EXPERIMENTS ON EVAPORATIVE EMISSIONS IN VENTILATED ROOMS

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ABSTRACT

In many new buildings the indoor air quality is affected by emissions of volatile organic compounds (VOCs) from building materials. The emission process may be controlled either by diffusion inside the material or evaporation from the surface but it always involves mass transfer across the boundary layer at the surface-air-interface.

Experiments at different velocity levels were performed in a full-scale ventilated chamber to investigate the influence of local airflow on the evaporative emission from a surface. The experiments included velocity measurements in the flow over the surface and measurements of chamber air concentrations.

The results show that the emission, expressed in terms of the mass transfer coefficient, increases with velocity for fixed temperature, relative humidity and air exchange rate. This emphasises the importance of testing materials at the correct velocity and turbulence level in order to obtain the actual emission rate for a given product.

KEYWORDS

Full-scale experiments, emission of VOCs, CFD

INTRODUCTION

Emissions of volatile organic compounds (VOCs) from building materials such as paint, linoleum, carpets, sealant and lacquer affect the indoor air quality in many new buildings. People exposed to the VOCs may report a decreased acceptability of the indoor air quality, irritation of mucous membranes and general symptoms such as fatigue and headache.

The emissions occur in a chainlike process: diffusion inside the emitting material; crossing the surface-air-interface; transport across the mass transfer boundary layer; and mixing into the bulk air. In any particular material one of these processes may be rate controlling. For freshly applied liquid films the emission is generally controlled by evaporation from the surface and depends on local airflow parameters such as temperature and velocity.

Assuming that emission of VOC's from a surface is limited by molecular diffusion through the boundary layer at the surface-air-interface, Fick's law describes the emission:

$$E = k_c(C_s - C) \qquad (1)$$

where E = emission rate
k_c = mass transfer coefficient
C_s = concentration at surface
C = concentration in bulk air

The mass transfer coefficient, k_c, can also be expressed in terms of the molecular diffusion coefficient, D, and the thickness of the diffusion boundary layer, δ_D, where $k_c = D/\delta_D$.

For a freshly applied surface the surface concentration is equal to the equilibrium vapour pressure, C_v, and as the surface ages the concentration decreases. The surface concentration is assumed to be

Table 2 Maximum velocities over the wood board.

N^* (h^{-1})	Center (m/s)	East (m/s)	West (m/s)	North (m/s)	South (m/s)
2	0.27	0.32	0.22	0.23	0.17
5	0.78	0.86	0.64	0.91	0.29

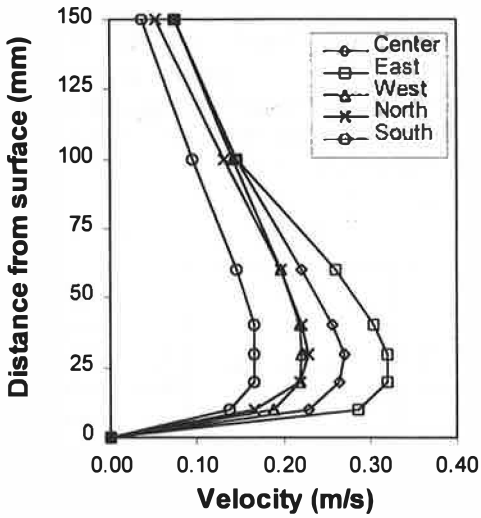

Figure 3 Velocity profiles over the wood board for $N^* = 2\ h^{-1}$.

