Building and Environment 95 (2016) 372–380

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Effect of high-voltage electric field on formaldehyde diffusion within building materials

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ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form
15 September 2015
Accepted 20 September 2015
Available online 25 September 2015

Keywords:
High-voltage electric field
Initial concentration
Partition coefficient
Diffusion coefficient

ABSTRACT

An experimental study concerning the diffusion of formaldehyde within building material in different high-voltage electric fields was conducted. Formaldehyde concentration was tested under electric field intensities of 0, 33.3, 66.6 and 100 kV/m. The Capsule Concentration Footprint Method (CCFM) was proposed to analyse the resulting experimental data. It was found that both equilibrium concentration and emission rate increased under greater electric field intensity. In addition, the experimental data indicated that high-voltage electric fields have a significant effect on partition coefficient, little effect on initial concentration and nearly no influence on diffusion coefficient. The partition coefficient decreased remarkably, while initial concentrations increased slowly due to the increasing electric field intensity. A formula was obtained to explain the relationship between partition coefficient and electric field intensity. A simulation of the adsorption between the formaldehyde and building material was conducted to illustrate the decrease in adsorption potential due to the greater electric field intensity, which helps to understand the principle established by the experimental data. The results of this study confirmed the feasibility of a new method for the reduction of formaldehyde in the man-made boards.

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1. Introduction

Volatile organic compounds (VOCs) that are emitted from many building materials are considered to be a major cause of poor indoor air quality [1]. On average, people spend over 80% of their time indoors, and a major part of this is inside homes [2]. Poor indoor air quality can cause a variety of symptoms such as dry coughs; difficulty concentrating; tiredness; headaches; nose, eye or throat irritations; and dizziness and nausea [3–6]. Materials capable of depositing, adsorbing and/or accumulating pollutants can influence indoor air quality during the entire service life of a building [7]. Therefore, an accurate characterization of the sorptive properties of building materials and the impact of sorption on indoor air quality is important.

Several significant accomplishments have taken place over the past 20 years regarding the testing of formaldehyde emissions from wood products. On the one hand, there have been many studies using different testing methods to evaluate formaldehyde release or content in materials [8–11]. On the other hand, there have been studies on the impact factors leading to the release of formaldehyde from wood-based panelling [12], such as temperature, air velocity, humidity and board properties. Published approaches for studying the characteristics of VOC sources and sinks fall into two categories: modelling and simulation and experimental investigation [13]. Modelling and simulation studies of VOC diffusion within building materials have experienced significant developments. Xiong and Zhang used a theoretical approach to derive the correlation that characterizes the relationship between emission rate and temperature for formaldehyde emission [14]. Huang studied the impact of temperature on the ratio of initial emittable concentration to total concentration for formaldehyde in building material. They found a theoretical novel correlation that showed the logarithm of emittable ratio is multiplied by the power of 0.5 of temperature and is linearly related to the reciprocal of temperature. Experimental

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http://dx.doi.org/10.1016/j.buildenv.2015.09.022
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Nomenclature

A	emission area of building material (m^2)
C_0	initial concentration of formaldehyde in test chamber (mg/m^3)
$C_m(x, t)$	instantaneous concentration of formaldehyde in building material (mg/m^3)
$C_m(L, t)$	concentration of formaldehyde in building material adjacent to the interface (mg/m^3)
$C(t)$	concentration of formaldehyde in chamber (mg/m^3)
$C_s(t)$	concentration of formaldehyde in the air adjacent to the interface (mg/m^3)
$C_{equ}(t)$	equilibrium concentration of formaldehyde in test chamber (mg/m^3)
D	mass diffusion coefficient for formaldehyde in building material (m^2/s)
E	electric field intensity (kV/m)
h_m	convective mass transfer coefficient (m/s)
K	partition coefficient between building material and air (dimensionless)
L	thickness of building material slab (m)
M	emission rate (mg/s)
t	time (s)
U	electric voltage (kV)
V	volume of air in chamber (m^3)
x	linear distance (m)

