Health risk assessment of formaldehyde released from several Chinese dishes cooking activities

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Abstract. To study the effect of Chinese dishes cooking activities on the health risk for domestic cook, numerical simulations are executed under different air flow rates for three oil-based Chinese dishes cooking activities. The concentration of formaldehyde in respiratory area during cooking process is obviously influenced by the cooking dishes. And the effect of air flow rate of range hood on the formaldehyde capture is not as significant as that of the cooking method. The predicated results show that the formaldehyde concentration is 4.5-5.5, 2.8-3.6 and 1.2-1.5 times of the prescribed limit when cooking the dishes of stir-fried mutton, pan-fried chicken with onion and deep-fried pork, respectively. The high air flow rate is recommended for improving formaldehyde capture efficiency (CE) of range hood. The potentially benefit effects induced by higher air flow rate is reliable in the cooking activity of stir-fry mutton. Using high air flow rate of 19 m³/min can reduce the risk by 11.86% compared with using low air flow rate of 10 m³/min. Low air flow rate is more suitable for cooking activities with low release rate of cooking oil fumes (COFs), in order to better protect the health of cooks.

1. Introduction

Cooking is a proven major source of indoor pollutants and poses a potential threat to human health. Typical Chinese cooking methods such as scramble or fry food usually include the procedure of heating oil, which involves volatilization of oil under high temperature. A large amount of cooking oil fumes (COFs) including over 300 types of reaction products is generated. It contains some chemical carcinogens such as aldehydes, benzenes and PAHs[1]. Epidemiological studies have confirmed that exposure to COFs is positively associated with the incidences of lung cancer and cervical cancer[2-3]. This also indicates that some compounds in COFs may play important roles in adverse effects on human health.

The degree of threat to human health caused by COFs depends on the components and concentrations of harmful chemicals in exposed environment. They are closely related to the release and diffusion characteristics of pollutants. Components and emission rates of COFs are influenced by factors such as cooking oil type, oil temperature, cooking methods and food type[4-5]. And the diffusion of indoor COFs is affected by driving effect of range hood and building ventilation condition. However, the capture efficiency (CE) of range hood is related to many factors, including the type of range hood, air flow rate, aerodynamic design and installation position[6]. Gao et al[7] found that the ventilation condition of building would interfere with the CE of range hood, and results in greatly different respiratory exposure concentrations of COFs with different ventilation conditions. With more and more attention paid to indoor pollution, many researchers have conducted health risk assessment of COFs components. Huang et al[8] reported that the lifetime cancer hazard risk associated with
formaldehyde, acetaldehyde and benzene in dwelling is $1.05 \times 10^{-5}$, $3.05 \times 10^{-6}$ and $1.86 \times 10^{-6}$ respectively. They all exceed the acceptable limit of $1.0 \times 10^{-6}$. However, the sampling probes for collection of COFs were directly placed 0.5 m above the cooking appliance, which is usually still in the trapping area of the range hood. The measured data are not equivalent to the concentration of human exposure to COFs components. In the numerical investigation of gaseous COFs diffusion, CO$_2$ is often used as simulation species to calculate the concentration of COFs in the respiratory zone\cite{9}. Few numerical simulations of the diffusion of carcinogens such as aldehydes and benzenes are available. Zhang et al.\cite{4} conducted a health risk assessment according to the emission concentration of VOCs in COFs, which is not the exposure concentration of human during cooking operation. Moreover, in the experiment, different oil temperatures were used to represent the corresponding cooking methods of steaming, roasting, frying, stir-frying and deep-frying. This is quite different from the actual cooking process. In order to conduct a more practical health risk assessment of COFs, further research is still needed on the occupant’s respiratory exposure level of gaseous pollutants in the actual cooking activities.

Formaldehyde has been classified as a group 1 carcinogen for humans by International Agency for Research on Cancer (IARC). It will be generated in most cooking activities of typical Chinese dishes. In this study, formaldehyde is selected as a representative pollutant to study the indoor diffusion of gaseous pollutants in COFs. Therefore, the objective of this study is to assess the health risks of formaldehyde in COFs for domestic cook during several Chinese dishes cooking activities. Three dishes of stir-fried mutton, pan-fried chicken with onion and deep-fried pork involved three different methods of cooking are selected to study in this paper. In addition, different air flow rates of range hood are implemented for every cooking activity. The appropriate air flow rates for three Chinese cooking activities are suggested in terms of minimizing the carcinogenic risk of formaldehyde exposure.

