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Influence of sorption area ratio and test method on formaldehyde reduction performance for sorptive building materials

Hoon Kim [a,*], Shin-ichi Tanabe [b]

[a] National Institute of Public Health, Department of Healthy Building and Housing, Saitama 351-0197, Japan
[b] Waseda University, Faculty of Science and Engineering, Department of Architecture, Tokyo 169-8555, Japan

HIGHLIGHTS

- Reduction tests were conducted with changes in sorption area ratios.
- CCSM always showed higher performance values than EMM in sorption flux $F_{s.}$
- The smaller sorption area ratio brought more advantages to the F_s values.
- HBF compensation narrowed the disparities between EMM and CCSM in F_s.
- F_s values were determined depending on the ratios of sorption area.

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ABSTRACT

Sorptive materials can be used to improve the air quality by adsorbing harmful chemicals and other pollutants in indoor air. This study aims to (1) investigate the differences in the reduction performance values with changes in surface area ratios of sorptive materials for the two test methods (constant concentration supplying method and emission material method, hereinafter CCSM and EMM); (2) discuss whether the sorption flux "F_s" and equivalent ventilation rate "Q_{eq}", which are two ways of representing the results, can accurately represent the reduction performance; and (3) suggest a method for compensating for disparities between the two test methods.

Under the standard sorption area condition, CCSM yielded F_s with higher performance than EMM. The evaluation using F_s gave more advantage to a smaller sorption area condition, and CCSM was less influenced by the area than EMM. Changes in the area ratios resulted in changes in F_s, but Q_{eq} was less affected. However, for an identical area ratio condition, F_s resulted in steady values, while Q_{eq} fluctuated owing to subtle changes in chamber concentrations. Compensation using the HBF (Hoetjer–Berge–Fujii) equation could improve EMM performance value and thus reduce the disparity between the two methods.

1. Introduction

The most effective means to improve indoor air quality are emission source control and appropriate ventilation; in addition, a sorptive material can be used to further improve the air quality. Sorptive building materials, which have sorptive abilities and can reduce the chemicals in indoor air, have been developed and used to make favorable indoor air environment. An application of sorptive materials that would be effective in reducing the concentration of harmful chemicals can also be used for eliminating annoyance such as ETS (environmental tobacco smoke) and odor.

The Japanese Guideline related with sick house syndrome assigned 13 chemicals including formaldehyde (HCHO) as indoor air pollutants. HCHO is human carcinogenic and detected widely and frequently indoors in Japan. The guideline value for HCHO employed frequently in many countries including Japan is 100 μg/m^3 which is the odor threshold, and implies that it will not have an influence on the health even if healthy people live within this guideline or less level throughout life.

HCHO is a colorless and irritating gas and the short-term exposure at levels exceeding 0.1 ppm (=125 μg/m^3) can cause eye, nose, throat irritation and nausea as well. High concentrations may trigger severe allergic reactions such as asthma. Excessively high or long-term exposure is associated with certain types of cancer, and the International Agency for Research on Cancer (IARC) and the National Toxicology Program classified it as a human carcinogen in 2006 and 2011 [1].

ISO 16000-23(2009) [2] was established to estimate the formaldehyde reduction performance of sorptive materials. JIS A 1905

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* Corresponding author. Tel.: +81 48 458 6250; fax: +81 48 458 6253.
E-mail address: kimhoon@niph.go.jp (H. Kim).

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(for HCHO) [3,4], which formed the basis for ISO 16000-23, was also established from the requirement for a test method for HCHO reduction performance in Japan. JIS A 1905, however, originally described the two methods, namely, part 1: Measurement of adsorption flux when supplying a constant concentration of formaldehyde (CCSM) [3], and part 2: Measurement of the capability for suppressing formaldehyde emission (Authors abbreviated to EMM since this method uses an HCHO emission material) [4].

EMM might have the advantage as a simple and easy test method although it was excluded from ISO16000-23. It is curious that the two test methods may yield different results for the same material, and previous studies [5,6] did not provide the correlation between both methods. Further, in different countries, different n/L (area specific air flow rate, [$m^3/(m^2\ h)$]) values are used for chamber tests, and it can lead to different result values for the same test method and material.

Moreover, ISO 16000-23 prescribes a more limited mass transfer coefficient (airflow velocity) [7] on a specimen surface than ISO 16000-9 "emission chamber test method," [8] which was established to evaluate the emission rate from building materials. This difference led our research group to develop the airflow control unit [9,10] in order to control the mass transfer coefficient and evaluate the reduction performance of sorptive building materials with a small (20 L) chamber (see Fig. 1) [11] most frequently used in Japan and Korea.

This study focused on the differences observed in the reduction performance values when surface area ratios (i.e. loading factors) of sorptive materials were changed for the two different test methods. The test results can be presented in terms of sorption flux "F_s" [$\mu g/(m^2\ h)$] and equivalent ventilation rate "Q_{eq}" [$m^3/(m^2\ h)$]. F_s indicates the intrinsic performance of removing a target substance and represents the mass sorbed per unit time over a unit area. Q_{eq} denotes an virtual ventilation effect obtained from the sorptive material in a room or chamber. Discussions will follow whether the two terminologies can present the reduction performance correctly under each test condition and method. Finally, a method of compensating for the disparities in the results between the two test methods is suggested.

