

THE INFLUENCE ON INDOOR AIR QUALITY OF ADSORPTION AND DESORPTION OF ORGANIC COMPOUNDS ON MATERIALS

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ABSTRACT

A simple test chamber method to quantify adsorption and desorption of organic compounds on material surfaces is described. Tests were performed with toluene and α -pinene in concentrations of 5 mg/m^3 by means of photoacoustic spectroscopy. The measurements showed distinct adsorption on and desorption from wool carpet, nylon carpet and a wooden bookshelf with books and papers. Window glass and ceiling sheets of rock-wool showed no adsorption of the two compounds. A model, based on a linear Langmuir adsorption isotherm, appears adequate to describe the results. The rate constants, calculated on the basis of this model, can be applied to evaluate and model the influence of adsorption and desorption on indoor air quality. The results are used to predict diurnal concentration variations in an indoor environment during different ventilation strategies.

INTRODUCTION

Recent investigations have shown that the sink effect of material surfaces affects the concentrations of indoor air pollutants (1-3). In the Danish Town Hall Study (4), it was shown that the presence of materials with fleecy surfaces is closely related to the occurrence of indoor climate problems.

In a previous study it was indicated that adsorption and desorption of indoor compounds on ordinary building materials can be of such magnitude that they can have a crucial influence on the indoor air quality (2). However, concentration values may vary considerably when different test methods are used.

The objective of this paper is to describe a simple test chamber method to quantify adsorption and desorption of organic compounds on material surfaces and to predict diurnal concentration variations of organic compounds in an indoor environment.

METHODS

Experiments were conducted in a 1.03-m^3 , glass test chamber. Different materials were exposed to two organic compounds with the objective of investigating the effect of adsorption and desorption of volatile organic compounds on indoor surfaces.

Theory

Tichenor et al. proposed a model to describe adsorption on material surfaces in a test chamber. If a Langmuir adsorption process is assumed, then equations (1) and (2) can be

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used to describe the rate of change of concentration and mass in the sink

$$\frac{dC}{dt} = NC_i - NC_t - k_a C_t L + k_d M L \quad (1)$$

$$\frac{dM}{dt} = k_a C_t - k_d M \quad (2)$$

where N is the air exchange rate (h^{-1}), C_i is the concentration of the pollutant in the inlet air (mg/m^3), C_t is the concentration in the chamber (mg/m^3), k_a is the adsorption rate constant (m/h), k_d is the desorption rate constant (h^{-1}), M is the mass per unit area on the sink (mg/m^2) and L is the ratio of sink area to chamber volume (m^{-1}).

Study materials

The following materials were evaluated: window glass, nylon carpet, wool carpet, ceiling sheets of rock-wool and a combination of: wool carpet, ceiling sheets of rock-wool and a wooden bookshelf with books and papers.

Each material was tested with two organic compounds: toluene and α -pinene. The selection of the organic compounds was based on their frequent occurrence in indoor air, that they represent different chemical classes and that they contribute significantly to odour or irritation effects of indoor air. A test was performed with a combination of several materials and α -pinene. The composition was 1 m^2 of wool carpet, 1.44 m^2 of ceiling sheets of rock-wool, 1.60 m^2 of wooden bookshelf and 0.5 m^2 of books and paper.

Procedure

A sample of the sink material was placed in the test chamber supplied with air at an air exchange rate around 1 h^{-1} . Before each experiment, the material was conditioned for 24 hours in the test chamber. At the start of each experiment, the compound was added to the chamber inlet flow (passive evaporation). The concentration of the pollutant in supply air was $5 \text{ mg}/\text{m}^3$.

Using photoacoustic spectroscopy, the concentration of the test compound was measured at the exhaust from the test chamber. The detector was calibrated on toluene and α -pinene. In addition to measuring of the outlet air, the background concentration was also measured. The concentration of the test compound resulted from the difference between the concentration in the outlet flow and the concentration in the background air. The same procedure was used to determine the concentration in the inlet air. Test values were collected approximately every 4-5 min in the supply air, the background air and the exhaust air from the test chamber.

Test conditions

The test conditions were simulating the common indoor environment of a building at an air exchange rate of 1 h^{-1} . Supplemented with two fans in the test chamber, it provided air velocities of 0.0 m/s to 0.1 m/s measured 0.1 m above the material. Before the start of the experiment the air in the chamber was measured by a ventilation efficiency procedure and found to be completely mixed.

