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MEASURING METHOD OF REDUCING EFFECT OF POLLUTANT CONCENTRATION WITH ABSORPTIVE BUILDING MATERIAL

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ABSTRACT

In this paper, measuring method of performance of passive adsorption building materials that are used for reducing pollutant concentration in a room is considered. The convective mass transfer characteristic has a great influence on its performance. In order to control the convective mass transfer precisely in the performance test, the authors have developed the Boundary Layer Type Small Test Chamber in which precise control of airflow along the test materials can be done. The equivalent ventilation rate (Q_{ads}) of adsorption performance is drawn as the new index that corresponds to the rate of convective mass transfer rate in the case of the adsorption surface concentration to be zero. To demonstrate the performance test, the adsorption test of the gypsum board that has the ability of decomposing HCHO within the board by the addition of some chemical materials is performed. The absorption rate of the gypsum board predicted by the CFD corresponds well with the experimental result.

INDEX TERMS

Boundary layer type Test Chamber, Passive absorptive material, Mass transfer

INTRODUCTION

The object of this study is to develop a method of analyzing and estimating in detail the indoor distribution characteristics and the conditions of the chemical substances using a general-purpose computer simulation (S.Murakami et al., 1998 and 2001). According to ASTM, ECA and similar standards, measurement of the emission rate for an internal diffusion controlling type building material is carried out with a perfect mixing type chamber (ASTM-D5116-90, 1990 and European Concerted Action, 1991). J. Zhang et al. (1996) and F. Haghight et al. (1998) have developed small chambers in which the airflow on the surface of the building material can be controlled, and measured the emission rates of chemical substances for several kinds of building materials. Based on these small chambers, Authors have developed a Boundary Layer Type Small Test Chamber in which precise control of the airflow

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at the boundary layer on the surface of a building material can be achieved (Qingyu Zhu et al., 2001). This paper gives an outline of this Boundary Layer Type Small Test Chamber and the performance test method for a passive adsorption material that can be used to reduce the pollutant concentration in a room using this chamber, and performance tests using the same chamber are described.

Evaluation of Adsorption Rates for Passive Adsorption Building Material

The performance of a passive adsorption building material is considered to be related to three points: the adsorption properties of the material (adsorption isotherm etc.), the diffusion characteristics and conditions inside the adsorption material, the convective mass transfer characteristics and conditions from the air to the surface of the adsorption material. The convective heat transfer coefficients in a room are generally of the order of 2 to 7 W/m^2K (6.1m/h to 20.9m/h for mass transfer coefficient according to the Lewis law), and so we would like to propose that the measurement of the adsorption rate for a passive adsorption material installed in a room should correspond to this condition.

The adsorption rate *ads* [mg/hm^2] is calculated from the concentration difference between the inlet and the outlet of the test chamber ($C_i - C_o$) [mg/m^3], the amount of ventilation in the test chamber Q_v [m^3/h], and the surface area of the test building material A [m^2].

$$ads = (C_i - C_o) \cdot Q_v / A \tag{1}$$

In clarifying the reduction of pollution in the room, if the adsorption rate of the passive adsorption material ads [mg/hm^2] can be expressed by converting it into the equivalent ventilation rate Q_{ads} [$(m^3/h)/m^2$] when clean air (pollutant concentration is zero) is introduced, it will allow the effect of ventilation and the effect of passive adsorption to be compared on the same scale.

$$A \cdot ads = (C_i - C_o) \cdot Q_v = (C_o - 0) \cdot Q_{ads} \cdot A \tag{2}$$

$$Q_{ads} = (C_i / C_o - 1) \cdot Q_v / A \tag{3}$$

The equivalent ventilation rate per unit area of building material Q_{ads} [$(m^3/h)/m^2$]](transport limited mass transfer coefficient) given in formula (2) indicates the mass transfer coefficient in the case where the concentration on the surface of the test building material is taken as zero and the reference concentration in the air is taken as C_o.

Measurement Method of the Boundary Layer Type Small Test Chamber

An outline of the measurement of the reduction of the HCHO concentration in a room due to a passive adsorption material (in this study, a formaldehyde HCHO absorbing and decomposing gypsum board) using the Boundary Layer Type Small Test Chamber will be given. The Boundary Layer Type Small Test Chamber that we have developed is shown in Figure 1.

