Journal of Aerosol Science 103 (2017) 132–140

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

A controlled study for the characterization of $PM_{2.5}$ emitted during grilling ground beef meat

Mehdi Amouei Torkmahalleh[a,b,*], Soudabeh Gorjinezhad[b], Melek Keles[d], Hediye Sumru Unluevcek[b], Cansu Azgin[b], Elif Cihan[c], Berfin Tanis[c], Nurseli Soy[c], Nergis Ozaslan[c], Fatma Ozturk[c], Philip K. Hopke[d]

[a] Chemical and Aerosol Research Team, Nazarbayev University, Astana 010000, Kazakhstan
[b] Chemical Engineering Program, Middle East Technical University Northern Cyprus Campus, Guzelyurt, Mersin 10, Turkey
[c] Department of Environmental Engineering, Faculty of Engineering and Architecture, Abant Izzet Baysal University, Golkoy Campus, 14280 Bolu, Turkey
[d] Center for Air Resources Engineering and Science, Clarkson University, Potsdam, NY 133699-5708, USA

ARTICLE INFO

Keywords:
Grilling
Beef meat
PM
OC/EC
Metal
Emission rate

ABSTRACT

Experiments were conducted in an on-campus house at Middle East Technical University Northern Cyprus Campus during January 2015. Low fat ground beef meat was grilled using an electric stove with no mechanical or natural ventilation. Five PM size fractions ranging from 3.3 μm to less than 0.43 μm were investigated in this study. The total particle emission rate and flux values were found to be 4.49×10^{1} mg min^{-1} and 1.45×10^{3} mg min^{-1} m^{-2}, respectively. Total OC emission rate and flux values were 2.3×10^{1} mg min^{-1} and 7.33×10^{2} mg min^{-1} m^{-2}, respectively, and total EC emission rate and flux values were determined to be 1.19 mg min^{-1} and 3.85×10^{1} mg min^{-1} m^{-2}, respectively. Analyses of trace metal concentrations showed that Fe (0.429 mg m^{-3}), Ti (0.270 mg.m^{-3}), Sr (0.27 mg m^{-3}), Ba (0.24 mg m^{-3}) and Li (0.23 mg m^{-3}) were the five most abundant trace elements in the PM produced during grilling ground beef. Pb, Mn, and V concentrations were found to be greater than the World Health Organization (WHO) exposure limit.

1. Introduction

Cooking was reported to be one of the major producers of indoor particulate matter (PM) (Dennekamp et al., 2001; Hussein et al., 2006; Wan, Wu, To, Chan, & Chao, 2011; Massey, Kulshrestha, Masih, & Taneja, 2012). Among 20 indoor activities including cooking and smoking performed in 15 houses in Australia, cooking was found to generate the highest level of $PM_{2.5}$ emission rate (He, Morawska, Hitchins, & Gilbert, 2004a). Among 87 cooking scenarios conducted in Amsterdam, Netherland and Helsinki, Finland, the $PM_{2.5}$ concentration ranged from 1.9 to 3.4 mg m^{-3} (Brunekreef et al., 2005). Among the possible cooking activities, grilling, charbroiling, and frying have been found to be responsible for the highest particle emission (McDonald et al., 2003; Nasir & Colbeck, 2013; See & Balasubramanian, 2008; See & Balasubramanian, 2006; He et al., 2004a). Sources that may contribute to frying or grilling PM emissions and indoor PM concentrations include, but are not limited to the cooking oil, gas or electric stove, meat and vegetables (To & Yeung, 2011; Jorgensen, Strandberg, Sjaastad, Johansen, & Svendsen, 2013; Amouei Torkmahalleh et al., 2012; See and Balasubramanian, 2006; Evans, Peers, & Sabaliauskas, 2008; Olson & Burke, 2006).

* Corresponding author at: Chemical and Aerosol Research Team, Nazarbayev University, Astana 010000, Kazakhstan.
E-mail address: mehdi.torkmahalleh@nu.edu.kz (M.A. Torkmahalleh).

http://dx.doi.org/10.1016/j.jaerosci.2016.10.011
Received 12 October 2016; Received in revised form 17 October 2016; Accepted 18 October 2016
Available online 29 October 2016
0021-8502/

Understanding the contributions of such sources is a key as it could then give us an idea to identify the most influential sources which can determine the overall PM size distribution of a cooking activity. Properly controlling the key sources such as reducing the lipid content of the meat, selecting a low emitting oil or improving the fuel quality, during cooking in a way that it reduces the indoor particle concentrations is beneficial.

