Journal of Hazardous Materials 302 (2016) 198–207

Contents lists available at ScienceDirect

Journal of Hazardous Materials

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

Emissions of air pollutants from indoor charcoal barbecue

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HIGHLIGHTS

- Emission inventory of air pollutants established for charcoals used in Taiwan.
- High-risk air pollutants emitted from charcoal briquette combustion.
- Harmful $PM_{2.5}$ was main particulate generated during charcoal combustion.
- More HCHO and C_2H_4O produced at flaming stage of charcoal combustion.

ARTICLE INFO

Article history:
Received 7 June 2015
Received in revised form
19 September 2015
Accepted 22 September 2015
Available online 26 September 2015

Keywords:
Indoor air quality
Barbecue
Formaldehyde
Acetaldehyde
Particulate matter

ABSTRACT

Ten types of commercial charcoal commonly used in Taiwan were investigated to study the potential health effects of air pollutants generated during charcoal combustion in barbecue restaurants. The charcoal samples were combusted in a tubular high-temperature furnace to simulate the high-temperature charcoal combustion in barbecue restaurants. The results indicated that traditional charcoal has higher heating value than green synthetic charcoal. The amount of PM_{10} and $PM_{2.5}$ emitted during the smoldering stage increased when the burning temperature was raised. The EF for CO and CO_2 fell within the range of 68–300 and 644–1225 g/kg, respectively. Among the charcoals, the lowest EF for $PM_{2.5}$ and PM_{10} were found in Binchōtan (B1). Sawdust briquette charcoal (I1S) emitted the smallest amount of carbonyl compounds. Charcoal briquettes (C2S) emitted the largest amount of air pollutants during burning, with the EF for HC, $PM_{2.5}$, PM_{10}, formaldehyde, and acetaldehyde being the highest among the charcoals studied. The emission of $PM_{2.5}$, PM_{10}, formaldehyde, and acetaldehyde were 5–10 times those of the second highest charcoal. The results suggest that the adverse effects of the large amounts of air pollutants generated during indoor charcoal combustion on health and indoor air quality must not be ignored.

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1. Introduction

Because of social change and urban crowding, people spend over 80% of their time indoors [1]. Under the fast development of industry and commerce, lifestyle and dietary habits of People also change quickly. Eating out has become quite common catering pattern in Taiwan. The self-service dining restaurants of buffet barbecue bloom in Taiwan in recent years [2]. Charcoal is made by slow thermal pyrolysis process, which burning wood or other materials in the absence of oxygen. Because charcoal has many advantages including higher energy content, easier to handle, burning evenly for a long time, easily to extinguish and reheat, and not liable to damage by insects and fungi, it has been widely used in barbecue [3]. However, people will probably expose to emitted air pollutants directly from charcoal-fired appliance during barbecue in indoor. It was noted that combustion pollutants, particularly carcinogenic compounds, could cause health effects on barbecue customers under insufficient ventilation. Formaldehyde, related to nasopharyngeal tumors [4], classifying as carcinogenic to humans (Group 1) by International Agency for Research on Cancer [5]. Acetaldehyde was classified as possibly carcinogenic to humans in 1987 and confirmed in 1999 by IARC [6,7]. The levels of airborne formaldehyde are often 2∼10-fold higher than those in outdoor air [8–10]. The common indoor noncombustion sources of formaldehyde and acetaldehyde are released from many industrial and consumer products; otherwise, they are also produced as byproducts from various combustion activities [11–13] such as cooking, smoking, heating, and incense burning.

Lee and Wang [14] burned mosquito coils in a chamber and found formaldehyde and acetaldehyde were the major carbonyls

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http://dx.doi.org/10.1016/j.jhazmat.2015.09.048
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Table 1
Commonly used charcoals in Taiwan.

