Science of the Total Environment 633 (2018) 308–316

Contents lists available at ScienceDirect

Science of the Total Environment

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

Characterization and health risk assessment of airborne pollutants in commercial restaurants in northwestern China: Under a low ventilation condition in wintertime

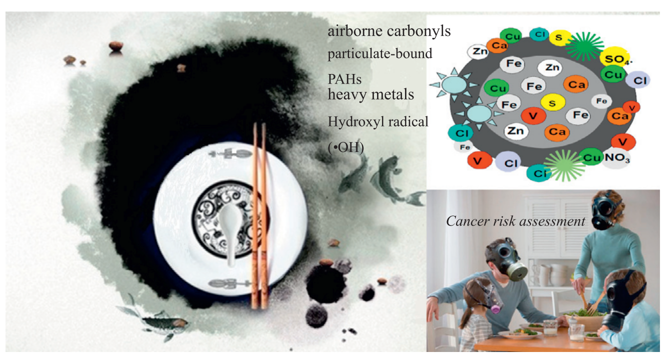
Wenting Dai [a,b], Haobin Zhong [a,b], Lijuan Li [a,b], Junji Cao [a,c], Yu Huang [a], Minxia Shen [a], Liqin Wang [a], Jungang Dong [d], Xuexi Tie [a,*], Steven Sai Hang Ho [e,**], Kin Fai Ho [f,g,***]

[a] *Key Laboratory of Aerosol Chemistry & Physics, SKLLQG, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710061, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *Institute of Global Environmental Change, Xi'an Jiaotong University, Xi'an 710054, China*
[d] *School of Architect, Xi'an University of Architect and Technology, Xi'an 710055, China*
[e] *Division of Atmospheric Sciences, Desert Research Institute, Reno, NV, United States*
[f] *Jockey Club School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong, China*
[g] *Shenzhen Municipal Key Laboratory for Health Risk Analysis, Shenzhen Research Institute, The Chinese University of Hong Kong, Shenzhen, China*

HIGHLIGHTS

- Cooking activities impacted on dining areas of restaurants.
- Cooking methods and fuels are dominated sources.
- In-dining cooking and cigarette smoke contributed to indoor pollution.
- Cancer risk assessments demonstrate the environments were not optimistic.
- Reactive organic species were formed under poor ventilation environments.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 January 2018
Received in revised form 7 March 2018
Accepted 11 March 2018
Available online xxxx

Editor: Jianmin Chen

Keywords:
Cooking emission
Carbonyls
PAHs

ABSTRACT

Impacts on indoor air quality of dining areas from cooking activities were investigated in eight categories of commercial restaurants including Szechwan Hotpot, Hunan, Shaanxi Noodle, Chinese Barbecue, Chinese Vegetarian, Korean Barbecue, Italian, and Indian, in Northwestern China during December 2011 to January 2012. Chemical characterization and health risk assessment for airborne carbonyls, and particulate-bound polycyclic aromatic hydrocarbons (PAHs) and heavy metals were conducted under low ventilation conditions in wintertime. The highest total quantified carbonyls ($\Sigma_{carbonyls}$) concentration of 313.6 μg m^{-3} was found in the Chinese Barbecue, followed by the Szechwan Hotpot (222.6 μg m^{-3}) and Indian (221.9 μg m^{-3}) restaurants. However, the highest $\Sigma_{carbonyls}$ per capita was found at the Indian restaurant (4500 μg capita^{-1}), suggesting that cooking methods such as stir-fly and bake for spices ingredients released more carbonyls from thermal cooking processes. Formaldehyde, acetaldehyde, and acetone were the three most abundant species, totally accounting for >60% of mass

* Correspondence to: X. Tie, Key lab of Aerosol Chemistry & Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China.
** Correspondence to: S.S.H. Ho, Division of Atmospheric Sciences, Desert Research Institute, Reno, NV, United States.
*** Correspondence to: K.F. Ho, Jockey Club School of Public Health and Primary Care, The Chinese University of Hong Kong, Shatin, Hong Kong, China.
E-mail addresses: tiexx@ieecas.cn (X. Tie), stevenho@hkpsrl.org (S.S.H. Ho), kfho@cuhk.edu.hk (K.F. Ho).

https://doi.org/10.1016/j.scitotenv.2018.03.124

Heavy metals
Commercial restaurants
Cancer risk assessment

concentrations of the $\Sigma_{carbonyls}$. Phenanthrene, chrysene, and benzo[*a*]anthracene were the three most abundant PAHs. Low molecular weight fraction ($\Sigma PAHs_{\leq 178}$) had the highest contributions accounting for 40.6%–65.7%, much greater than their heaver counterparts. Diagnostic PAHs ratios suggest that cooking fuel and environmental tobacco smoke (ETS) contribute to the indoor PAHs profiles. Lead was the most abundant heavy metal in all sampled restaurants. High quantity of nickel was also found in samples due to the emissions from stainless-steel made kitchen utensils and cookware and ETS. Cancer risk assessments on the toxic substances demonstrate that the working environment of dining areas were hazard to health. Formation of reactive organic species (ROS) from the cooking activities was evidenced by measurement of hydroxyl radical (•OH) formed from simulating particulate matter (PM) react with surrogate lung fluid. The highest •OH concentration of 294.4 ng m^{-3} was detected in Chinese Barbecue. In addition, the elevation of the concentrations of PM and •OH after non-dining periods implies that the significance of formation of oxidizing-active species indoor at poor ventilation environments.