The test chamber was supplied with air from a climate chamber with a temperature of

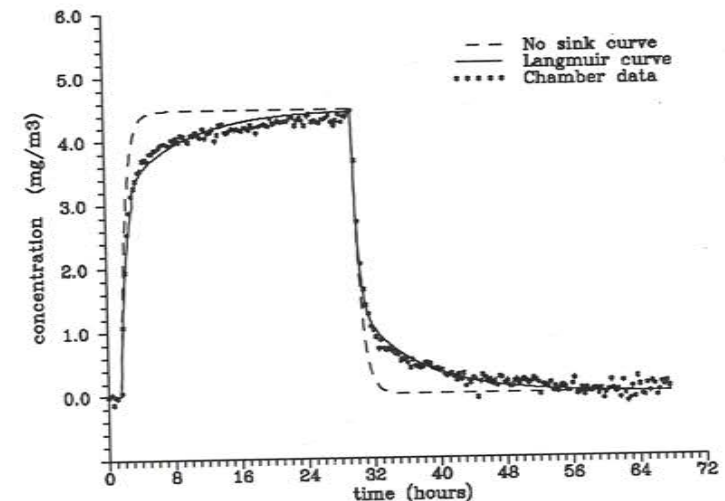
22°C . The relative humidity ranged from 20 to 50 %.

Data analysis

Data obtained from the tests were analyzed assuming a Langmuir type adsorption. These analyses yielded values for: M_{eq} , the mass per unit area on the sink at equilibrium; k_a , the adsorption rate constant; k_d , the desorption rate constant; and k_c , the equilibrium constant, given by $k_a/k_d(1)$. Values for k_a and k_d were obtained by means of a nonlinear regression curve fit routine; in this case NLIN by SAS.

RESULTS

The effect of adsorption and desorption of α -pinene to nylon carpet is illustrated in figure 1. All the other tests showed similar results, except tests for window glass and ceiling sheets of rock-wool, which exhibited no measurable sink effect with regard to either compound. Every fifth measurements is marked on the figure which corresponds to a measurement every 20 min.



Figur 1: Adsorption and desorption of α -pinene on nylon carpet.

The experimental results, including values for k_a , k_d , k_c and M_{eq} are listed in table 1 (the Langmuir-values are calculated from the desorption phase). Note that the tests conducted with window glass and ceiling sheets of rock-wool showed no sink effect with either α -pinene or toluene. Results for these materials are therefore not included in table 1. All tests were conducted at 22°C except where noted.

The test performed with a combination of several materials is marked in table 1 with a

loading factor, L , at 4.4 m^{-1} . This is the ratio of the total area of material surfaces to chamber volume. M_{eq} , k_a , k_d , and k_e are mean values describing the applied combination of materials, assuming that the materials contribute with equal sink effect.

Table 1: Experimental results, incl. M_{eq} , k_a , k_d and k_e calculated on the basis of model.

Material	Compound	N	L	C_{eq}	M_{eq}	k_a	k_d	k_e
		h^{-1}	m^{-1}	mg/m^3	mg/m^2	m/h	h^{-1}	m
Wool carpet	α -pinene	1.25	0.97	4.46	10.11	0.448	0.195	2.302
Wool carpet	toluene	1.04	0.97	4.65	2.75	0.257	0.429	0.599
Nylon carpet	α -pinene	1.25	0.97	4.32	9.92	0.433	0.187	2.320
Nylon carpet	toluene	1.25	0.97	4.94	2.64	0.185	0.340	0.544
Wool carpet at 32°C	α -pinene	1.23	0.97	4.44	10.43	0.386	0.159	2.430
Combination	α -pinene	1.21	4.4	4.13	4.48	0.093	0.085	1.098

DISCUSSION

Adsorption to and desorption from common material surfaces were demonstrated for typical air pollutants occurring in indoor air. The measurements showed distinct sink effect of wool carpet, nylon carpet and a wooden bookshelf with books and papers to toluene and α -pinene. Window glass and ceiling sheets of rock-wool showed no adsorption of the two compounds.

The adsorption of α -pinene was higher than the adsorption of toluene for both wool carpet and nylon carpet. The results are consistent with previous studies which indicated that pollutants with low vapour pressure are adsorbed more easily than pollutants with a high vapour pressure (2,3).

A linear form of the Langmuir adsorption isotherm appear adequate to describe the results obtained for all the materials studied, including the carpets. Tichenor et al. found previously that rough, complex materials, as carpets, appear to be governed by mechanisms other than the Langmuir processes (1).

Sink strengths, represented by k_e , showed that wool carpet and nylon carpet adsorbed approximately equal quantities of each compound. Sink strengths of α -pinene were approximately 2.3 m and of toluene 0.5-0.6 m. In a previous study sink strengths of 0.14-0.97 m were found (1), but for different materials and test compounds.

The two compounds selected in the present study represent common pollutants occurring in indoor air, but it is recommended that further studies on adsorption and desorption be performed with a realistic mixture of pollutants typically occurring in indoor air.

The humidity in the test chamber air and the humidity in the background air were measured. The measurements showed that natural variations in humidity had no measurable effect on adsorption and desorption.

