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Review

Influence of indoor environmental factors on mass transfer parameters and concentrations of semi-volatile organic compounds

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H I G H L I G H T S

- The influence of indoor factors on the mass transfer parameters of SVOCs is reviewed.
- Six environmental factors are included in the review.
- Data on mass transfer parameters from measurements and models are summarized.
- The mechanism for the influence is analyzed and tentatively quantified.

A R T I C L E I N F O

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A B S T R A C T

Semi-volatile organic compounds (SVOCs) in indoor environments can partition among the gas phase, airborne particles, settled dust, and available surfaces. The mass transfer parameters of SVOCs, such as the mass transfer coefficient and the partition coefficient, are influenced by indoor environmental factors. Subsequently, indoor SVOC concentrations and thus occupant exposure can vary depending on environmental factors. In this review, the influence of six environmental factors, i.e., indoor temperature, humidity, ventilation, airborne particle concentration, source loading factor, and reactive chemistry, on the mass transfer parameters and indoor concentrations of SVOCs was analyzed and tentatively quantified. The results show that all mass transfer parameters vary depending on environmental factors. These variations are mostly characterized by empirical equations, particularly for humidity. Theoretical calculations of these parameters based on mass transfer mechanisms are available only for the emission of SVOCs from source surfaces when airborne particles are not present. All mass transfer parameters depend on the temperature. Humidity influences the partition of SVOCs among different phases and is associated with phthalate hydrolysis. Ventilation has a combined effect with the airborne particle concentration on SVOC emission and their mass transfer among different phases. Indoor chemical reactions can produce or eliminate SVOCs slowly. To better model the dynamic SVOC concentration indoors, the present review suggests studying the combined effect of environmental factors in real indoor environments. Moreover, interactions between indoor environmental factors and human activities and their influence on SVOC mass transfer processes should be considered.

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1. Introduction

Semi-volatile organic compounds (SVOCs) in indoor environments partition among the gas phase, airborne particles, settled dust and available surfaces (Weschler and Nazaroff, 2008). Building occupants can be exposed to environmental SVOCs via inhalation, dermal exposure and dust ingestion (Bekö et al., 2013).

Indoor SVOCs originate from both indoor and outdoor sources. SVOCs of outdoor origin, such as some polycyclic aromatic hydrocarbons (PAHs) (Miguel et al., 1998; Shah et al., 2005), enter the indoor environment mainly through indoor/outdoor air exchange. Their source strength is controlled by the conditions outdoors. SVOCs of indoor origin, such as phthalates (Clausen et al., 2004; Xu et al., 2009), are emitted from materials and products into the indoor environment and partition among different phases. Their emission and sorption processes are controlled directly by the conditions indoors.

According to the mass conservation law, the dynamic indoor gas-phase concentration of an SVOC of indoor origin can be described by a physical model (Wei et al., 2017; Xu et al., 2009):

$$\frac{\mathrm{d}C_g}{\mathrm{d}t}\cdot V = \sum E - \sum S - \sum X - \sum R \tag{1}$$

where C_g is the bulk gas-phase SVOC concentration assumed to be uniform in an indoor environment with volume V; t is the time; E is the emission rate of the SVOC from the source; S is the sorption rate of the gas-phase SVOC onto an indoor sink, such as airborne particles, settled dust, and surface materials; X is the exhaust rate of the gas- and particle-phase SVOC from indoor air to outdoor air; and R is the reaction rate of the SVOC with an oxidant. Unlike volatile organic compounds (VOCs), whose emission rate from building materials is mostly controlled by intra-material diffusion (Little et al., 1994), SVOC emission and sorption processes are dominated by external mass transfer (Xu and Little, 2006), and intra-material diffusion can be neglected (Liu et al., 2012).

Sources of indoor origin can be classified into four categories, i.e., continuous source with constant source strength, continuous source with variable source strength, intermittent source with constant time-pattern, and intermittent source with variable time-pattern (Seifert and Ullrich, 1987). Among these categories, SVOC emissions from continuous sources, e.g., surface source materials, have been the most studied sources. The emission rate (E, μg/s) of an SVOC from a surface source to the gas phase is described by the specific source/gas mass transfer coefficient (h_m, m/s) for the SVOC, the area of the source material (A, m^2), the gas-phase concentration immediately adjacent to the material surface (y_0, μg/m^3), and the bulk gas-phase SVOC concentration (C_g, μg/m^3) (Xu et al., 2012, 2009; Xu and Little, 2006):

$$E = h_m A (y_0 - C_g) \tag{2}$$

The sorption rate (S, μg/s) of a gas-phase SVOC onto an indoor sink surface can be obtained from the gas/material mass transfer coefficient (h_{ms}, m/s), the area of the material (A_s, m^2), the material-phase concentration of the SVOC (C_s, μg/m^3), the material/gas partition coefficient (K_s, dimensionless), and the C_g (Liu et al., 2013, 2015a; Xu et al., 2012, 2009):

$$S = h_{ms} A_s \left(C_g - \frac{C_s}{K_s} \right) \tag{3}$$

The exhaust rate (X, μg/s) of an SVOC of indoor origin from indoor air to outdoor air is calculated from the air flow rate (Q, m^3/s), the particle-phase concentration of the SVOC (F, μg/m^3), and the C_g:

$$X = Q(C_g + F) \tag{4}$$

The reaction rate (R, μg/s) of an SVOC in a phase with an indoor oxidant is calculated from the pseudo-first-order rate constant (k_1, s^{-1}) and the content of the SVOC in the phase (C, μg) (Wei et al., 2017):

$$R = k_1 C \tag{5}$$

The SVOC mass transfer parameters and indoor concentrations are influenced by indoor environmental factors. For example, the indoor temperature accounted for 79% of the variability in indoor air concentrations of polychlorinated biphenyls (PCBs) over a 2-day period (MacIntosh et al., 2012). Increasing the indoor temperature is related to increases in the amount of phthalate metabolites in the occupants' urinary concentrations, due to higher phthalate concentrations in the air (Pilka et al., 2014).

The objective of the present study was to review existing studies with the aim of analyzing and quantifying the influence of indoor environmental factors on SVOC mass transfer parameters and concentrations. The present review includes both emission and sorption processes occurring in indoor environments. For each environmental factor, the review addresses the emission of SVOCs from source materials and the sorption of SVOCs onto sink