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Carbonyl compounds in dining areas, kitchens and exhaust streams in restaurants with varying cooking methods in Kaohsiung, Taiwan

*Jen-Hsuan Cheng, Yi-Shiun Lee, Kang-Shin Chen**

Institute of Environmental Engineering, "National" Sun Yat-Sen University, Kaohsiung, Taiwan, Chinese Taipei, E-mail: d003030004@gmail.com

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ABSTRACT

Eighteen carbonyl species in C_1–C_{10} were measured in the dining areas, kitchens and exhaust streams of six different restaurant types in Kaohsiung, southern Taiwan. Measured results in the dining areas show that Japanese barbecue (45.06 ppb) had the highest total carbonyl concentrations (sum of 18 compounds), followed by Chinese hotpot (38.21 ppb), Chinese stir-frying (8.99 ppb), Western fast-food (8.22 ppb), Chinese–Western mixed style (7.38 ppb), and Chinese buffet (3.08 ppb), due to their different arrangements for dining and cooking spaces and different cooking methods. On average, low carbon-containing species (C_1–C_4), *e.g.*, formaldehyde, acetaldehyde, acetone and butyraldehyde were dominant and contributed 55.01%–94.52% of total carbonyls in the dining areas of all restaurants. Meanwhile, Chinese–Western mixed restaurants (45.48 ppb) had high total carbonyl concentrations in kitchens mainly because of its small kitchen and poor ventilation. However, high carbon-containing species (C_5–C_{10}) such as hexaldehyde, heptaldehyde and nonanaldehyde (16.62%–77.00% of total carbonyls) contributed comparatively with low carbon-containing compounds (23.01%–83.39% of total carbonyls) in kitchens. Furthermore, Chinese stir-frying (132.10 ppb), Japanese barbecue (125.62 ppb), Western fast-food (122.67 ppb), and Chinese buffet (119.96 ppb) were the four restaurant types with the highest total carbonyl concentrations in exhaust streams, indicating that stir-frying and grilling are inclined to produce polluted gases. Health risk assessments indicate that Chinese hotpot and Japanese barbecue exceeded the limits of cancer risk (10^{-6}) and hazard index (=1), mainly due to high concentrations of formaldehyde. The other four restaurants were below both limits.

Introduction

In indoor environments, air pollutants such as airborne particles, monoxide (CO), acid and volatile organic gases (VOCs) may be harmful to human health. Indoor air quality has therefore received considerable public attention since many people spend most of their time in a house or office. In Taiwan, residential and business buildings are usually closely neighbored near urban areas because of the high population density. Restaurants are often run on the first or second floor of the buildings, while inhabitants live in the upper floors. Inhabitants may complain about fumes or odors from nearby restaurants. The Taiwan Environmental Protection Agency (EPA) therefore requires restaurant owners to maintain a clean indoor environment and to have devices for controlling fumes and other emissions. In this regard, the Taiwan-EPA formally issued the standards for indoor air quality in 2012 to

* *Corresponding author.* E-mail: shin@mail.nsysu.edu.tw (Kang-Shin Chen).

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regulate the concentrations of nine substances in indoor environment. The standards regulate the levels of coarse particles (PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), total VOCs, bacterium and fungi, fine particles ($PM_{2.5}$) and formaldehyde. The last two are newly added, being 35 $\mu g/m^3$ for $PM_{2.5}$ (24-hr value) and 80 ppb (1-hr value) for formaldehyde (a carbonyl species), while the other seven were enforced earlier *via* the so-called "suggested values" in the past (not shown here).

Most airborne carbonyl compounds (carbonyls) associated with human activities are generated by exhaust gases of incomplete combustions of fossil fuels in industrial processes (Cavalcante et al., 2006; Cetin et al., 2003; Cheung et al., 2008; Ho et al., 2002; Liu et al., 2006; Muller, 1997; Pang et al., 2006; Seco et al., 2007; Wang et al., 2010) and motor vehicles (Cheung et al., 2008; Correa et al., 2003; K.F. Ho et al., 2006; Kean et al., 2001; Pang et al., 2006; Schauer et al., 1999; Siegl et al., 1999) and aldehyde and ketone are among the major VOC species in photochemical air pollution (Atkinson et al., 1995; Carlier et al., 1986; Carter, 1994; Muller, 1997; Viskari et al., 2000). However, studies indicate that carbonyls such as formaldehyde and acetone can be released from decorative paint on woods, furnishings and walls (Baez et al., 2003; Clarisse et al., 2003; Gilbert et al., 2005), from detergents and organic solvents (Cetin et al., 2003), and from cooking oils or foods (Andreu-Sevilla et al., 2009; Huang et al., 2011; Seaman et al., 2009; Wuwilliams et al., 1990). For example, Chinese stir-frying generates oil droplets and gases in fumes containing polycyclic aromatic hydrocarbons (PAHs), aldehyde and ketone (Fu et al., 1997; He et al., 2004; Kataoka, 1997; Wu et al., 2004). Many of these PAHs and carbonyl compounds are toxic and exhibit matagenicity, cancinogenicity and genetic toxicity (Chiang et al., 1997; Qu et al., 1992). A study of indoor air quality by (Lee et al., 2001) measured the concentrations of CO, CO_2, PM_{10}, and PAHs (benzene, toluene, methylene, chloride, and chloroform) in the dining areas of Chinese hotpot restaurant and a Korean barbecue shop. Zhao et al. (2007) measured concentrations of particulate organic matter emitted from Western-style fast food cooking. Wang et al. (2007) measured the indoor and outdoor carbonyl compounds in twelve dwellings in the four largest cities in China. However, few studies have compared carbonyl compound concentrations in restaurants that use different cooking methods. S.S.H. Ho et al. (2006) measured thirteen carbonyl compounds (C_1–C_9) from the exhausts in fifteen commercial kitchens in Hong Kong. A source-apportionment analysis indicated that emissions from restaurants contributed to 20%–30% of carbonyl compounds in the atmosphere of Kaohsiung metropolitan area (Wang et al., 2010).