Some of the terms used in this study are defined as follows:

- Sorptive material: the building material that reduces the pollutants in the air through a physical sorption process or a chemical reaction.
- Emission material: the building material releasing chemical pollutants such as HCHO; a raw medium-density fiberboard (MDF) was used in this study.
- Composite material: the material containing both emission material and sorptive material to test the reduction performance compliance with EMM.
- A (surface area of test specimen): the exposed surface area of the test specimen. In Japan, $A = 0.043\ m^2$ ($= 0.147\ m \times 0.147\ m \times 2$ surfaces) is usually used as the standard surface area (A_{std}) for emission testing on building materials and in this study $A_{std} \times 1/3$, $A_{std} \times 1/2$ and $A_{std} \times 2/3$ were applied for reduction performance tests.
- L (loading factor): the ratio of the exposed surface area of the test specimen over the free test chamber volume. In Japan $L = 2.2\ m^2/m^3$ is frequently used and in this study the standard loading factor $L_{std} = 2.2\ m^2/m^3$
- n (air exchange rate): air exchange rate per hour at the chamber [h^{-1}, ACH]
- n/L (area specific air flow rate, $= Q/A$): the ratio between the air exchange rate and product loading factor. $n/L = Q/A$, which is the ratio of the supply air flow rate to the area of the test specimen [$m^3/(m^2\ h)$].

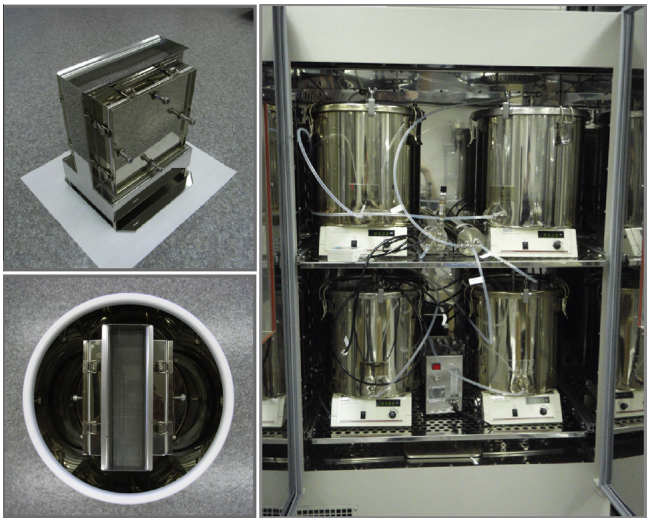

Fig. 1. Air flow control unit and 20 L small chamber system.

2. Material and methods

The chamber method, one of the dynamic headspace methods, was designed to resemble the conditions of an actual room; this method is used to simulate and test emission rates of chemicals from building materials as supplying clean air. It would certify high levels of accuracy and repeatability in emission tests. In reference to ISO 16000-9, many types of chambers have been designed and developed in many countries of the world. The Japanese type small chamber has 20 L volume and cylindrical shape and is made of stainless steel (SUS304); such chambers are frequently used in Japan and Korea (Fig. 1).

The mass transfer coefficient (i.e. airflow velocity) can be controlled with a fan-installed airflow control unit and magnetic stirrer; in this study it was applied that an air velocity of 0.14 m/s at a point 10 mm away from the specimen surface. The target substance was HCHO, which was supplied from cured raw MDF for EMM and from HCHO gas diluted by mixing equipment for CCSM. The tested sorptive materials were expected that could show a quick response as a chemisorption agent which targeted on HCHO. The sorptive material DM (decontaminating matter) was an amine-series catching agent liquid, and TG(treated gypsum) was a 9.5-mm-thick gypsum board to which the liquid agent was added. DM was investigated in Test 1 and Test 3, and TG in Test 2 and Test 4.

For the chemisorption, a performance decrement (saturation) depends on the total amount of the chemical agent reacting to the object substance. On the other hand, the physisorption can be explained with pore and adsorption area which occupied by substance molecules. Adsorption area varies with the kind of porous materials such as activated carbon, zeolite and diatomite. In general, the activated carbon which is the representative example of physisorption has around 1000 m^2/g in surface area and 1–100 nm in pore diameter. Linear, Langmuir, Freundlich and BET equations are frequently used for adsorption isotherm, and JIS is explaining the relation between adsorption amount and supply gas concentration by using Langmuir equation through experiments.

Sorption capacity can be calculated using the supplied gas concentration, airflow rate and breakthrough time through breakthrough test. In practice, acceleration test is employed using high concentration of HCHO gas since it may demand a prolonged period in a practically low concentration and a breakthrough of 0.5% to the adjusted gas concentration indicates the sorption saturation. Several related examples could be found in Annex of ISO 16000-23 and JIS A 1905-1, and there 5000 $\mu g/m^3$ of HCHO concentration was applied.

However, the breakthrough test skipped this time since this study aimed to investigate the effect of area ratio on a reduction performance.

2.1. Reduction performance test with the emission material method (EMM)

Table 1 and Fig. 2 show the conditions of the chamber test for EMM. MDF cured over a long period of time has a stable HCHO emission rate, and in this study, MDF cured for more than two months was used as the HCHO emission source. The JIS standard for specific materials is defined by four grades with a labeling system based on the HCHO emission level from F☆ to F☆☆☆☆: F☆: more than 120 $\mu g/(m^2\ h)$, F☆☆: 20–120 $\mu g/(m^2\ h)$, F☆☆☆: 5–20 $\mu g/(m^2 \cdot h)$, and F☆☆☆☆: less than 5 $\mu g/(m^2\ h)$. Japanese Building Standards Act ordained that materials ranked with F☆☆☆☆ can be used indoors without restriction, and F☆☆☆ and F☆☆ can be used within only a given proportion to interior surface area, and F☆ shall not be used in indoor at all.