Building and Environment 65 (2013) 146–153

Contents lists available at SciVerse ScienceDirect

Building and Environment

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

Determination of dynamic intake fraction of cooking-generated particles in the kitchen

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ARTICLE INFO

Article history:
Received 4 January 2013
Received in revised form
5 April 2013
Accepted 5 April 2013

Keywords:
Cooking
Particle dispersion
Dynamic intake fraction
Indoor air quality
Kitchen ventilation

ABSTRACT

This paper attempts to determine the individual intake fraction of particles generated from a simplified cooking process of edible oil heating in the kitchen. First, two separate sets of experiments, utilizing real-time Malvern particle sizer and TSI aerosol monitor, respectively, are combined to obtain the size-dependent emission rate of fume particles from the cooking process. Second, a drift flux model for particle dispersion, getting particle source-releasing conditions from the experimental data, is applied to predict the dynamic concentration in the kitchen. Third, size-dependent dynamic intake fraction of the particles by an individual in the kitchen, based on a breathing model defined, is determined from the predicted particle concentrations. It is found from the case studies that the inhaled particle concentration is highly attributed to the air distribution under different ventilation conditions of the kitchen space, even if both the ventilation rate and final capture efficiency of the exhaust system are the same. It is confirmed that different air inflow results in even different magnitude of intake fraction, ranged from $\sim 10^{-3}$ to $\sim 10^{-5}$. Lower intake fraction is observed under the open door conditions because inflow from the lower-level of the door produces some effect as the displacement ventilation. Results also show that size distribution of the inhaled mass is similar to that at the source, and the dynamic intake fraction is little sensitized to the particle size, due to the short-time and short-distance particle dynamics during the cooking process. The present work quantifies the attributed fraction of cooking-generated particles taken in by exposed individual through integrating the experimental and numerical methods. It helps to evaluate the indoor air quality and understand the health risk due to cooking activity in the kitchen space.

1. Introduction

Cooking-generated airborne contaminants, including the gaseous and particulate matters, have been considered as one of the major indoor pollutants and significantly harm to individual health. More and more recent studies have focused on the indoor air quality issue in the public and residential kitchens [1–4], when epidemiological results concluded the significant linkage between health effects and exposure to particulate matters from cooking [1,5–8]. Especially, Chinese-style cooking has been found contributed approximately 30% to indoor concentrations of particles from 0.5 to 5 μm [9] and grilling Chinese-style food could lead to elevated submicron particle and PM2.5 concentrations even up to 5 and 90 times higher than normal, respectively [10]. However, the quantitative assessment of high individual exposure to cooking-generated particles during a specified cooking process has not been well understood. In recent years, a few studies have attempted to numerically relate indoor exposed particle concentration with the releasing process or condition. Lai and Chen [11] carried out a CFD simulation work of cooking-emitted particle dispersion in a residential flat with an assumed non-dimensional particle emission rate of 1 s^{-1}. Lai and Ho [12] studied the spatial concentration variation of cooking-emitted particles in a residential kitchen by assuming a constant particle size of 3.5 μm. Some other studies focused on the performance of particle transport models for the indoor environment and the numerical prediction of particle inhalation [13–16]. Few studies defined a real emission source of cooking-generated particles for the prediction of spatial exposure. Individual intake of cooking particles and its relationship with the emission characteristics and ventilation conditions have not been reasonably clarified.

Individual intake fraction is defined as the attributed pollutant mass taken in by an exposed individual per unit mass emitted from

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http://dx.doi.org/10.1016/j.buildenv.2013.04.006

a source. In this framing, risk can be estimated by multiplying the quantity of particles emitted from a source by an appropriate intake fraction and then by a health risk factor [17]. Intake fraction is recognized as an effective measure for comparing the magnitude of individual exposure to pollutant emissions released under different conditions. Few studies have reported the intake fraction associated with cooking activity. Nazaroff [18] comprehensively discussed how intake fraction varies with governing parameters for episodic indoor pollutant releases, such as those from cleaning, cooking, or smoking. It was also indicated that the intake fraction should depend on building related factors (e.g., ventilation rate), occupant factors, and pollutant dynamic factors.

This study aims to determine the dynamic size-dependent intake fraction of cooking-generated particles in a kitchen room. Experiments are conducted to obtain the size-dependent volume frequency and total emission rate of the particles, and then the size-dependent emission rate through multiplying the two parameters. A drift flux model, integrated with a breathing model, is applied to predict the particle concentration and individual inhaled level during a specified cooking process under different ventilation conditions. Finally, the dynamic intake fraction is determined through combining the experimental and numerical work. This study realizes to frame a method for investigating the dynamic intake fraction of cooking-generated particles in the kitchen. The inhaled particle mass and its size distribution obtained by such work help to understand the health risk due to cooking activity in the kitchen space.

