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Q1 Determination of time- and size-dependent fine particle emission with varied oil heating in an experimental kitchen

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ABSTRACT

Particulate matter (PM) from cooking has caused seriously indoor air pollutant and aroused risk to human health. It is urged to get deep knowledge of their spatial–temporal distribution of source emission characteristics, especially ultrafine particles (UFP < 100 nm) and accumulation mode particles (AMP 100–665 nm). Four commercial cooking oils are auto dipped water to simulate cooking fume under heating to 265°C to investigate PM emission and decay features between 0.03 and 10 μm size dimension by electrical low pressure impactor (ELPI) without ventilation. Rapeseed and sunflower produced high $PM_{2.5}$ around 6.1 mg/m^3, in comparison with those of soybean and corn (5.87 and 4.65 mg/m^3, respectively) at peak emission time between 340 and 460 sec since heating oil, but with the same level of particle numbers 6–9 × 10^5/cm^3. Mean values of $PM_{1.0}/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ at peak emission time are around 0.51–0.66 and 0.23–0.29. After 15 min naturally deposition, decay rates of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} are 13.3%–29.8%, 20.1%–33.9% and 41.2%–54.7%, which manifest that $PM_{1.0}$ is quite hard to decay than larger particles, $PM_{2.5}$ and PM_{10}. The majority of the particle emission locates at 43 nm with the largest decay rate at 75%, and shifts to a larger size between 137 and 655 nm after 15 min decay. The decay rates of the particles are sensitive to the oil type.

Introduction

Particulate pollution from cooking emissions has been considered a serious environmental problem that is influencing indoor air quality, regional environments and human health (Buonanno et al., 2011; Huang et al., 2011; Kabir and Kim, 2011; Kim et al., 2011; Zhang et al., 2010). Cooking contributed 0.6%–1.6% to source apportionment of $PM_{2.5}$ collected during the high pollution events of 5–25 January 2013 at the urban sites of Beijing, Shanghai, Guangzhou and Xi'an (Huang et al., 2014). Cooking with gas and stove has been identified as one of the most significant particle generating activities indoors (Abdullahi et al., 2013), responsible for 43.2% of residential indoor PM concentrations (Zhao et al., 2006). The $PM_{2.5}$ concentrations in the cooking samples, meat roasting, cafeteria frying, fish roasting, snack-street boiling, and cafeteria boiling in Ya'an, China were 2.5–9.6 times higher than those in the corresponding backgrounds (Li et al., 2015). Cooking has been associated with lung cancer risk in retrospective case–control studies in Shanghai (Kim et al., 2015).

Many studies investigated the mass concentrations and size distribution of aerosol generated from cooking, which were

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proved to be affected by cooking oils, styles and temperature. Karimatu reviewed the emission range for particle number and mass concentration with different cooking conditions (Abdullahi et al., 2013). $PM_{2.5}$ mass concentrations ranged 0.4–1.8 mg/m^3 from cooking fume were 4.3 to 20.2 times higher than ambient air (Wang et al., 2015). Particle number concentrations increased to 1.4 × 10^6 particles/cm^3 during cooking hours from the background 1220 to 6200 particles/cm^3 (Yu et al., 2015). Torkmahalleh investigated emission rates of seven commercial cooking oils, soybean, safflower, canola, and peanut oils produced lower $PM_{2.5}$ emission fluxes around 10^5 μg/(min·m^2) than corn, coconut, and olive oils with 10^6 μg/(min·m^2) at 197°C (Torkmahalleh et al., 2012). Cooking styles, like frying, grilling, toasting could elevate indoor submicrometer particle number concentration levels by more than five times, while $PM_{2.5}$ concentrations could be up to 3, 30 and 90 times higher than the background levels during smoking, frying and grilling, respectively (He et al., 2004).

However, few have special attention to the time and size distribution for oil heating and their naturally decay character, especially for ultrathin particles. In recent years, there are some report on volume-based size distribution of accumulation and coarse particles ($PM_{0.1–10}$) from cooking fume during oil heating (Gao et al., 2013a, 2013b, 2013c). Wang reported that the average number concentrations of 14.6–100 nm and 100–661.2 nm particles elevated by 10 fold from the background level in the living room and by 20–40 fold in the kitchen, while $PM_{2.5}$ went up to about 160 mg/m^3 in the kitchen and about 60 mg/m^3 in the living room (Wan et al., 2011).