The objective of this work was to quantify the concentrations of eighteen carbonyl compounds in C_1–C_{10} in the dining areas, kitchens and exhausts of six restaurants that use different cooking methods and are located in urban Kaohsiung (22°38′N, 120°17′E), southern Taiwan. Human health effects in the dining areas were also examined.

1. Methods and materials

Six restaurants with different cooking methods were sampled in urban Kaohsiung: Chinese buffet, Chinese hotpot, Japanese barbecue, Western fast food, Chinese–Western mixed (abbreviated as C–W mixed style), and Chinese stir-frying. Besides different cooking methods such as food, cooking oil and heating source, these restaurants had exhaust pipes that were available for us to set up sampling devices. Table 1 lists the general information and characteristics of each restaurant. The heating source in each restaurant was either liquefied petroleum gas (LPG) or electricity, and the cooking oil was vegetable oil. However, the Chinese hotpot restaurant used alcohol grease underneath the pot for heating, and the Japanese barbecue restaurant used coals for grilling. The combustion of LPG emits trace amounts of carbonyl emissions (Zhang and Smith, 1999), and electricity produces no carbonyl emissions. Therefore, the main sources of carbonyl compound emissions are oils, coal, and foods. The dining area and kitchen area were sampled concurrently while exhaust pipes were sampled separately. Notably, the kitchen of the Chinese hotpot restaurant was essentially a storeroom rather than a kitchen (*i.e.*, it had no exhaust pipe). Thus, the kitchen and exhaust pipe of the Chinese hotpot restaurant were not measured. All samplings were taken over a 30-min period during lunch time (11:00–13:00) or dinner time (18:00–20:00) at a fixed flow rate of 1 L/min (AirCheck 2000, SKC, USA) in dining areas and kitchens and at 0.2 L/min (Pocket Pump, SKC, USA) at the outlets of exhaust pipes, using a silica cartridge impregnated with 2,4-dinitrophenylhydrazine (2,4-DNPH). The flow rate through the cartridges was measured with a rotameter before and after each sampling period. The rotameter was calibrated in the laboratory against a soap bubble flow meter (APB-805010, A. P. BUCK, USA). An ozone scrubber was connected to the inlet of the 2,4-DNPH silica cartridge to prevent interference from ozone. The sampled cartridges were then marked and stored in the laboratory refrigerator below 4°C and analyzed within 24 hr. During analysis, the sampled cartridges were slowly eluted with 1 mL of acetonitrile (CAN) into a 5 mL volumetric flask. A 10 μL aliquot of the eluted 2,4-DNPH was then injected into a high performance liquid chromatograph (HPLC) system (HP-1100, Agilent Technologies, USA) through an auto-sampler for further analysis.

Carbonyl compounds were identified and quantified according to retention times and peak areas of individual calibration standards. All analysis procedures were compiled with the

Table 1 – A summary of six restaurants investigated.

Restaurant	Cooking oil	Heating source	Control device
Western fast food	Roast, bake	LPG, electricity	Electrostatic precipitator
C–W mixed style	Bake, soybean oil	LPG, electricity	Oil–water separator & Electrostatic precipitator
Chinese buffet	Roast, bake, soybean oil	LPG	Electrostatic precipitator
Chinese stir-frying	Soybean oil	LPG	Electrostatic precipitator r
Japanese barbecue	Coal, grilling	(None)	Oil–water separator & Electrostatic precipitator
Chinese hotpot	Alcohol grease	(None)	(None)

LPG: liquefied petroleum gas; C–W mixed style: Chinese–Western mixed style.