2. Governing equations and numerical methods

2.1. Governing equations

ANSYS Fluent is used to simulate the three-dimensional flow and species field. The RNG $k$-$\varepsilon$ turbulence model is selected to predict the flow field characteristic because of its stability and precision\cite{10}. A second-order discretization method is used for convection terms, and the SIMPLE algorithm is chosen for pressure-velocity coupling. In this study, the air is treated as incompressible fluid. The equations for conservation of mass, momentum, energy and species transport can be written as the follows:

$$\nabla \cdot (\rho \vec{v}) = S_m$$

$$\nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\vec{\tau}) + \rho \vec{g}$$

$$\nabla \cdot (\vec{v} (\rho E + p)) = \nabla \cdot \left[ (k + k_t) \nabla T \right] + S_h$$

$$\nabla \cdot (\rho \vec{v} Y_i) = \nabla \cdot \left[ \rho D_{i,m} + \frac{\mu}{S_{Ci}} \right] \nabla Y_i + S_i$$

where $\rho$ is fluid density, kg/m$^3$; $\vec{v}$ is fluid velocity, m/s; $p$ is the static pressure, Pa; $\vec{\tau}$ is the stress tensor, N/m$^2$; $\rho \vec{g}$ is the gravitational body force, N/m$^3$; $E$ is energy, J; $k$ is the molecular conductivity, W/(m·K); $k_t$ is the conductivity due to turbulent transport, W/(m·K); $T$ is temperature, K; $Y_i$ is the mass fraction of species $i$ in the mixture; $D_{i,m}$ is the mass diffusion coefficient for species $i$, m$^2$/s; $S_{Ci}$ is the turbulent Schmidt number; $\mu$ is the turbulent viscosity, kg/(m·s); $S_m$, $S_h$, $S_i$ is any defined source term.
2.2. Kitchen model and Boundary conditions
The geometric model for numerical simulation is a laboratory kitchen which is built in a large experimental chamber as shown in Figure 1[11]. The size of the kitchen is 2.7m×2.0m×2.3m. A Chinese range hood is installed above the cooking bench surface with a height of 750mm. The height of the cooking bench and the occupant are 0.8m and 1.68m, respectively. The distance between the occupant and the cooking bench is 5cm, which is a typical distance for Chinese cooking. The pan is placed on the left stove 0.22m from the pan center to the wall adjacent to the cooking bench.

The pan bottom is defined as pollutant/heat source with diameter 240mm in this simulation. According to the experimental study conducted by Zhao et al[12], emission characteristics of formaldehyde during the cooking activities of three typical Chinese domestic dishes are determined. The pollutant source released formaldehyde at constant rate of 4.563×10⁻⁸kg/s, 3.285×10⁻⁸kg/s, 1.46×10⁻⁸kg/s respectively for stir-frying, pan-frying and deep-frying dishes. And the corresponding temperature of heat source are 77.9°C, 104.1°C and 122.6°C[12]. For each cooking activity of Chinese dish, four air flow rates of 10m³/min, 13m³/min, 16 m³/min and 19m³/min are set separately at the outlet of range hood. In order to control the boundary conditions, the ceiling inlet is set as pressure-inlet boundary to supplement air. Heat flux at the occupant surface is 24.66W/m². The ambient temperature is 22°C. The wall is set to be adiabatic, impermeable and slippery.

2.3. Model validation
The grid independence test is conducted with three different sizes of mesh. Dozens of sampling points are extracted from the release source to the human nose, and their concentration of formaldehyde are compared as shown in Figure 2. By increasing the grid cells from 2.26 million to 3.59 million, there is no significant change in the predicted concentration of formaldehyde. Therefore, the grid number of 2.26 million is selected for present numerical studies.

