JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Particulate matter emissions and gaseous air toxic pollutants from commercial meat cooking operations

Nicholas Gysel, William A. Welch, Chia-Li Chen, Poornima Dixit, David R. Cocker III, Georgios Karavalakis[*]

Department of Chemical and Environmental Engineering, University of California, Riverside, CA 92521, USA
Center for Environmental Research and Technology, University of California, Riverside, CA 92507, USA

ARTICLE INFO

Article history:
Received 22 November 2016
Revised 15 March 2017
Accepted 16 March 2017
Available online xxxx

Keywords:
Charbroiled meat cooking
Particulate emissions
Particle number
Carbonyl compounds
VOCs

ABSTRACT

This study assessed the effectiveness of three novel control technologies for particulate matter (PM) and volatile organic compound (VOC) removal from commercial meat cooking operations. All experiments were conducted using standardized procedures at University of California, Riverside's commercial test cooking facility. PM mass emissions collected using South Coast Air Quality Management District (SCAQMD) Method 5.1, as well as a dilution tunnel-based PM method showed statistically significantly reductions for each control technology when compared to baseline testing (*i.e.*, without a catalyst). Overall, particle number emissions decreased with the use of control technologies, with the exception of control technology 2 (CT2), which is a grease removal technology based on boundary layer momentum transfer (BLMT) theory. Particle size distributions were unimodal with CT2 resulting in higher particle number populations at lower particle diameters. Organic carbon was the dominant PM component (>99%) for all experiments. Formaldehyde and acetaldehyde were the most abundant carbonyl compounds and showed reductions with the application of the control technologies. Some reductions in mono-aromatic VOCs were also observed with CT2 and the electrostatic precipitator (ESP) CT3 compared to the baseline testing.

Introduction

Commercial cooking has been shown to be an important contributor to ambient particle emissions (with particulate matter less than 2.5 μm in size, $PM_{2.5}$) in urban environments and megacities (Allan et al., 2010; Schauer et al., 1999, 2002; Sun et al., 2011; Zhao et al., 2015). Emission inventory data showed that $PM_{2.5}$ emissions from restaurant operations in the Los Angeles Basin contributed approximately 9.15 tons per annual average day for 2014, with an estimate to exceed 10 tons per annual average day for 2023 (AQMP, 2012). In the greater Los Angeles Basin, restaurant operations including charbroilers (chain-driven and under-fired) are responsible for about 84% of the $PM_{2.5}$ emissions from this source category (AQMP, 2012). With an environmental problem of this magnitude, the South Coast Air Quality Management District (SCAQMD) was forced to implement rules as part of the Air Quality Management Plan for reducing 7 tons per day of PM_{10} from charbroilers. At present time, SCAQMD evaluates rule development efforts for restaurants including under-fired charbroilers to install control devices with at least 85% reduction in $PM_{2.5}$ emissions.

Recently, there is an intense research activity within the scientific community for the understanding of cooking organic

* *Corresponding author*. E-mail: gkaraval@cert.ucr.edu (Georgios Karavalakis).

http://dx.doi.org/10.1016/j.jes.2017.03.022

aerosol contribution to total organic aerosol in urban settings due to the importance of airborne particulate emissions and negative effects on human health (Mohr et al., 2012; Li et al., 2014; Robinson et al., 2006; Schauer et al., 1999). Numerous studies have found associations between particulate air pollution with asthma exacerbations, increased respiratory symptoms, decreased lung function, increased medication use, and increased hospital admissions (BeruBe et al., 2007; Kreyling et al., 2006; Utell and Frampton, 2000). Epidemiological studies have shown that exposure to particulate air pollution is associated with increased cardiovascular and respiratory morbidity and mortality (Pope, 2000; Sioutas et al., 2005). Oberdorster et al. (2005) have shown that ultrafine particles are more biologically active than larger particles due to their greater surface area per mass. It was also found that the small size facilitates uptake into cells and transcytosis across epithelial cells into the blood circulation to reach potentially sensitive areas, as well as penetrating the skin distribute *via* uptake into lymphatic channels.

