was covered with an airtight micro-cell. The VOC concentration in the micro-cell gradually increased and finally reached an equilibrium concentration. Under the condition of uniform distribution of initial concentration, the profile of VOC concentration in the micro-cell was determined by the order of the D_c value. A chart of the time history of VOC concentration as a function of D_c and thickness of building materials was prepared in advance by numerical analysis and then D_c was estimated by overlapping the measurement result with this chart. A chart of emission rate as a function of D_c and building material thickness was also prepared and the determination procedure of the emission rate taking into account the consistency between the 20 L small chamber method with in- and out-flow and the micro-cell method under an airtight condition was proposed. The estimation results of D_c and emission rate by this method were reasonably consistent with the results of the conventional method.

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1. Introduction

Indoor air quality is one of the most important factors when designing a healthy indoor climate [1]. It has been reported that many building materials emit volatile organic compounds (VOCs), which cause sick building syndrome, for example, nose, eye or throat irritation, asthma and other chemical sensitivities [2]. In order to prevent indoor air pollution by VOC emitted from building materials, it is necessary to select suitable building materials with low VOC emissions, and to predict the VOC concentration level in rooms at the design stage. From this point of view, information on physical/chemical properties of building materials, such as VOC emission rate, effective diffusion coefficient and chemical content (initial concentration in building materials), is important for healthy indoor environmental design.

Assuming one-dimensional diffusion along the direction of material thickness, VOC emission rate E at steady state is denoted as shown in equation (1) using representative VOC concentration in building material C_m (mg/m³) and gas phase concentration of VOC in chamber C_a (mg/m³).

$$E = \frac{C_m - C_a}{R_m + R_a} \quad (1)$$

Here, R_m (s/m) indicates the resistance of mass transfer defined by both effective diffusion coefficient D_c and diffusion length scale, and R_a (s/m) is the resistance of convective mass transfer defined by flow characteristics over the surface of the building material. On the other hand, in a case of representative VOC concentration in chamber C_a as a perfect mixing concentration, C_a is defined as follows if the concentration in supply air is assumed to be zero.

$$C_a = \frac{EA}{Q} \quad (2)$$

Here, Q (m³/s) is supply airflow rate to the chamber and A (m²) represents the surface of the building material. Substitute equation (2) into equation (1) and the following result is obtained.

$$E = \frac{C_m}{R_m + R_a + \frac{A}{Q}} \quad (3)$$

In the case of large R_m and small R_a ($R_m \gg R_a$), the flow and turbulent structures over the surface of the building material do not

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affect the order of the emission rate and A/Q becomes only the control parameter of measurement to obtain data comparable with other measurements. This is called an inner diffusion-type building material. On the other hand, in a case of small R_m and relatively large R_a ($R_m < R_a$), the emission rate is strongly affected by not only airflow characteristics over the surface of the building material but also the value of A/Q . This is called an external diffusion (evaporative diffusion)-type material. In order to estimate the VOC emission characteristics for various building materials and to execute screening or labeling of building products, information on the initial concentration (C_0) and diffusion coefficient (D_c) as internal conditions of the building material, as well as emission rate (E) and mass transfer coefficient as external conditions, is required.

Several test chamber methods for measuring VOC emission rates from building materials have been proposed [3–7] and the measuring methods are standardized by ISO 16000-9, 10 and 11 and widely used to categorize and label the emission characteristics of building materials [8–10].

On the other hand, in order to carry out a detailed numerical prediction for VOC concentration distribution in indoor air, more fundamental information, including effective diffusion coefficient and initial VOC concentration level, is required. Concerning the effective diffusion coefficient, D_c , twin chamber methods using CLIMPAQ or FLEC, the cup method and the mercury intrusion porosimetry test (MIP) method are usually used for estimation. Haghighat et al. undertook a comprehensive review of the measurement of diffusion coefficients of VOCs for various building materials [11]. In his review article, the twin chamber method using CLIMPAQ [12,13], the cup method [14,15] and the MIP method [16,17] were reviewed and a comparison of these methods was presented. As for the twin chamber methods using FLEC, Meiningerhaus and Uhde reported comprehensive diffusion studies of VOC mixtures in a building material [18]. For the MIP method, Xiong et al. proposed a new procedure to predict the diffusion coefficient [19].

