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Review of factors impacting emission/concentration of cooking generated particulate matter

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HIGHLIGHTS

- Smoke temperature of the oil is well correlated with PM emission rates.
- Cooking on gas burners produce higher PM compared to electric stoves.
- Changing in cooking manner may reduce the cooking PM emissions.
- Exposed surface area of the oil and oil temperature impact the PM emission.
- Addition of salt to the oil prior heating may reduce the PM emission.

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ABSTRACT

Studies have shown that exposure to particulate matter (PM) emitted while cooking is related to adverse human health effects. The level of PM emissions during cooking varies with several factors. This study reviewed controlled studies available in the cooking PM emissions literature, and found that cooking method, type and quality of the energy (heating) source, burner size, cooking pan, cooking oil, food, additives, source surface area, cooking temperature, ventilation and position of the cooking pan on the stove are influential factors affecting cooking PM emission rates and resulting concentrations. Opportunities to reduce indoor PM concentrations during cooking are proposed. Minor changes in cooking habits and manner might result in a substantial reduction in the cook's exposure to the cooking PM. Finally, the need for additional studies is discussed.

1. Introduction

Airborne particulate matter (PM) is among six primary pollutants monitored by the U.S. Environmental Protection Agency (EPA) through the Clean Air Act (EPA, 2014). Although not part of the regulations, indoor PM is important since people spent most of their time indoors (Wallace et al., 2004). Long et al. (2000) found that the indoor sources of PM are typically short term and high concentration events that generate coarse particles (2.5 μm < D_p < 10 μm) and ultrafine particles (UFPs) (particles < 100 nm in diameter (D_p < 0.1 μm). Cooking emissions in a residential or commercial kitchen results in human exposure to both $PM_{2.5}$ and UFPs (Abdullahi et al., 2013). Previous studies identified cooking as one of the most important sources in generating indoor PM (Dennekamp et al., 2001; Hussein et al., 2006; Wan et al., 2011; Massey et al., 2012). Nasir and Colbeck (2013) demonstrated that the $PM_{2.5}$ and particle number emission rates measured during cooking activities in the kitchen (N = 24) were higher than the corresponding values for smoking in the living rooms (N = 20). He et al. (2004) investigated $PM_{2.5}$ and submicron particle (7 nm to 808 nm) emission rates in 15 houses in Australia while performing 20 indoor activities such as cooking (frying, grilling, toasting, microwaving, oven use, kettle), smoking, sweeping floor, vacuuming, candle burning and hair drying. They found cooking as the largest source of indoor air pollution with the highest level of $PM_{2.5}$ (2.78 ± 17.8 mg·min^{-1}). Wallace and Ott (2010) conducted a 3-year study in a variety of indoor environments in the United States including two occupied homes, one test home, two cars as well as 22 restaurants. They found that cooking using gas or electric stoves and toaster ovens were among the major sources of indoor UFP.

International Agency for Research on Cancer (IARC) classified high temperature frying emissions as "probably carcinogenic to human (Group 2A)" (IARC, 2006). Polyaromatic hydrocarbons (PAHs) are among the carcinogenic and mutagenic compounds in cooking

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emissions that exist in the both the gaseous and particulate phases (Jorgensen et al., 2013; Beko et al., 2013). See and Balasubramanian (2006) performed a risk assessment of exposure to the indoor aerosol associated with Chinese cooking and reported a high potential of adverse health effects for those who may be exposed to cooking fumes such as cooks, workers, and customers of restaurants. Ko et al. (2000) found that exposure to cooking fumes is an important risk factor for lung cancer among nonsmoking Taiwanese women. They reported that the lung cancer risk increased with the number of cooked meals per day to about threefold for nonsmoking women who cooked daily. Their study suggested that cooking habits (e.g. waiting in the kitchen until heated cooking oil reaches to a high temperature before cooking food), may increase the risk of lung cancer. Studies involving large populations in India (Agrawal, 2012) and USA (Barry et al., 2010) showed a positive association between asthma and employing solid fuels such as wood, coal, and biomass during indoor cooking.

Adetona et al. (2013) studied pregnant women exposure to PAHs. They compared creatinine adjusted hydroxy-PAH (OH-PAH) concentrations in pregnant women in Trujillo, Peru who cooked using wood to those who cooked using kerosene, liquefied petroleum gas, or a combination of fuels. Women who cooked exclusively using wood or kerosene experienced higher creatinine adjusted OH-PAH concentrations in their urine samples compared to those who cooked using LPG or coal briquette. Data from 5561 males and 6029 females living in 11 countries were analyzed by Jarvis et al. (1998). Among male participants, no significant correlation was found between respiratory symptoms and gas cooking while airway obstructions were observed. In females, wheeze and airway obstruction were found to be associated with gas cooking.

Wong et al. (2013) conducted a study on five years of data in 47 countries among primary (aged 6–7 years) and secondary (aged 13–14 years) school children to understand the impact of cooking combustion sources (open fire and gas cooking). They found an increased risk of asthma while using open fire cooking among both groups of children. No association between asthma and gas cooking in both groups of children was concluded.