The time consumption for desorption is defined to the time corresponding to 0.5 percent of the equilibrium concentration. The time varied among the experiments. The desorption of toluene from carpet finished after approximately 13.5 hours. The corresponding time for α -pinene was 30 hours. Desorption of α -pinene from the combination of several materials finished after 65 hours. The time necessary for desorption depended on k_a , k_d and N . Compared with the results of Seifert et al. (6-50 hours) (4), Tichenor et al. (12-50 hours) (1) and Kjær and Nielsen (6-63 hours) (2) it is evident that the results are of similar in magnitude.

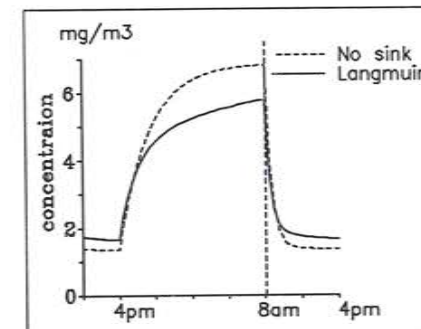
Modelling

The test chamber model (eqs. (1) and (2)) can be generalized to predict the concentration of a compound, emitting from a source in a room, adsorbing to and desorbing from material surfaces in the room

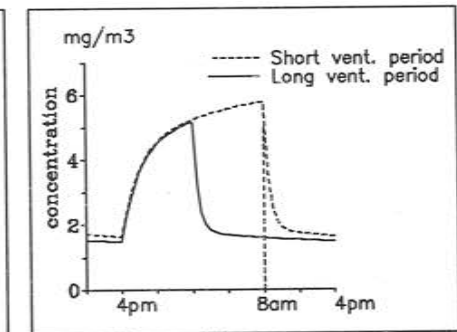
$$V \frac{dC}{dt} = G + C_v Q_v + C_i Q_v + k_a C_i L + k_d M_i L \quad (3)$$

where G is the emission rate of the source (mg/h), Q_v is the inlet airflow and C_i is the inlet concentration while the remainder is recognizable from eqs. (1) and (2). As an example the model is applied on a small office space with a floor area of 7 m^2 and a volume of 17 m^3 . The surface materials comprise a similar mixture as studied in the test chamber. The office is ventilated with a higher air exchange rate during working hours than during the remainder of a 24-hour period. By applying the k_a and k_d values determined in the test chamber, the night and day variations of the concentration can be calculated by equation (3).

Examples of the predictions are shown in figures 2 and 3. Figure 2 illustrates the concentration variations at a constant source strength and at an air exchange rate of 1.5 h^{-1} during the period 8 am - 4 pm, and a reduced air exchange rate (0.3 h^{-1}) during the period 4 pm - 8 am.



Figur 2: Concentration variations at constant source strength ($35 \text{ mg}/\text{h}$) and an air exchange rate of 1.5 h^{-1} during the working hours and 0.3 h^{-1} for the remainder of 24 hours.



Figur 3: Constant source strength ($35 \text{ mg}/\text{h}$) and $N = 1.5 \text{ h}^{-1}$ in the periods 12 pm-4 pm and 8 am-4 pm respectively and $N = 0.3 \text{ h}^{-1}$ for the remainder of 24 hours.

The figure shows that the desorption of pollutants adsorbed during the night contribute to a higher concentration during the working hours compared with the concentration level assuming that the sink effect is negligible. To reduce the concentration during the working hours the ventilation strategy can be modified by elevating the air exchange rate in a period before the start of the working hours. Figure 3 illustrates the concentration variations at a constant source strength and an air exchange rate of 1.5 h^{-1} during the period 12 pm - 4 pm and a reduced air exchange rate (0.3 h^{-1}) during the period 4 pm - 12 pm. The increased concentration from desorption of pollutants during working hours is reduced as the pollutants are desorbed during the night.

The sink effect may also have a positive effect. Occurrence of unusually high exposures causes adsorption of that pollution. The materials may retard the growth of the concentration of pollution. By optimizing the ventilation strategy the desorption of the pollution from the materials can be forced to take place at certain time periods.

It is recommended that the influence of adsorption and desorption on indoor air quality is evaluated in full-scale experiments.

Conclusions

Simple test chamber experiments to quantify adsorption and desorption of organic compounds on material surfaces were conducted.

Experiments with toluene and α -pinene showed significant adsorption on and desorption from wool carpet, nylon carpet and a wooden bookshelf with books and papers. Window glass and ceiling sheets of rock-wool showed no adsorption of the two compounds.

A model, based on a linear Langmuir adsorption isotherm, appears adequate to describe the adsorption and desorption. The rate constants included in the model, can be applied to predict the influence of adsorption and desorption on indoor air quality.

Based on the model the concentration variations in a office space was simulated. The results show that adsorption and desorption may have an important impact on the diurnal ventilation strategy to be selected in a buildings.

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