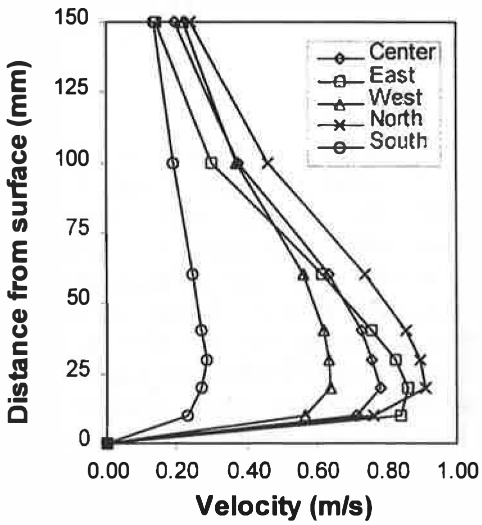

Figure 4 Velocity profiles over the wood board for $N^* = 5\ h^{-1}$.

Concentration

The measured chamber concentrations over time are shown in figures 5 and 6 as well as the prediction from the mass transfer model developed by Tichenor et al. (1993).

The chamber concentration reaches its maximum after approximately 0.5 h for $N^* = 2\ h^{-1}$ and after 1 h for $N^* = 5\ h^{-1}$. Then the concentration drops rapidly within 10 h.

In the early stage of the emission process there is a significant difference between concentrations from one velocity level to another but after approximately 2 h the concentration levels are very similar.

In general, there is good agreement between the experimental data and the model prediction but the model seems to predict lower peak concentrations.

Concentrations from experiments with the same total supply flow rate are very similar although there is a 10 % difference between the peak concentrations for $N^* = 2\ h^{-1}$. For $N^* = 5\ h^{-1}$ there is a difference of 12 % in the amount of VOC applied but the difference in concentration is not as significant.

Mass transfer

The emission rate can be conveniently expressed in terms of a mass transfer coefficient (equation 1). In the present work the mass transfer coefficient has been obtained through non-linear regression by fitting the experimental data to the solutions of equations 3 and 4 (see table 3).

Table 3 Mass transfer coefficients from non-linear regression.

Experiment	k_c (m/h)	Std. Dev. (m/h)	Std. Dev. (%)
1	10.29	0.84	8.2
2	11.07	1.29	11.7
3	4.01	0.19	4.7
4	3.64	0.21	5.8

The standard deviations from the regressions are within 12 %, which is satisfactory. The mass transfer coefficients from experiments with identical flow rates agree within 10 %.

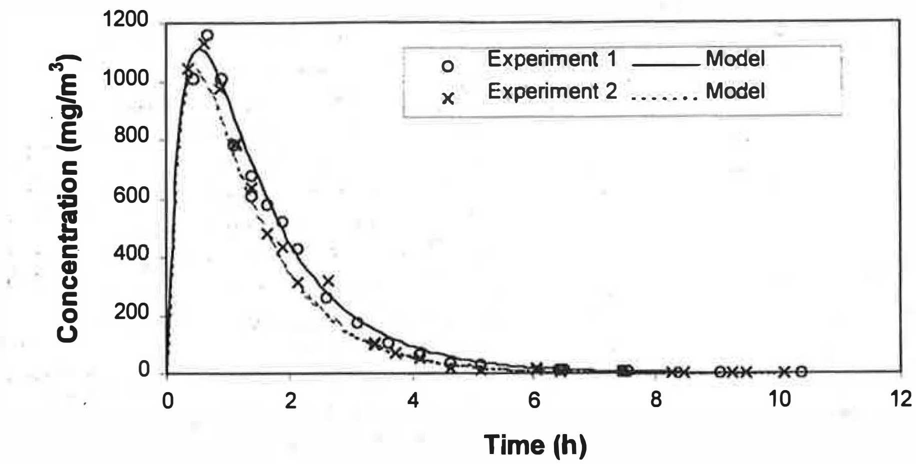

Figure 5 Measured concentration in the chamber air and model predictions (Tichenor et al. 1993) for $N^* = 5\ h^{-1}$.