The chamber is installed inside a thermostatic chamber. The area inside the inner chamber where the test building material can be placed is 0.5m×0.3m maximum. The average wind velocity over the building material can be controlled to be constant in the range 0 to 0.2 m/s by the speed of the fan. This paper gives the results of the experiments in which the average wind velocity was controlled to be 0.10m/s. This corresponds to a convective heat transfer coefficient of 5.2W/m^2K (mass transfer coefficient: 15.7m/h) on the surface where the test building material is placed (Qingyu Zhu et al., 2001).

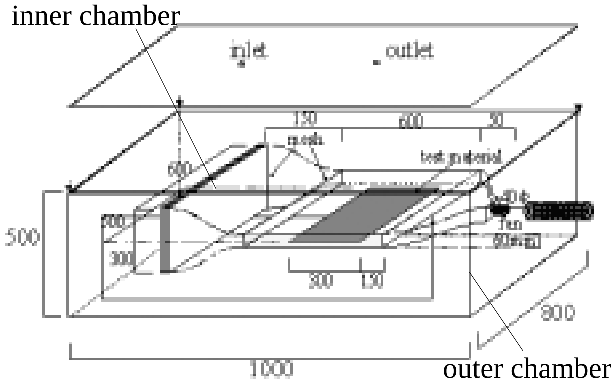


Figure 1. Boundary Layer Type Small Test Chamber

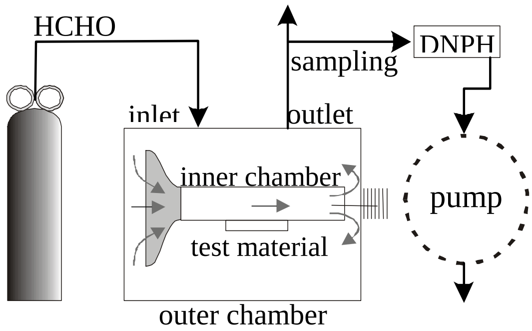


Figure 2. Measurement System

In the adsorption experiments, an HCHO standard gas adjusted to a fixed concentration is introduced into a chamber where a passive adsorption material is placed and the adsorption amount is measured from the concentration difference between in the inlet and outlet. In the measurement, the air inlet and outlet of the chamber is sampled by being adsorbed with a DNPH cartridge (0.3L/min., 10L or 15L), and chemical substances are quantitatively and qualitatively analyzed by HPLC. The lower limit of detection of HCHO is 1ppb in the experiment. The experimental conditions are shown in Table 1.

Table 1. Cases Analyzed

Case No.	Temperature [^{o}C]	HCHO Concentration at inlet[mg/m^3]	Relative humidity [%]
1	15	0.10	0
2	23	0.10	0
3	23	0.10	50
4	23	0.10	75
5	23	0.48	0
6	40	0.10	0

(Air changer rate 0.5 h^{-1}, U_{center}=0.10 [m/s])

Table 2. Conditions of CFD Analysis

Numerical model : Low Re k-ε model (Abe-Nagano model)	
Grid points (3D): 216,600	Space difference: QUICK(convection term)
inlet boundary	U_{in}=1.44m/s, l_{in}=1/7×L_f, k_{out}=3/2 (U_{in}×0.05)^2, ε_{in}=C_μ×$k_{in}^{3/2}$/l_{in} (L_f=(inlet diameter)=7mm)
outlet boundary	U_{out}=(mass flow conservation) k_{out}, ε_{out}= free slip
Fan in inner chamber	U_{fan}=2.69(m/s)(enforced value) k_{out}= 3/2(U_{fan}×0.05)^2, ε_{in}=C_μ×$k_{in}^{3/2}$/l_{in} (l_{in}= 1/7×L_f, L_f= (fan radius)=20mm)
Wall boundary	No-slip