Several previous studies investigated the emitted PM and its chemical composition during different normal cooking activities such as grilling or frying (Shu et al., 2015; Zhang, Gangupomu, Ramirez, & Zhu, 2010; McDonald et al., 2003; See & Balasubramanian, 2008; Dennekamp et al., 2001; He et al., 2004b). However, a key question that has remained unanswered among such studies is what the oil and/or the cooked meat contributed to PM, organic carbon (OC), elemental carbon (EC) and metal emissions. It is difficult to make definitive conclusions regarding the contribution of each PM source during normal cooking activities since multiple sources coexist in one cooking activity. Controlled studies are required to characterize the PM emitted from one cooking source separate from all other sources.

There are only a limited number of controlled cooking PM characterization studies that have been reported. Amouei Torkmahalleh et al. (2012) found that oil itself generated PM, and canola and soybean oils were among the lowest emitting oils. Another controlled study demonstrated that table salt, sea salt, and black pepper markedly reduced the $PM_{2.5}$ (up to 91%) emission rates during heating of low emitting cooking oils (Amouei Torkmahalleh, Zhao, Rossner, Hopke, & Ferro, 2013a). Wallace et al. (2015) showed that the electric coil or pan itself does not directly produce PM, but rather than it is the organic compounds deposited on the surface of the metals that generate PM. Several controlled studies found differences in the PM emissions using different stoves (Buonanno, Morawska, & Stabile, 2009; Jorgensen et al., 2013) and cooking oils (Gao, Cao, Zhang, & Luo, 2013). Only one study was previously conducted (Anis & Anis, 1989) to investigate PM mass size distributions from heated fat-rich ground beef. However, no data regarding the PM, OC, and EC emission rates as well as elemental compositions were reported (Anis & Anis, 1989).

The aim of this study was to examine the size segregated mass concentrations and emission rates of the emitted PM, OC, and EC as well as the emitted metal concentrations during grilling low-fat ground beef.

2. Materials and methods

2.1. Particle emission experiments during grilling beef meat

The experiments were conducted in January 2015 in an on-campus house at Middle East Technical University Northern Cyprus Campus. The house was unoccupied more than a year, and only two investigators were present in the house during the course of experiments.

No activities other than cooking took place. The dimension of the kitchen where cooking toke place was 29.97 m^3 (H (270 cm), L (370 cm) and W (300 cm)). All of the doors and windows were closed to reduce the impact of outdoor particles on the experiments. No mechanical ventilation was operating. The heating systems in all of the rooms were off to avoid possible dust resuspensions through the air ducts. Between the experiments, all of the doors and windows were left open for 24 h to reduce the indoor concentrations to a background level. The temperature of the kitchen was measured to be 13–15 °C during the sampling campaign.

Some low fat (according to the butcher) ground beef was purchased from a local market. For each experiment, 250 g of the meat was placed in a PTFE-coated aluminum pan (24 cm diameter) such that 0.031 m^2 of the pan's surface was covered by the meat. The meat was heated using an electric stove at its medium setting. After five minutes of grilling, the meat was flipped using a spatula, and grilling continued for thirteen more minutes for a total of eighteen minutes of grilling. The stove was switched off, but sampling continued for two more minutes, for a total sampling time of twenty minutes. The temperature of the ground meat reached 90 °C at the end of the eighteen minutes grilling period. Prior to the start of each cooking experiment, the pan and the stove were washed with detergent, rinsed thoroughly, and dried.

2.2. Preliminary experiments for the measurement of the effective volume

A PTFE-coated aluminum pan containing 150 ml corn oil (oil's surface area: 0.031 m^2) was heated for 14 minutes resulting in a maximum oil temperature of 250 °C. Then, the stove was turned off and sampling continued for six more minutes (total of twenty minutes). All of the experimental parameters during the preliminary study such as sampling distance, room temperature, ventilation and etc. were the same as for the grilling experiments.

2.3. Background experiments

Background concentrations (PM=4.1 μg m^{-3}, OC=0.6 μg m^{-3}, EC=0.05 μg m^{-3} and metals=0.87 μg m^{-3}) were measured before the experiments on three different days, and cooking particle concentrations were corrected for the background concentrations. Particles emitted by the heated (for 20–14 min heating plus 6 min cooling), empty (without beef meat), prewashed (with detergents) cooking pan using the prewashed electric stove (at medium setting) were considered as the background particles. The pan and stove were left to air dry before starting each experiment. All of the experiments including background measurements, preliminary experiments, and beef meat grilling were replicated three times. All of the experiments were performed using an electric stove at its medium heat setting.