results have indicated that emittable ratio increases significantly with increasing temperature, and this increase was 14-fold from 25.0 to 80.0 °C [15]. Ma and Chen applied a three-dimensional lattice Boltzmann method to simulate desorption and diffusion processes of VOCs in porous materials [16]. Although numerous researchers have focused on the modelling of VOC emissions from building materials and furnishings in ventilated space, it is more difficult to research the diffusion of VOCs experimentally; however, experimental studies have already obtained certain achievements. Parthasarathy studied the effects of temperature and humidity on formaldehyde emission from samples collected from temporary housing units [17]. Wei developed a liquid-inner tube diffusion-film-emission reference for quickly evaluating the performance of chamber systems for furniture/building material VOC emission tests [18]. Small-scale environmental chamber experiments have been performed using painted hardwood panels to evaluate the production of VOCs and formaldehyde at different ozone concentrations and reaction times by Huang [19]. Lin used a chamber to investigate the impact factors of temperature, relative humidity, air exchange rate and volatile organic compound properties on VOC specific emission rates and concentrations from wooden flooring [20]. Overall, the theoretical and experimental research on VOC emission has made great achievements.

However, VOC emissions from building materials have been rarely studied under the action of an external electric field. Electric fields have been used in many heat and mass transfer studies. Farmanzadeh performed a theoretical investigation of the adsorption of formaldehyde molecules onto the exterior surface of single-walled (8, 0) zinc oxide nanotubes and considered the effect of external electric fields on adsorptive properties. The results showed that the electric field can easily modulate the adsorptive energy of formaldehyde on zinc oxide nanotubes [21]. The effects of an electric field on CO and NO adsorption on a Pt (111) surface were studied by Koper [22]. The effects of an external electric field on the adsorption of O_2 molecules on the surface of Au-doped graphene was studied using density functional theory calculations by Zhang, and the adsorption energy decreased under a positive electric field [23]. Lebovka investigated the influence of a pulsed electric field treatment on the convective drying of potato tissue and concluded that the effective moisture diffusivity increased with increasing strength of the pulsed electric field [24]. The application of electric fields in heating and mass transfer applications has a broad prospect for development. Therefore, the study of high-voltage electric fields applied to VOC emissions is essential.

Three emission characteristic parameters, initial concentration, diffusion coefficient and partition coefficient, were found to be useful for describing formaldehyde and VOC emissions from building material [25–29]. Therefore, in this study, these emission parameters were studied in detail under the action of different high-voltage electric fields. High-voltage electric fields were introduced for the removal of formaldehyde in man-made boards, which may be a highly useful method for formaldehyde reduction. Furthermore, research results from the diffusion of formaldehyde under the effects of an external electric field will make it easier to study the effects of high-voltage on other VOCs, experimentally and theoretically.

2. Experiments

2.1. Experimental principle

For one board of building material placed in an airtight chamber with inner volume V (Fig. 1), the following assumptions were made: (1) the building material is uniform; (2) VOC mass transfer is one-dimensional; (3) the initial VOC concentration is homogenous; (4) the partition coefficient K and the diffusion coefficient D are constant for a given voltage; (5) the VOC concentration in the chamber is uniform.

2.2. Experimental apparatus

The schematic diagram of the experimental apparatus used in this study is described in Fig. 2. It was mainly composed of five parts: airtight chamber, high-voltage electric field generation system, constant temperature control system, formaldehyde concentration sampler system and temperature and humidity monitoring system.

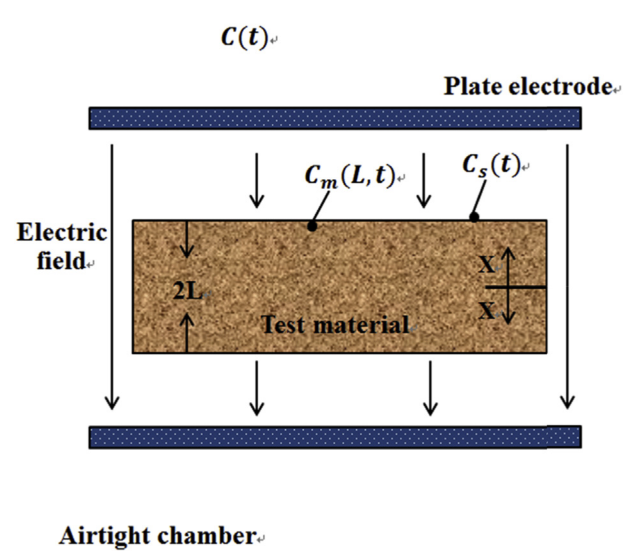

Fig. 1. Schematic diagram of the problem.

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