Numerical Analysis of Flow field and Diffusion field

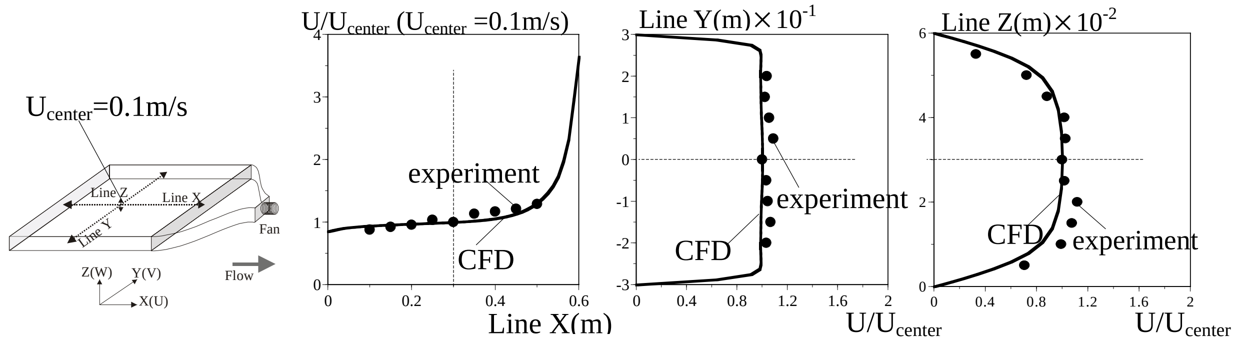
The analysis is performed while the air change rate to the outer chamber is fixed at 0.5 [h^{-1}], as for the experimental conditions. The cases analyzed of the flowfield are shown in Table 1. A 3D analysis of the flow field is performed based on a low Reynolds number type k-ε model (Abe-Nagano model) (Nagano et al., 1994). Analytical conditions are shown in Table 2.

After the analysis of the flow field, boundary conditions for adsorption are given at the surface where the test building material is placed and then the diffusion and mass adsorption are analyzed. Because the saturated absorption amount C_{ad} is extremely large in this case, the concentration C_s on the surface of the building material is set as zero, corresponding to the assumption that the Henry coefficient k_h in the Henry type adsorption isothermal formula ($C_{ad}=K_h \times C$) is infinity, and the diffusion field (transport in the air) is analyzed by the steady method. The mass diffusion coefficient for HCHO in the air (D_a) is taken as 1.46×10^{-5} m²/s at 15 °C, 1.53×10^{-5} m²/s at 23 °C, and 1.69×10^{-5} m²/s at 40°C (the Chemical Engineering Society, 1968).

Results of the Flow field Analysis

The average wind velocity U_{center}=0.1 m/s at the central position in the measurement barrel in the inner chamber (Figure 1) is made non-dimensional as the representative wind velocity and is shown in Figure 3 together with the results of the wind velocity measurements. As shown in Figure 3, in the inner chamber, the wind velocity in the center of the measurement barrel increases as the boundary layer grows with distance downstream where the fan is installed. When the results of numerical analyses are compared with the experimental results, they agree with each other with sufficient accuracy for the flow field (Fig.3(2,3)). An extremely uniform (two-dimensional) distribution was obtained for the distribution of the average wind velocity in the Y direction inside the measurement barrel (Fig.3(3)).

The existence of scatter in the results for wind velocity measurements from the experiments near the floor are considered to be caused by measurement errors due to the blocking effect of the thermostat anemometer used for measurement and other factors. The velocity vectors by the CFD in the chamber are shown in Figure 4.



(1) Measurement Line (2) U(x) in Line X (3) U(y) in Line Y (4) U(z) in Line Z

Figure 3. Velocity distribution in inner chamber (comparison of experiment and CFD)

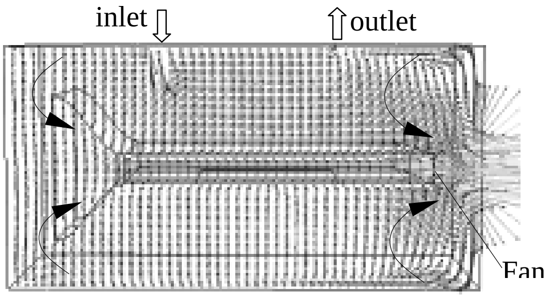


Figure 4. Velocity vectors (cross section X-Z)

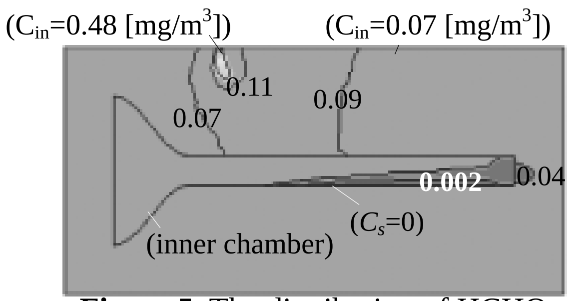


Figure 5. The distribution of HCHO (cross section X-Z, [mg/m³])

Results of CFD Analysis on Diffusion Field and Mass Transfer Coefficient Analysis

The results of the CFD analysis of the diffusion field for case 5 corresponding to experiments (the distribution of concentrations inside the chamber) are shown in Figure 5. As shown in Figure 5, a boundary layer with a low concentration is growing near the surface of the building material downstream of the measurement barrel in the inner chamber, and the average concentration outside the boundary layer is approximately 0.07 mg/m^3 (outlet concentration). Table 3 shows the experimental results and the results of the CFD analysis in the steady state on the HCHO adsorption rate and the mass transfer coefficient for the passive adsorption building material, HCHO adsorbing gypsum board.

