

# The spatial distribution of pollutant transport to and from indoor surfaces

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## Abstract

Spatial distributions in surface flux and concentrations complicate the assessment of indoor mass-transfer coefficients and can bias the resulting estimates of indoor exposure. To better understand these phenomena, we quantify the spatial distribution of ozone flux and mass-transfer coefficients for indoor surfaces in several field locations using NaNO<sub>2</sub> coated filters. The 12-h average transport-limited deposition velocity for ozone,  $\bar{v}_{t,\text{ozone}}$ , corrected for the diameter of the filters, ranged from 1.2 m h<sup>-1</sup> on a wall to 18.7 m h<sup>-1</sup> near an operating recirculation supply vent in an apartment. For 10 filters distributed evenly around walls of a laboratory, large multi-person office, apartment with recirculation on (excluding a near-supply vent sample) and apartment with recirculation off, the average  $\bar{v}_{t,\text{ozone}}$  were respectively,  $3.3 \pm 1.1$ ,  $3.5 \pm 1.3$ ,  $2.8 \pm 0.8$  and  $2.3 \pm 0.8$  m h<sup>-1</sup>. We observed (1) a tighter distribution of flux for filters placed near one-another than for filters separated by greater than one meter, (2) higher fluxes near sources of air movement such as supply vents and computers, and (3) consistent results in a single location over 5 days. Measurements obtained with devices such as coated filters can be corrected for size by using a range of device sizes during an experiment. We find the mass-transfer coefficient in a room-sized laboratory chamber to be proportional to the device diameter raised to the power of  $-0.45$ .

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## 1. Introduction

The transport-limited deposition velocity,  $v_t$ , is a mass-transfer coefficient that characterizes pollutant flux to indoor surfaces. Flux is defined as the product of  $v_t$ , and the concentration gradient across a boundary layer that has developed over a surface. Mathematically, the local, instantaneous flux,

$J(s, t)$ , to or from a surface is given by

$$J(s, t) = v_t(s, t)[C_b(s, t) - C_s(s, t)], \quad (1)$$

where  $s$  denotes surface location or coordinates,  $t$  is time,  $C_b(s, t)$  is the concentration at the outer edge of the concentration boundary layer that has developed over a reactive surface, and  $C_s(s, t)$  is the near-surface gas concentration of the pollutant. All else being equal, as the flux to surfaces increase, indoor concentrations decrease. In understanding indoor systems, Eq. (1) can sometimes be simplified because the  $C_s(s, t)$  can be estimated by considering

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dynamics taking place at the surface. For example, nitric acid deposition to an indoor surface is nearly completely irreversible, and as a result  $C_s(s, t)$  is effectively zero. In contrast, for emission from a solvent spill,  $C_s(s, t)$  is the saturation concentration of the solvent.

In mass-conservation models used to estimate indoor air concentrations (or exposure), the area-integrated flux is the total instantaneous mass rate of change in a room due to surface interactions. Therefore, it is desirable to quantify the underlying parameters, such as  $v_t(s, t)$ , that control fluxes. The term  $v_t(s, t)$  is independent of concentrations for the dilute systems typical of indoor environments. Instead  $v_t(s, t)$  depends on the flow conditions near the surface and the gaseous pollutant diffusivity. Thus  $v_t(s, t)$  can be determined from location specific measurement (Morrison et al., 2003; Sparks et al., 1996; Salmon et al., 1990) or model calculations of flow conditions (Nazaroff and Cass, 1987). However, Nazaroff et al. (1993) cautioned that deposition rates are strongly dependent on flow conditions which will vary greatly among building types and ventilation, and that using average deposition velocities for a room or building may be inappropriate since the local values may vary considerably (Thatcher et al., 2002). Thus, to improve the usefulness of the concept of deposition velocity for indoor air quality modeling and exposure assessment, we require a better understanding of the magnitude and variability of air/surface pollutant transport.

This research is directed to measuring the spatial distribution of ozone surface flux in several field settings. We combine these results with a correction factor, resulting from using measurement devices which necessarily have smaller dimensions than the room dimensions, to arrive at the spatial distribution of transport-limited deposition velocities. The distribution, in turn, allows us to qualitatively evaluate building characteristics that influence  $v_t$ .

### 1.1. Spatial scales and measurement of $v_t$

Care must be taken when interpreting results from spatial-distribution measurements because the size of the collecting/emitting surface influences the reported value of  $v_t$ . The stagnant-film model of mass transfer can be used to demonstrate this size dependent effect. Due to surface emission or deposition flux, a concentration gradient and boundary layer will develop over the measurement

surface, but not necessarily over the surrounding walls. The flux in this case is equal to the product of a concentration gradient and a mass-transfer coefficient, itself equal to the diffusion coefficient,  $D$ , divided by the thickness of the stagnant film,  $\delta$ . All else being equal, as the film thickness increases the flux and the mass-transfer coefficient decreases. Non-stagnant concentration boundary layers also exhibit this behavior: the thicker the concentration boundary layer over a surface, the lower the flux and the lower the resulting mass-transfer coefficient.

This issue of device dimensions is addressed by considering the concentration boundary layer that has developed over a device used to measure the mass-transfer coefficient. See Figs. 1(a) and (b) for a two-dimensional representation of a case in which the pollutant, e.g. ozone, is consumed readily by the measuring surface but not by the surrounding walls. For example, deposition of ozone to a disk coated with a reactive media (see Section 2) is used to determine the time-averaged local mass-transfer coefficient on a wall. A concentration boundary layer will develop over the disk with varying thickness depending on the fluid-mechanical nature and direction of flow as well as the distance from the edge of the disk. The value of  $v_t$  derived from disk 1 is proportional to the thickness of the boundary layer,  $\delta_1$ . If the researcher uses a larger disk, Fig. 1(b), the mean thickness of the concentration boundary layer will be greater,  $\delta_2$ . Given the same time interval for deposition, the time-integrated flux will be larger for disk 1 than for disk 2 and  $v_t$  derived from disk 1 will be larger than that derived from disk 2.

Preferably, the size of the device should not influence the assessment of  $v_t$ . This will be the case for measurements of a pollutant that tends to be consumed by all surfaces, such as acid gases, where the appropriate boundary layer for measurement should look something like Fig. 1(c); in this figure, a flat concentration boundary layer develops over a wall and no sensing surface is present. Assuming flow conditions and pollutant diffusivities to be equal for all panels of Fig. 1,  $\delta_3 > \delta_2 > \delta_1$ . Thus, a measurement as shown in Figs. 1(a) and (b) always over-predicts  $v_t$ . Unlike the ozone example, placing a collector as shown in Fig. 1(d) should not influence the thickness of the boundary layer. Since  $\delta_3 = \delta_4$ , flux measured in Fig. 1(d) will represent the true length-averaged flux regardless of the length  $L_4$ . The value of  $v_t$  derived from disk 4 is the “true” local value to be used for modeling indoor dynamics.

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