

## EFFECT OF REDUCING INDOOR ACETALDEHYDE CONCENTRATION OF SORPTIVE BUILDING MATERIAL

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### ABSTRACT

In order to decrease the concentration of indoor pollutants, sorptive building materials have been used. Giving the construction materials themselves the property of reducing the concentration of indoor pollutants has been reported as simple and effective, because it is highly effective without requiring the operation of special equipment. Concentration reduction performance of indoor air pollutants by sorptive building materials depend significantly on air exchange rate, loading factor, mass transfer coefficients etc. In this study, we examined how the concentration of chemical compounds, temperature, and relative humidity influenced the sorptive performance for acetaldehyde, which was well reproduced experimentally with the computational fluid dynamics (CFD) simulations. The experiments and CFD analysis show that sorptive building materials have a fairly strong effect of decreasing acetaldehyde concentrations in rooms, and that this effect can be expected in practical use.

### INTRODUCTION

The use of sorptive building materials as room surfaces seems to contribute significantly to improving the indoor air quality (IAQ), because this method does not require the use of any equipment. (Ataka Y et al., 2004, Tiffonnet A et al., 2002, Van O et al., 1995, JIS A 1905-1, 2007 and JIS A 1905-2, 2007) We developed a formaldehyde sorptive building material, proposed and commercially applied the method of evaluating the capability of building materials for reducing the formaldehyde concentration present in room air. (Seo J et al., 2010). We also developed an activated charcoal mixed gypsum board for reducing the concentration of volatile organic compounds (VOCs), e.g., toluene, etc., thus to examine the effect on reducing the concentration of VOCs in room air. (Seo J et al., 2009). Meanwhile, acetaldehyde, one of aldehydes, is

classified as an indoor air pollutant requiring caution for health although the level is lowered in the guideline for indoor concentration recommended by World Health Organization (WHO).

In this study, the effect of reducing acetaldehyde present in room air was reviewed by using a gypsum board, as a sorptive building material, in which an absorbent was mixed which chemically reacts with aldehydes. Effects of temperature, relative humidity, and acetaldehyde concentration on the performance of sorptive building material were validated using CFD analysis.

### METHODS

Performance tests on the effectiveness of sorptive building materials in reducing acetaldehyde were conducted using a 400-liter small test chamber, Boundary Layer-Type Small Test Chamber (BLTSTC) as shown in Figure 1. The BLTSTC has two chambers (the inner chamber and the outer chamber) and is made out of stainless steel (SUS 304) with an electrolytic ground surface. To control the mass transfer coefficient, the fan is incorporated into the outer chamber. This paper gives the results of the experiments in which the average wind velocity was controlled to be 0.10 m/s. This

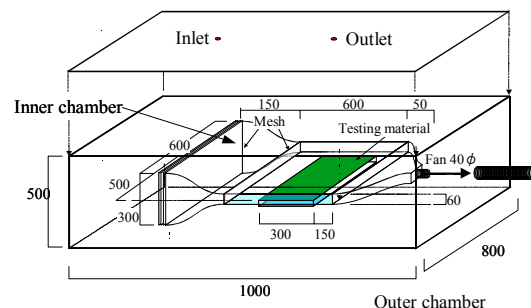


Figure 1 Boundary Layer-Type Small Test Chamber

corresponds to water vapor mass transfer coefficient of 15.5 m/h. The selected experiment sample was an aldehyde-based sorptive building material and the pollutant to be examined was acetaldehyde. Experiments were controlled to be at 18°C, 23°C and 28°C, the RH of 0, 50, 75 %, and the air exchange rate of 0.50 h<sup>-1</sup> (Seo J et al., 2010 and Zhu Q et al., 2001). The acetaldehyde concentration supplied to the chamber was 100 and 300 µg/m<sup>3</sup>. Air samples were taken from the supply and exhaust of the test chamber with a DNPH cartridge (0.15 L/min, 5 L), and these chemical substances were quantitatively and qualitatively analyzed by HPLC (Ataka Y et al., 2004 and Seo J et al., 2010).

The analytical conditions of the chamber are shown in Table 1. The flow field was analyzed by three-dimension analysis based on a low Reynolds number type *k-ε* model, Abe-Nagano model. (Abe K et al., 1994) The analysis was carried out under an air exchange rate of 0.5 h<sup>-1</sup> as the experimental condition. After analysis of the flow field, the boundary conditions for sorption were given at the surface where the test building material was placed, and then the diffusion and mass sorption were analyzed. The surface concentration of the sorptive building material was set as zero because the saturated sorption amount  $C_{ad}$  of the sorptive building material was extremely large, corresponding to the assumption that the Henry coefficient  $K_h$  in the Henry type sorption isothermal formula ( $C_{ad} = K_h \times C$ ) is infinity. The transportation of toluene is expressed and analyzed by Equation (1).