Commercial cooking can generate particulate emissions, volatile organic compounds (VOCs), heterocyclic aromatic amines, and polycyclic aromatic hydrocarbons with the quantities of these pollutants strongly dependent on cooking procedures, such as cooking temperature, ingredients, duration, and other factors (Lewtas, 2007; McDonald et al., 2003; Nolte et al., 1999; Saito et al., 2014). Many studies have evaluated the effects of different cooking styles on PM and VOC emissions (Abdullahi et al., 2013; Cheng et al., 2016; He et al., 2004). Western cooking operations involve the consumption of beef and chicken, whereas Chinese cooking mainly involves frying with pork, poultry, beef, seafood, and vegetables. Zhao et al. (2007) showed a dominant presence of β-sitosterol and levoglucosan in $PM_{2.5}$ confirming that vegetable oils are consumed during Chinese cooking operations. Huang et al. (2011) reported a significant production of formaldehyde, acetaldehyde, and benzene during residential cooking activities in Hong Kong. Mugica et al. (2001) reported the non-methane organic compounds, including some monoaromatic hydrocarbons, of cooking emissions from tortillerias, restaurants, rotisseries, and fried food places in Mexico. They found that food cooking can be an important source of these species. Schauer et al. (1999) showed that formaldehyde and acetaldehyde were the predominant aldehydes from commercial charbroiling meat cooking operations. Buonanno et al. (2009) conducted a study to characterize particle emissions during grilling and frying and they found higher emission factors at higher food temperatures, as well as higher particle emissions as a function of the oil used. Rogge et al. (1991) reported increasing organic acids and higher PM emissions for meats with higher fat contents. McDonald et al. (2003) compared cooking methods and identified under-fired charbroiling meat cooking emitted the highest amount of $PM_{2.5}$ per pound of meat cooked. They also found that charbroiling emissions were almost exclusively composed of organic carbon (OC) in nature with almost no elements or inorganic ions. Hildemann et al. (1991) estimated that approximately 21% of all organic $PM_{2.5}$ in Los Angeles was from meat cooking, while Schauer et al. (2002) estimated that 23% of the $PM_{2.5}$ organic carbon mass emitted in Los Angeles was contributed from meat cooking activities.

Although previous studies have provided substantial data about indoor and outdoor cooking emissions, there is very limited data on the effects of aftertreatment control technologies on emissions from commercial cooking operations. In California, and most of the United States, smaller restaurant chains operating with under-fired charbroilers are not required to control their PM emissions, which are an environmental burden and also complicates the human risk assessment on cooking emissions. Thus, it is necessary to study emissions from under-fired charbroiled meat cooking operations with and without aftertreatment control technologies. This work examines the physical and chemical characteristics of $PM_{2.5}$, particle number emissions and gaseous toxic pollutants from meat cooking processes.

1. Materials and methods

1.1. *Test facility and protocol*

The meat cooking experiments were conducted at the University of California Riverside, Center for Environmental Research and Technology (CE-CERT) commercial cooking facility. The facility was equipped with a Nieco Model 9025 conveyorized charbroiler fired with natural gas. Total emissions were captured by a 48-inch by 48-inch Captive-Aire stainless steel hood and ducted to the second level of the facility with an upblast blower. The blower had a variable speed drive and controller, which was used to adjust the velocity and flow rates through the stack to meet the Uniform Mechanical Code (UMC) and National Fire Protection Association (NFPA).

Prior to testing, the hamburger patties were prepared by loading them onto sheet pans lined with freezer paper. The 1/3-pound meat patties used in this study were finished grind, pure beef hamburger, 21% fat by weight, 58%–62% moisture, 3/8-inch-thick, and 5 in. in diameter. The fat and moisture content of the patties were verified in accordance with recognized laboratory procedures (Association of Official Analytical Chemists, AOAC, Official Actions 960.39 and 950.46, respectively). Patties were cooked to an average internal temperature of 175 ± 5 °F, to confirm a medium-well condition. Internal meat temperature was determined with a stack of hamburger patties placed in a temperature measurement system.

Cooking cycles were developed in conjunction with the California and National cooking restaurant associations and private entities to best mimic commercial cooking processes and were six minutes in duration.

1.2. *Sampling and analysis*

A sampling system (Fig. 1) was devised to simultaneously collect multiple filter and gas samples. A sample was isokinetically withdrawn from the stack at a fixed flow rate and diluted with VOC and particle-free air using a partial flow venturi dilution system. The dilution system included quartz filters (Q1–Q3), Teflon filters (T1–T4), equipped with orifices to control flow rate through the filters and differential pressure (P1–P7) to measure filter loading. The total PM mass was determined by gravimetric analysis of 47 mm (Teflo®, Pall Gelman, USA) filters. The filters were conditioned and