Recently, Stabile et al. (2015) measured the exhaled nitric oxide (NO) by 43 non-atopic nonsmoking women while cooking as an indication of short term respiratory effects (airway inflammation). They found an association between the exposures of women to cooking PM and short-term exhaled NO, in particular for those who utilized electric stove for cooking. Their results revealed a potential link between short-term exposure to cooking aerosol and women respiratory inflammation.

As there would be a direct relationship between cooking PM concentration and health problems, the key idea in the current review study is to identify and discuss the parameters that influence the emissions of cooking PM. None of the previous review articles on cooking emissions (Kim et al., 2011; Abdullahi et al., 2013; Calvo et al., 2013) have specifically and extensively reviewed controlled studies.

2. Methods

A careful literature search was performed to select the articles that reported experimental data on cooking PM. Among the selected articles, those that performed a controlled study on cooking PM emissions are discussed. Some literature provided PM emission rate data, and some other reported PM concentrations while cooking. To make definitive conclusions from these reviewed studies, the cooking procedure used in each study was carefully reviewed to understand the variability of the cooking factors during the cooking, and their impact on PM emission rates or concentrations. In the next section of this study, a comprehensive review of these controlled cooking PM studies is presented.

3. Discussion

3.1. Controlled studies

Factors that may affect the cooking emission rates include cooking method, cooking oil, energy source (stove), cooking pan, food (e.g. meat, vegetables and rice), additives, sauces, oil temperature, and the surface area of the pan. The variability of the factors affecting cooking emission rates makes it difficult to understand the contribution and impact of each factor. (Kim et al., 2011; Kumar et al., 2013; Amouei Torkmahalleh et al., 2012; Chowdhury et al., 2012; Evans et al., 2008). In fact, the different combinations of those factors together with different cooking habits form a cooking style such as Asian, Western, or Middle Eastern styles. The following sections discuss the literature findings on different influential factors. In both cases, the positive or negative effects of the cooking factor on the PM emission rate or concentration was explored.

3.2. Cooking method

This section is aimed to understand the impact of different cooking methods on particle emissions. Cooking methods include wet cooking such as water-based cooking (boiling, steaming and stewing) and frying (stir-frying, pan-frying [sautéing], and deep-frying) as well as dry cooking (grilling, broiling, oven baking, toasting, and microwaving). Olson and Burke (2006) measured the $PM_{2.5}$ emission rates and concentrations for multiple cooking methods through monitoring daily activity diary for seven days. Grilling and frying showed the highest source emission rates (173 $mg \cdot min^{-1}$ and 60 $mg \cdot min^{-1}$), respectively. See and Balasubramanian (2006) studied five different cooking methods, including steaming (1000 ml water), boiling (1000 ml water), stir-frying (15 ml corn oil), pan-frying (15 ml corn oil), and deep-frying (1000 ml corn oil), and measured particle number concentrations ranging from 10 nm to 500 nm using a TSI Model 3034 Scanning Mobility Particle Sizer (SMPS). Tofu (150 g) was used for all of their cooking tests. In the frying experiments, the temperature of the oil was recorded to be below its smoke temperature (235 °C). They showed that frying compared to steaming and boiling led to greater particle concentrations, suggesting cooking with oil produces more particles than water-based cooking. This result was also observed by Zhang et al. (2010). They studied the particle size distribution in the range of 7.6 to 289 nm using a TSI Model 3936L85 SMPS, and also total particle number concentration from 5 nm to few microns using a water-based Condensation Particle Counter (Model 3785, TSI Inc). They reported lower average UFP concentrations for boiling pasta with subsequent stir-frying compared to frying chickens. Meat frying was demonstrated to produce higher particle surface concentrations compared to fish boiling when Portuguese style cooking was performed using gas stoves (Bordado et al., 2012). However, no information regarding temperature of cooking, type of oil or its condition during frying was provided in this study. Again, similar observations were made by Alves et al. (2014). They reported higher $PM_{2.5}$ concentrations during frying and grilling compared to stewing and boiling. Wallace et al. (2004) conducted experiments to measure UFP concentrations during cooking activities such as frying, grilling, sautéing, boiling water and using the oven in a four bedroom house in Washington DC, USA. They studied particles ranging from 10 nm to 1000 nm using an SMPS comprised of a model 3071 differential mobility analyzer (TSI, Inc., St. Paul, MN) coupled to a model 3010 condensation particle counter (CPC) (TSI). Frying was reported to generate more UFPs than other cooking methods. Breakfast cooking including heating water for coffee and toasting resulted in $PM_{2.5}$ concentrations about half of those from frying. It was shown that pan-frying emits higher PM_{10} and $PM_{2.5}$ concentrations compared to boiling and steaming (Lee et al., 2001). Huboyo et al. (2011) reported lower indoor $PM_{2.5}$ concentrations when tofu boiling was performed compared to tofu frying for the particle diameter range of 0.3 μm to 0.5 μm. A similar observation for