The numerical results of velocity components at the intersection line of Section1 and Section2 are compared with experimental results reported in the reference[11], as shown in Figure 3. The simulation data is consistent with the experimental result. Therefore, the numerical model is feasible to predict the characteristics of local flow field driven by range hood.
3. Result and discussion

3.1. CE of range hood
CE is commonly used as an index to evaluate the performance of range hood. It is defined as the ratio of pollutant capture rate to pollutant generation rate. In the cooking activities of three different Chinese dishes, the formaldehyde CE of range hood with different rates is shown in Figure 4. No matter what cooking method used, the formaldehyde CE of range hood increases with the increase of air flow rate. Release rate is a significant factor affecting the CE of range hood. The higher the release rate is, the greater the CE of range hood is, especially at the low and medium air flow rates. Under the condition of 16 m$^3$/min, CE in the cooking activity of stir-fried mutton is more than 0.7% higher than that of cooking pan-fried chicken with onion and deep-fried pork. But under the condition of low and high air flow rate such as 10 m$^3$/min and 19 m$^3$/min, there is hardly any difference.

3.2. Health risk assessments
Inhalational carcinogenic risk assessment of formaldehyde produced by cooking activity is calculated with the following equations, provided by the United States Environmental Protection Agency’s (USEPA) Superfund Program[13]:

$$ILCR = \frac{CA \times ET \times EF \times ED}{AT} \times IUR$$
where $ILCR$ is the incremental lifetime cancer risk; $C4$ is the exposure concentration, $\mu g/m^3$; $ET$ is the exposure time, h/day; $EF$ is the exposure frequency, day/year; $ED$ is the exposure duration, year; $AT$ is the average lifetime, h.

Table 1. Parameters used in the health risk assessment[14-15].

| $ET$ (h/d) | $EF$ (d/year) | $ED$ (year) | $AT$ (h) | $IUR$ ($(\mu g/m^3)^{-1}$) |
|------------|---------------|-------------|----------|---------------------------|
| 0.20/0.14/0.51 | 255           | 53          | 613200   | $1.3 \times 10^{-5}$      |

The inhalation region extends out only in front of the body, and there is almost no air inhaled from either of the sides or from behind the body[16]. In front of the person, the area 5 cm from the skin surface from nose to breast is defined as the respiratory zone. The average concentration of respiratory zone as shown in Figure 5 can be approximated to the exposure concentration of formaldehyde. The carcinogenic risks of formaldehyde in COFs from three Chinese dishes cooking activities are depicted in Figure 6. The formaldehyde concentration in the respiratory area increases first and then decreases with the increase of air flow rate. This trend is consistent in the three cooking activities. The trends of $ILCR$ are the same as that of concentration. Although the release rate and exposure concentration of deep-fried pork are lower than that of pan-fried chicken with onion, the $ILCR$ is higher because of longer exposure time. GB/T18883-2002 (Indoor air quality standard) stipulates that the indoor average concentration of formaldehyde in one hour is 100$\mu g/m^3$. When cooking the dishes of stir-fried mutton, pan-fried chicken with onion and deep-fried pork, the formaldehyde concentration is 4.5-5.5, 2.8-3.6 and 1.2-1.5 times of the prescribed limit, respectively. The $ILCR$ for three Chinese dishes with several air flow rates of range hood are all above the acceptable level ($1 \times 10^{-6}$) but within the tolerant limit ($1 \times 10^{-4}$). In order to reduce the $ILCR$, it is better to use the high air flow rate of range hood such as 19$m^3/min$ when stir-fried mutton. On the contrary, 10$m^3/min$ is a recommended air flow rate for cooking two other dishes. The air flow rate of 13$m^3/min$ is not a suggested operating conditions for cooking activities of these three dishes.

![Figure 5. The formaldehyde concentration of respiratory zone in three cooking activities.](image5.png)

![Figure 6. ILCR of formaldehyde in three cooking activities.](image6.png)

4. Conclusions

The present paper numerically studies the formaldehyde exposure concentration under three Chinese cooking dishes. And the effect of air flow rate of range hood on formaldehyde diffusion is also evaluated. High air flow rate is recommended for improving formaldehyde CE of range hood. But for reducing the human health risk of formaldehyde, high air flow rate may not be appropriate. High air flow is suitable for cooking activities with high release rate of COFs, such as stir-fried mutton. Using high air flow rate of 19$m^3/min$ can reduce the risk by 11.86% compared with using low air flow rate of 10$m^3/min$. On the contrary, low air flow is suitable for cooking activities with low release rate of COFs. The air flow rate of 13$m^3/min$ is not a suggested operating conditions for cooking activities of these three dishes.
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