An electrical low pressure impactor (ELPI) manufactured by Dekati Ltd. (Tampere, Finland) was used to collect particles from 30 nm to 10 μm into 12 size fractions. ELPI is widely used for size distribution and density measurement of fine aerosol from wood combustion sources, urban/rural air, pharmaceutical aerosols or motor vehicle exhaust (Coudray et al., 2009; Glover and Chan, 2004; Held et al., 2008; Maricq et al., 2000). The particles pass through a unipolar corona charger, where particle surfaces are saturated with positive charges according to their Stokes diameter, and then impacted on different stages according to their inertia related to their aerodynamic diameter. Finally, the measured current values are inverted to yield particle number concentrations using transfer functions provided by the manufacturer. Mass concentration gives the total mass of all particles in each size range, which is formed by multiplying the current distribution by a vector formed from the masses of spheres having diameter equal to midpoint values of each stage. Due to the dependence of the particle charging efficiency on the Stokes diameter, the particle density must be known for accurate inversions. However, the value of the aerosol density is usually not precisely known so that the particle density estimated of 1.0 g/cm^3 is generally provided by the ELPI technique as a default value for particles measured with aerodynamic diameter (Held et al., 2008). Mass concentrations for cooking fine particles with a gas stove were measured by assuming a specific gravity of 1.0 g/cm^3, derived from typical of combustion particles (Wallace et al., 2004). More details about the ELPI measurement principle can be found elsewhere (Marjamaki et al., 2000).

The aim of this work is to quantify source emission character of particles ranging from 0.03 to 10 μm emitted during a specified oil-heating period for edible commercial oils. In order to gain a better understanding of the relationship between particulate mass and number concentration with heating time and particle size, four commercial oils (rapeseed, sunflower, soybean and corn oils) have been measured by ELPI when heated to 265°C by auto dipping water to simulate cooking fume. Results of this work are expected to provide information on time- and size-dependent fine particle emission dependent on oil style, which will assess the indoor air quality for Chinese style residential kitchen.

1. Experimental method

The size of the kitchen is 4.5 m (L) × 4.0 m (W) × 3.0 m (H) as shown in Fig. 1. Three hundred milliliter different oil (rapeseed, sunflower, soybean and corn oil) in a Supor nonstick pan was heated by liquid gas. When the oil temperature reaches up to 265°C with a real time temperature monitor (PT 1000 temperature sensor), auto dipping equipment will spray 5 ml water within 2 ses following 8 sec interval. After oil temperature reached 265°C again, auto dipping equipment will repeat spray water. Auto dipping equipment was designed to sprayed water twice for all the experiments. Afterwards, fire was shut to stop heating oil. It is observed that they will take within 24 sec to finish auto dipping. The measurements of mass concentration are conducted under nearly no ventilation condition with smoke sucker shutting and the door of the kitchen closed throughout the experimental process, which means the air exchange rate is near zero, and no infiltration of particles from outdoor sources. The kitchen was refreshed with fresh air

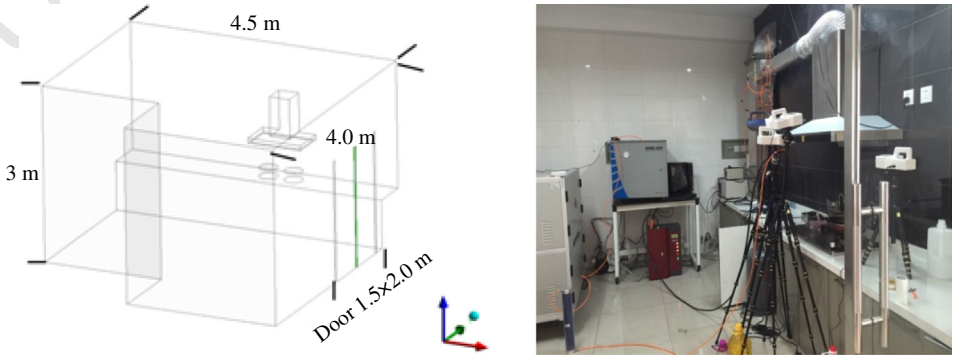

Fig. 1 – Schematic and real kitchen with the layout of measuring point using the TSI and ELPI monitors.

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