When the relative humidity is 0% and the HCHO concentration at the air inlet in the experiment is controlled at 0.1 mg/m^3 (0.08 ppm), the HCHO concentrations at the air outlet in the experiment become 0.01 mg/m^3 at 15 ^{o}C, 0.018 mg/m^3 at 23 ^{o}C and 0.01 mg/m^3 at 40 ^{o}C, the average HCHO adsorption rates of the test building material are calculated as 0.11 mg/m^{2}h at 15^{o}C, 0.11 mg/m^{2}h at 23 ^{o}C and 0.12 mg/m^{2}h at 40^{o}C, and the average HCHO adsorption rate for the test building material is almost constant and unaffected by temperature. The equivalent ventilation rates Q_{ads} (transport limited mass transfer coefficients) are 12.0 [(m^3/h)/(m^2)] at 15 ^{o}C, 6.11 [(m^3/h)/(m^2)] at 23 ^{o}C and 12.0 [(m^3/h)/(m^2)] at 40 ^{o}C. At 23 ^{o}C, the average HCHO adsorption rate of the test building material is constant at 0.11 mg/m^{2}h and is unaffected by the relative humidity, and the equivalent ventilation rates Q_{ads} are almost constant as 6.11 [(m^3/h)/(m^2)] at 0% relative humidity, 5.50 [(m^3/h)/(m^2)] at 50% and 5.80 [(m^3/h)/(m^2)] at 75%. Because the reference concentration in the air is supposed to be the concentration at the air outlet of the chamber C_o, the equivalent ventilation rate Q_{ads} that are calculated from formula (3) are heavily dependent on the reference concentration in the air C_o.

Table 3. Predicted and experimental results for Average Adsorption Rate and Average Mass Transfer Coefficient

Temperature	15^{o}C		23^{o}C						40^{o}C	
	CFD	Exp.	CFD	Exp.			CFD	Exp.	CFD	Exp.
Relative humidity [%]	0	0	0	0	50	75	0	0	0	0
intlet concentration [mg/m^3]	0.10	0.10	0.10	0.10	0.10	0.10	0.48	0.48	0.10	0.10
outlet concentration [mg/m^3] $\times 10^{-1}$	0.16	0.1	0.15	0.18	0.20	0.19	0.70	1.0	0.15	0.10
Average adsorption rate [mg/(m^{2}h)]	0.11	0.12	0.11	0.11	0.11	0.11	0.55	0.51	0.11	0.12
Average mass transfer coefficient [m/h]	6.88	12.0	7.33	6.11	5.50	5.80	7.86	5.10	7.33	12.0
The equivalent ventilation rate [(m^3/ h)/(m^2)]	6.88	12.0	7.33	6.11	5.50	5.80	7.86	5.10	7.33	12.0

CONCLUSIONS

(1) The performance test on the passive adsorption building material needs conditions in

which the airflow characteristics and conditions on the surface boundary layer of the test material are controlled. The characteristics and conditions are evaluated by the convective heat transfer coefficient. The analysis in this paper corresponds to the measurement conditions of 5.2 w/m^{2}K for the convective heat transfer coefficient (15.7 m/h for mass transfer coefficient).
(2) The equivalent ventilation rate Q_{ads} from the adsorption rate is used as an evaluation index with which to compare the reduction effect of pollution by adsorption directly with the ventilation. This corresponds to the mass transfer coefficient when the concentration on the surface of the absorption material was taken as zero.
(3) The adsorption performance of the adsorption building material was confirmed by conducting an adsorption performance test with an HCHO absorbing and decomposing gypsum board using a boundary layer type chamber where the airflow characteristics and conditions are easily controlled, and the equivalent ventilation rates Q_{ads} were obtained. The average adsorption rate of the HCHO absorbing gypsum board by CFD analysis corresponds well with the experiment results.

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