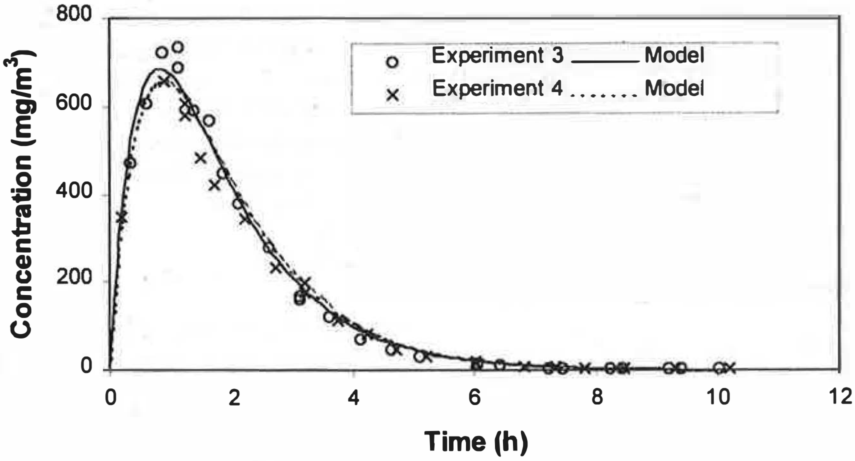

Figure 6 Measured concentration in the chamber air and model predictions (Tichenor et al. 1993) for $N^* = 2\ h^{-1}$.

For comparison of mass transfer coefficients from experiments with different velocity levels the average of the maximum velocities in center, north and south locations is used as reference velocity (see figure 7).

Topp et al. (1997) performed a series of CFD calculations on emission in a full-scale ventilated room and a test chamber using a Low Reynolds Number (LRN) formulation of the k-ε turbulence model. Results from the full-scale room with the pollutant source located at the ceiling and the test chamber are included in figure 7.

The experiments in the present work were performed at Schmidt number $Sc = 2.6$ while $Sc = 1.0$ in the CFD calculations by Topp et al. (1997) and thus only allows for qualitative comparison.

From the figure it appears that

increasing the velocity yields a proportional increase in mass transfer coefficient.

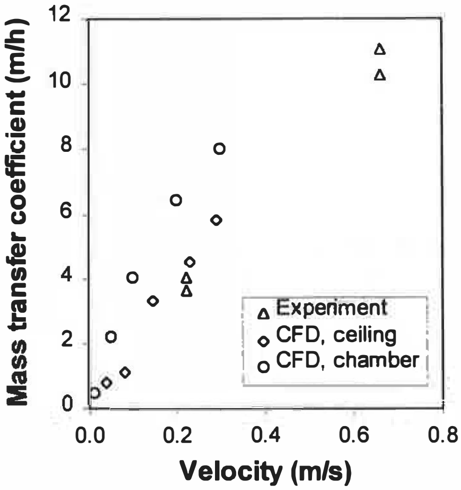

Figure 7 Relation between mass transfer coefficient and velocity. CFD results from Topp et al. (1997) included.

DISCUSSION

Experiments were performed in a full-scale ventilated chamber at two different velocity levels to investigate the effect of local airflow on the evaporative emission from a surface.

The results agree with the model predictions by Tichenor et al. (1993) and show that after reaching its maximum the chamber concentration drops rapidly within 10 h, which is consistent with the results obtained by Chang and Guo (1992). They studied the emission characteristics of a mixture of organic compounds, including decane, and concluded that the first phase of the emission process is mainly controlled by evaporation from the surface. After that the decay rate slows down, as diffusion transport inside the material becomes the controlling mechanism of the emission process.

Two experiments were performed at each velocity level and the results are consistent indicating a high level of repeatability.

It was found that the velocity level in the boundary layer flow over the surface has a strong impact on the mass transfer coefficient as the mass transfer coefficient increases in proportion to the velocity. This emphasises the importance of testing materials at the correct velocity and turbulence level to overcome scaling problems when transferring results from a small-scale test chamber to a full-scale ventilated room.

A source of error is introduced as the mass transfer coefficient has been obtained from a best-fit method. The standard deviation on the mass transfer coefficient is in all experiments less than 12 %.

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