Chemical and physical parameters that govern VOC emission characteristics from building materials are wide-ranging and great efforts in terms of time and expense are required for the identification of these parameters [20].

The overarching goal of this study is to develop a simplified method for concurrent/simultaneous measurement that can estimate the emission rate E , initial concentration C_0 and effective diffusion coefficient D_c by a single unsteady concentration measurement in a chamber. In particular in this study, we demonstrate the estimation procedure using an airtight micro-cell-type chamber and compare the results of emission rate and effective diffusion coefficient estimated by this proposed method with those of conventional methods.

2. Proposed method

The focus of the experiments was on the time history of VOC concentration in the chamber that occurs when a target building material is covered with an airtight chamber (we call this a micro-

cell-type chamber in this paper). The VOC concentration in the airtight micro-cell-type chamber gradually increases owing to emission from the surface of the building material, and finally reaches an equilibrium concentration. In other words, the VOC emission rate from building materials gradually decreases toward zero. Under the condition of a uniform distribution of initial VOC concentration in the building material, the profile of the time history of gas phase VOC concentration in the micro-cell-type chamber, which is normalized by initial concentration in building materials, is determined by only the order of the effective diffusion coefficient. When a diagram chart of the time history of VOC concentration as a function of effective diffusion coefficient and thickness of building materials is prepared by numerical analysis in advance, emission rate, initial concentration and effective diffusion coefficient can be evaluated by overlapping the measurement result with this chart. This proposed method estimates VOC emission rate and effective diffusion coefficient using both numerical analysis and continuous unsteady concentration measurement in the micro-cell-type chamber until it reaches equilibrium. Subsequently, the initial concentration in the building material is also obtained from the equilibrium concentration value.

Because the emission rate from building materials in the micro-cell-type chamber gradually changes over time until an equilibrium concentration is reached, we propose two types of procedures for determining the representative emission rate: (i) the emission rate when the concentration in the micro-cell-type chamber reaches the guideline value (e.g. 0.4 mg/m³ for TVOC, 0.1 mg/m³ for formaldehyde) as a simplified method, and (ii) the emission rate when the ratio of the concentration in the micro-cell C_{ref} to the surface concentration in the building materials C_s becomes a certain value (e.g. $C_{ref}/C_s = 0.24$), which are determined as representative values in accordance with the boundary condition and consistency with other emission tests.

In this way, the proposed method enables estimation of the emission rate E , effective diffusion coefficient D_c and initial concentration C_0 in building materials with a single unsteady concentration measurement. As the prerequisite condition of this method, uniform initial concentration distribution in building material is assumed.

2.1. Outline of numerical analysis for preparing D_c diagram chart

Fig. 1 depicts the outline of the measurement system and the external appearance of the micro-cell-type chamber. The numerical analysis is carried out in one dimension, since the micro-cell is roughly rectangular in shape (100 mm × 550 mm × 600 mm height) and one-dimensional diffusion from the surface of the building material to the inner ceiling of the micro-cell-type chamber can be assumed at the central portion. The governing equations are as follows.

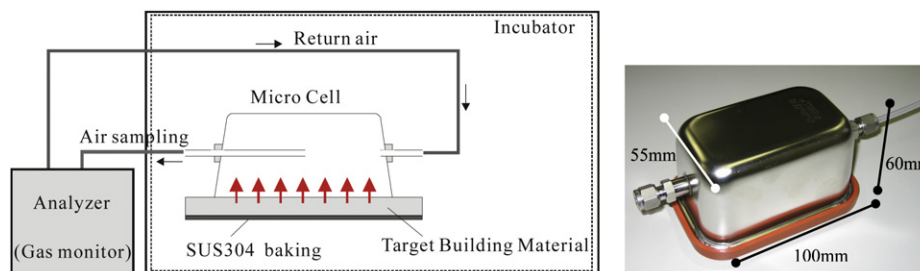


Fig. 1. Outline of measurement system for proposed method.

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