1. Introduction

Fuel combustions for cooking and heating are one of the major sources of indoor air pollution which influence half of population in the world (WHO, 2002). Cooking methods such as grill, deep and stir fries, bake, and boil can produce many organic and inorganic air pollutants. Foods, ingredients, and cooking oils as raw materials produces different emissions from cooking processes. High operation temperatures may lead to different degrees of degradation of nutrients (i.e., sugar, protein, and fat), which can form a series of primary pollutants in cooking oil fumes (COFs) (Shields et al., 1995; Lee et al., 2001; Svendsen et al., 2002; Pan et al., 2008; Kabir and Kim, 2011; Alves et al., 2014).

Airborne carbonyls, polycyclic aromatic hydrocarbons (PAHs), heavy metals, and particulate matter (PM) are often observed in cooking emissions (Shields et al., 1995; Lee et al., 2001; Svendsen et al., 2002; Lund and Petersen, 2006; Kabir and Kim, 2011). Many of these species are known carcinogens (IARC, 2016) (Table 1). Formaldehyde can cause nasopharyngeal cancer (IARC, 2004) and is suggested to be potentially associated with leukemia (Zhang et al., 2009a, 2009b) and acetaldehyde is also a suspected carcinogen (Baez et al., 2003; Zhang et al., 1994). Zhang et al. (2009a, 2009b) reported that as much as 1.6% of lung cancer cases in China can be ascribed to inhalation of PAHs in polluted air. Besides, anthropogenic fine particles are often enriched with toxic heavy metals, which are of particularly concern on human health (Dockery and Pope, 1996). Many epidemiological studies demonstrated that inhalation of the toxic pollutants from cooking can raise lung cancer risks, obviously even in non-smokers (Seow et al., 1998; Seow et al., 2000; Parkin et al., 2005; Samet et al., 2009; Yuan et al., 2014). In addition, Asian women have a higher incidence of lung cancer than men despite their smoking prevalence is comparatively lower (Seow et al., 2000). Cooking emission pollutants can be thus considered as potential carcinogens. The adverse health effects from ambient PM are linked to the formation of reactive oxygen species (ROS) in cardiopulmonary tissues. While hydroxyl radical (•OH) is the most reactive species, it can react with different organic molecules at diffusion-controlled rate constants (Held et al., 1996; Forman et al., 2010).

Table 1
Classification of carcinogenic carbonyls, PAHs and heavy metals (IARC, 2016).

Compounds	Classification[a]
Formaldehyde	Group 1, 2012
Acetaldehyde	Group 2B, 1999
Fluorene	Group 3, 2010
Phenanthrene	Group 3, 2010
Benzo[*b*]fluoranthene	Group 2B, 2010
Benzo[*k*]fluoranthene	Group 2B, 2010
Benzo[*a*]pyrene	Group 1, 2012
Indeno[1,2,3-*cd*]pyrene	Group 2B, 2010
Benzo[*ghi*]pyrene	Group 3, 2010
Dibenzo[*a,h*]anthracene	Group 2A, 2010
Chromium (Cr)	Group 3, 1990
Cobalt (Co)	Group 2B, 1991
Nickel (Ni)	Group 2B, 1990
Arsenic (As)	Group 1, 2012
Selenium (Se)	Group 3, 1987
Cadmium (Cd)	Group 1, 2012
Mercury (Hg)	Group 3, 1993
Lead (Pb)	Group 2B, 1987

Group 2A: Probably carcinogenic to humans.
Group 2B: Possibly carcinogenic to humans.
Group 3: Not classifiable as to its carcinogenicity to humans.
[a] Group 1: Carcinogenic to humans.

Xi'an (33.42°N-34.45°N and 107.40°E-109.49°E), the capital city in Northwestern China, has a population of over 8 million in an urban area of 1066 km^2. There were >1000 food production enterprises and 24,757 catering service licensed restaurants in 2015 (Zhao et al., 2016). However, indoor air quality of dining areas impacted by different cooking activities is often overlooked. Currently, researches are mostly focused on emission profiles from cooking processes, while air samples were collected directly from the exhausts in kitchens. According to the Chinese National Data in 2014, the total number of restaurant employees was 2.5 million in Mainland of China (National Bureau of Statistics of China, 2014). The health of the workers who serve in dining areas (e.g., waiters, waitress, and cashiers) must be taken into account. This is particularly critical due to low indoor ventilation rates resulted from heat preservation in northern China in winter. In this study, air samples were collected in dining areas of common types of restaurants at an urban center in Xi'an city. Chemical profiles were obtained and factors affected the indoor air quality of dining places were determined. Health assessments were also conducted regarding to pollutant levels. The results are essential reference for establishment of local regulations for indoor air quality in commercial restaurants.

2. Data and methods

2.1. Sampling site description

Eight commercial restaurants were selected in this study based on their ubiquity. They were all located in the Great Wild Goose Pagoda at Qujiang District in southeastern Xi'an, and catalogized as Szechwan Hotpot (R1), Hunan (R2), Shaanxi Noodle (R3), Chinese Barbecue (R4), Chinese Vegetarian (R5), Korean Barbecue (R6), Italian (R7) and Indian (R8). Table 2 lists the details of each restaurant, including major foods served, ingredients involved, cooking methods, fuel types, exhausts in kitchens, and ventilation systems equipped in dining areas.

All ground-floor restaurants were selected in this study. The kitchen was located at the same level which separated from the dining area in each restaurant. The kitchen door was kept closure all the times, and most dishes were transferred through a pick-up window (<0.5 m^2) on the wall of kitchen. As the sampling campaigns were conducted in winter, heat was supplied to indoors through central hot-water circulation