$$\frac{\partial \bar{C}_1}{\partial t} + \frac{\partial \bar{U}_j \bar{C}_1}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \left( D_o + \frac{\nu_t}{\sigma_t} \right) \cdot \frac{\partial \bar{C}_1}{\partial x_j} \right) \quad (1)$$

Overbar: ensemble-mean value

$C_1$  : acetaldehyde concentration at a point in space [µg/m<sup>3</sup>]

$D_o$  : molecular diffusion coefficient of acetaldehyde [m<sup>2</sup>/s]

$\bar{U}_j$  : ensemble-mean velocity [m/s]

$\nu_t$  : turbulent eddy viscosity [m<sup>2</sup>/s]

$\sigma_t$  : turbulent Schmidt number [ - ]

The diffusion field is analyzed by the steady method. The mass diffusion coefficient  $D_o$  for acetaldehyde in the air was taken as 11.5×10<sup>-6</sup> m<sup>2</sup>/s at 18 °C, 11.8×10<sup>-6</sup> m<sup>2</sup>/s at 23 °C, 12.2×10<sup>-6</sup> m<sup>2</sup>/s at 28 °C, respectively. (The Society of Chemical Engineers, Japan, 1999)

Table 1 Conditions for CFD analysis

Numerical model	Low Reynolds <i>k-ε</i> model (Abe-Nagano model)
Grid system (3D)	Grid system 216,000 cells
Supply boundary	$U_{in} = 1.44$ m/s $k_{in} = 3/2 \cdot (U_{in} \times 0.05)^2$ , $\epsilon_{in} = C_\mu \cdot k_{in}^{3/2} / L_{in}$ $L_{in} = 1/7 L_o, L_o = 7.0 \times 10^{-4}$ m
Exhaust boundary	$U_{out} =$ (mass flow conservation), $k_{out}, \epsilon_{out} =$ free slip
Wall boundary	No-slip
Fan in inner chamber	$U_{fan} = 2.69$ m/s (enforced value) $k_{out} = 3/2 (U_{fan} \times 0.05)^2$ , $\epsilon_{in} = C_\mu \cdot k_{in}^{3/2} / L_{in}$ $L_{in} = 1/7 L_o, L_o = 20$ mm (fan radius)

## RESULTS

Table 2 and Figures 2 to 4 show the result of the experiment and CFD analysis. The sorptive building material used in the experiment exhibited the effect of reducing acetaldehyde concentration in a given condition, and did not re-emit absorbed acetaldehyde in the re-emission test of acetaldehyde. Figure 2 shows changes in acetaldehyde concentration supplied during the experiment at 23 °C and RH 0 % and at the chamber exhaust after acetaldehyde was absorbed by the sorptive building material. Acetaldehyde concentration at the supply exhibited some changes, but the concentration at the exhaust was kept almost constant to prove the effect of reducing acetaldehyde concentration. For the cases 1, 2 and 6, in which the acetaldehyde concentration was set to 100 µg/m<sup>3</sup> and the temperature in the chamber was controlled to be at 18 °C, 23 °C and 28 °C, the sorption flux for acetaldehyde of the sorptive building material was kept at approximately 70 µg/m<sup>2</sup>h, so that the effect of reducing acetaldehyde concentration of the sorptive building material was kept uniform without regard to ambient temperature. In cases 2, 3 and 4 in which temperature was controlled to be at 23 °C and relative humidity changed, the equivalent ventilation rate was kept constantly at 1.0~1.6 m<sup>3</sup>/hm<sup>2</sup>, to exhibit that the effect of reducing acetaldehyde concentration of the sorptive building material used in the experiment was not significantly affected by relative humidity. The wind velocity distribution in the entire chamber was very constant, and the area close to the fan particularly showed constant air flow and a boundary layer was formed on the surface of the sorptive

Table 2 Sorption effectiveness of building materials

Case	1		2		3	4	5	6	
CFD / Exp.	CFD	Exp.	CFD	Exp.	Exp.	Exp.	CFD	CFD	Exp.
Temp. [°C]	18		23		23	23	23	28	
Relative humidity [%]	0	0	0	0	50	75	0	0	0
Supply conc. [ $\mu\text{g}/\text{m}^3$ ]	100	100	100	100	100	100	300	100	100
Exhaust conc. [ $\mu\text{g}/\text{m}^3$ ]	19	48	18	46	53	59	55	18	58
Sorption flux [ $\mu\text{g}/\text{m}^2\text{h}$ ]	109	74	109	73	66	59	327	109	64
Equivalent ventilation rate [ $\text{m}^3/\text{hm}^2$ ]	5.9	1.5	6.0	1.6	1.2	1.0	6.0	6.1	1.1

building material in the inner chamber. In the BLTSTC, the wind velocity in the center of the measurement barrel in the inner chamber increases as the boundary layer grows with distance downstream where the fan is installed (Seo J et al., 2011).