2. Determination of emission characteristics

The experiments are conducted in a laboratory kitchen which is built in a large experimental chamber. The sizes of the kitchen and the surrounding space are 3.5 m (L) × 1.8 m (W) × 2.4 m (H) and 20 m (L) × 15 m (W) × 3.5 m (H), respectively. The rapeseed oil is applied in the experiments and an electric griddle with 7 thermal control levels is used to heat the oil in a round-bottomed wok. To simplify the cooking process for the present work, an oil-preheating stage of 2 min is considered, which is typical for the Chinese-style cooking such as frying. Fig. 1 shows the monitored temperature during the heating process with a constant electric power.

Two sets of experiments are designed to quantify the emission characteristics, one for particle volume frequency under full ventilation condition to decide the volume-based size distribution, and another for particle mass concentration (PM0.1–10) under well-mixed condition to determine the total source strength. The volume distribution of particles arising from the heated oil is directly measured using a real-time Malvern Spraytec size analyzer, which is a laser-diffraction sizer system for the aerosol particle characterization. Fifteen repeated measurements are performed, using a same amount rapeseed oil 80 g. Mean oil consumption for each measurement is 1.12 g, standard deviation 0.148 g. Measurement sampling rate is 1 s, and the sampling location is set at nearly the top level of wok within 2 min of heating. Before heating the oil, outdoor air is flushed through the window and door of the kitchen, lasting for 20 min, to avoid bias from the previous measurement. During each measurement, the door and window are open to keep a ventilation rate 518.4 m^3/h.

The total source strength is derived by the variation of particle mass concentration with time measured using the TSI Model 8533 DustTrak aerosol monitor. The door and window of the kitchen are closed and all the cracks are well sealed during the measuring. Five repeated measurements are performed. Regarding each measurement, wok is set at five different locations with different straight-line distances from the specified measuring point. As shown in Fig. 2, points A–E denote the locations of wok center in the room when mass concentration is measured using the TSI Model 8533 DustTrak aerosol monitor at the specified sampling point SP. The distance between point A and B, Dis (A, B), is 0.8 m, and Dis (B, C) = 0.6 m, Dis (C, SP) = 0.2 m, Dis (SP, D) = 0.6 m, Dis (D, E) = 0.6 m. The procedure is as follows: 45 min of ventilation through exhaust hood before each measurement, followed by 120 min of mass concentration under closed condition during which the cooking process (2 min of oil heating) begins at 1.5 min and ceases at 3.5 min. The experiments are designed to firstly measure the dynamic variation of mass concentration in the closed kitchen space, and then to decide the natural decay rate and source emission rate of particles from the variation curve. The two parameters are estimated through the following mass balance

$$\frac{dC_{in}}{dt} = P\alpha C_{out} - (\alpha + k)C_{in} + \frac{S}{V} \quad (1)$$

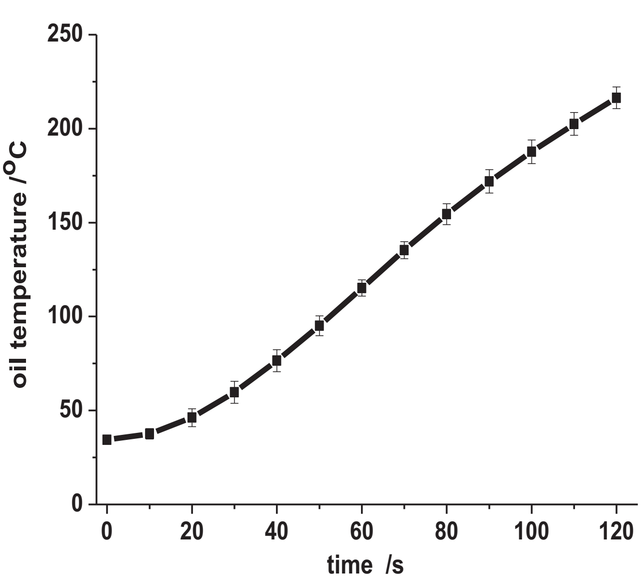

Fig. 1. Monitored oil temperature during the 2-min heating of the rapeseed oil.

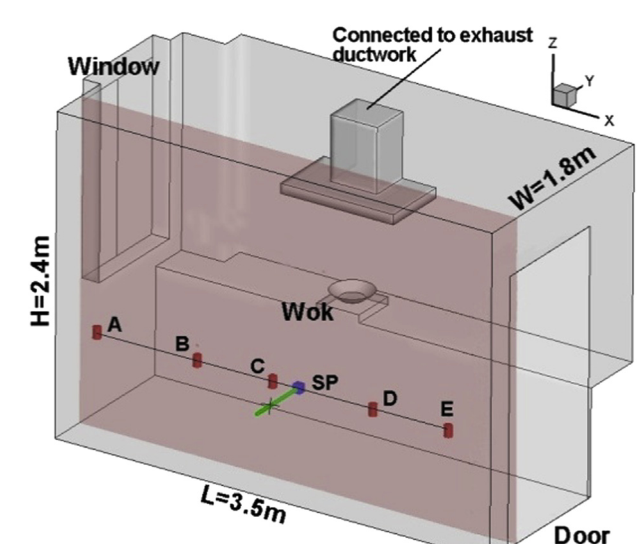

Fig. 2. Schematic diagram of the kitchen room and the layout of measuring points of aerosol monitor.