Charcoal ID	Charcoal name	Photo	Country source	Approximately profile
C1S	Eco-friendly charcoal		China	Brick shape
C2S	Charcoal briquettes		China	Oblate spheroid shape 4 cm in diameter
C3S	Charcoal briquettes		China	Oblate spheroid shape 4 cm in diameter
I1S	Sawdust briquette charcoal		Indonesia	Hexagon 4 cm in diameter and 1 cm diameter hollow core
I2	Mangrove charcoal		Indonesia	15–20–cm long and 3–6–cm in diameter
I3S	Charcoal briquettes		Indonesia	Oblate spheroid shape 4 cm in diameter
T1S	Eco-friendly charcoal		Taiwan	Quasi rectangular pyramid($4 \times 4 \times 7$ cm)
T2	Acacia charcoal		Taiwan	Irregular shape 15 cm in diameter
T3	Longan charcoal		Taiwan	Irregular shape 15 cm in diameter
B1	Binchōtan		Southeast Asia	10–15 cm long and 2–4 cm in diameter

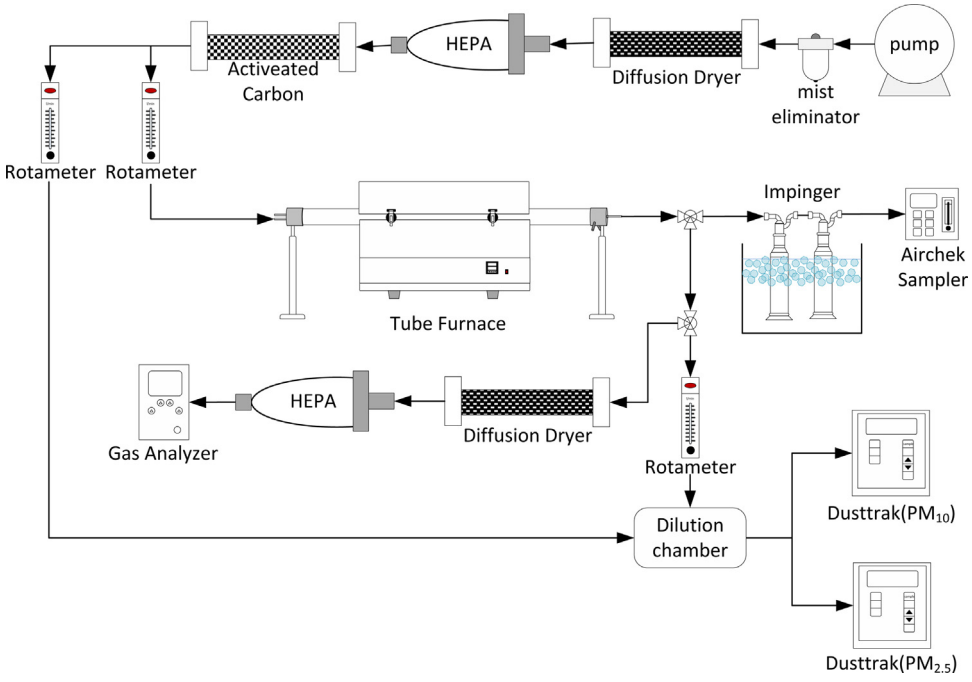

Fig. 1. Experimental system of charcoal combustion.

species presented in smoke. Manoukian et al. [15] indicated that the maximum concentrations of formaldehyde and acetaldehyde in an experimental room were produced immediately after burning of incense sticks. Huang et al. [16] found that the generated formaldehyde were almost the same by using towngas and liquefied petroleum gas as cooking fuels. However, acetaldehyde, the highest emitted carbonyl species, was only observed at the kitchen using towngas as cooking fuel. Carteret et al. [17] investigated average emission factors of formaldehyde were 14.4 mg/kg and 8.0 mg/kg from wick and injection heater with five kinds of fuel respectively. The emission factors of formaldehyde were higher than those of acetaldehyde for two kinds of heater. Cerqueira et al. [18] characterized the average concentration ratio of formaldehyde to acetaldehyde in the stove with burning of 5 kinds of wood was in the range of 2.1–2.9. Pyrenean oak produced the highest emissions for both formaldehyde and acetaldehyde and maritime pine produced the lowest emissions. Kabir et al. [19] showed that formaldehyde and acetaldehyde were the abundant among emitted carbonyl compounds from the combustion of commonly used barbecue charcoals produced from 4 countries in Korea. Rahman and Kim [20] also indicated that aldehydes were the most dominant odorant released during combustion of barbecue charcoals

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