In the 3 different temperature conditions by means of CFD analysis, sorption flux was approximately  $109 \mu\text{g}/\text{m}^2\text{h}$  and the equivalent ventilation rate was constantly at  $5.9\sim 6.1 \text{ m}^3/\text{hm}^2$ , to prove the effect of reducing acetaldehyde concentration of the sorptive building material in CFD analysis. The sorption flux and equivalent ventilation rate was kept constant although the acetaldehyde concentration at the supply increased to  $300 \mu\text{g}/\text{m}^3$ , to demonstrate matching to the experiment result. As shown in Figure 4, a boundary layer with a low concentration develops near the surface of the building material downstream of the measurement barrel in the inner chamber, and the acetaldehyde concentration at the exhaust was  $55 \mu\text{g}/\text{m}^3$  in case 5. The Henry type sorption isothermal formula was used as a sorptive model on the surface of sorptive building material in the CFD analysis.

Applying the Henry type sorption isothermal formula increases the amount of acetaldehyde-saturated absorption of building material. It is considered that the capability contributed to different result of CFD analysis from the experiment result. It is necessary to review absorption models, considering chemical reaction of sorptive building materials.

## CONCLUSION

In this study, the effect of reducing acetaldehyde concentration of pollutant-sorptive building materials was identified through the experiment and CFD analysis, and reviewed the effect of temperature, relative humidity and acetaldehyde concentration on the performance of sorptive building materials. It was identified that the building material for absorbing pollutants in room air us contributes to keeping the effect of reducing acetaldehyde concentration constant without regard to changes in temperature,

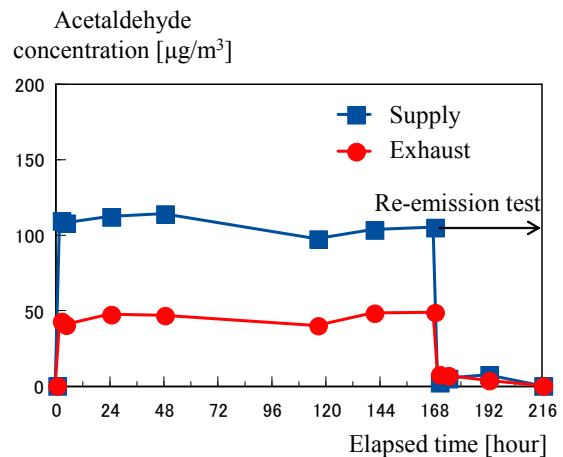


Figure 2 Acetaldehyde conc. at supply and exhaust for sorptive building materials (23 °C, RH 0 %): Exp.

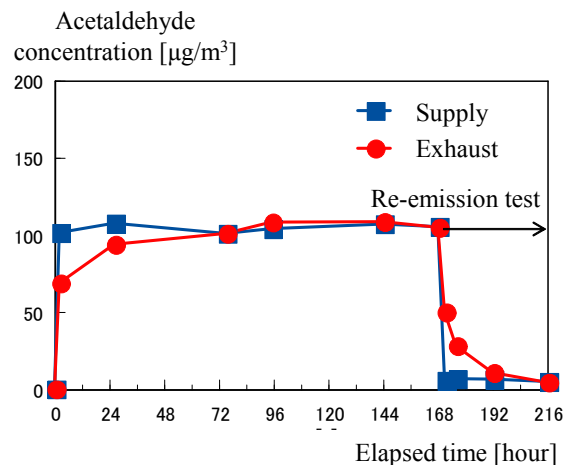


Figure 3 Acetaldehyde conc. at supply and exhaust for general building materials: Exp.

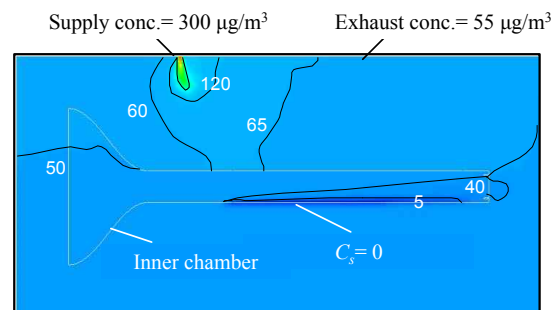


Figure 4 Distribution of acetaldehyde conc. in chamber (Case5) [ $\mu\text{g}/\text{m}^3$ ]: CFD

relative humidity and acetaldehyde concentration. It is needed to further study the sorptive models to be applied to CFD analysis for accurately verifying the experiment. The sorptive building material in an actual building to review the effect of improving room air quality by reducing pollutants in room air.

The experiments show that sorptive building materials have a fairly strong effect by decreasing acetaldehyde concentrations in rooms, and that this effect can be expected in practical use.

### ACKNOWLEDGEMENTS

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