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Additive impacts on particle emissions from heating low emitting cooking oils

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HIGHLIGHTS

- Particle emissions were compared for cooking oils with and without additives.
- Sea salt, table salt and black pepper reduced the particle number emission rates.
- Tumeric and garlic powder had no effect on particle emissions from the heated oil.

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ABSTRACT

The effect of five additives, including table salt, sea salt, black pepper, garlic powder, and turmeric, on the emission of $PM_{2.5}$ and ultrafine particles (UFP) from heated cooking oil (200 °C) were studied. One hundred milligrams of the additives were added individually to either canola or soybean oil without stirring. Black pepper, table salt, and sea salt reduced the $PM_{2.5}$ emission of canola oil by 86% ($p < 0.001$), 88% ($p < 0.001$), and 91% ($p < 0.001$), respectively. Black pepper, table salt, and sea salt also decreased the total particle number emissions of canola oil by 45% ($p = 0.003$), 52% ($p = 0.001$), and 53% ($p < 0.001$), respectively. Turmeric and garlic powder showed no changes in the $PM_{2.5}$ and total number emissions of canola oil. Table salt and sea salt, decreased the level of $PM_{2.5}$ emissions from soybean oil by 47% ($p < 0.001$) and 77% ($p < 0.001$), respectively. No differences in the $PM_{2.5}$ emissions were observed when other additives were added to soybean oil. Black pepper, sea salt, and table salt reduced the total particle number emissions from the soybean oil by 51%, 61% and 68% ($p < 0.001$), respectively. Turmeric and garlic powder had no effect on soybean oil with respect to total particle number emissions. Our results indicate that table salt, sea salt, and black pepper can be used to reduce the particle total number and $PM_{2.5}$ emissions when cooking with oil.

1. Introduction

Cooking emissions results in human exposure to both $PM_{2.5}$ (particulate matter less than 2.5 μm) and ultrafine particles (UFP) (Abdullahi et al., 2013). Dennekamp et al. (2001) found that gas and electric cooking generate ultrafine particles. Cooking on gas or electric stoves and toaster ovens were found to be among the highest sources of indoor UFP exposure (Wallace and Ott, 2010). Hussein et al. (2006) found that cooking and tobacco smoking were the main sources of indoor particles in a home. Among cooking activities, frying has been found to be responsible for the highest particle emissions (Zhang et al., 2010; Olson and Burke, 2006; See and Balasubramanian, 2008; Lee et al., 2001; Li et al., 2003).

Task ventilation and/or changes in cooking methods can be used to reduce exposure to cooking emissions. Howard-Reed et al. (2003) found that using a central fan and electrostatic precipitator (ESP) reduced particles number concentrations generated by indoor sources by 25–50% and 55–85%, respectively, compared to the fan-off conditions. A similar observation was reported by Wallace et al. (2004) in that ESP, mechanical air filtration and central heating and air conditioning reduced the indoor ultrafine and fine particle concentrations from cooking 51%, 23%, and 14%, respectively. An in-duct ESP resulted in PM_{10} reductions between 30 and 70% in five homes (Fugler and Bowser, 2002).

See and Balasubramanian (2008) conducted a compositional analysis of cooking fumes. They found that cooking with water compared to cooking with oil reduces the exposure to carbonaceous particles, PAHs and toxic metals but increases the exposure to inorganic anions such as F, Cl, and SO_4^{2-}. See and Balasubramanian (2008) found that steaming reduced the $PM_{2.5}$ concentration level

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by about 65% in comparison to deep frying. Zhang et al. (2010) studied the black carbon, ultrafine particle, and $PM_{2.5}$ concentrations generated by different cooking styles. Their results indicate that water-based cooking (Italian style) reduced the level of black carbon, UFP, and $PM_{2.5}$ concentrations by 75%, 93%, and 85%, respectively, compared to oil-based cooking (Chinese style). Zhang et al. (2010) and Buonanno et al. (2011) found that the fat content of the food was related to the production of cooking particles.

Emissions of particles from heated cooking oil depend on the selection of oils. Amouei Torkmahalleh et al. (2012) found that soybean, canola, and safflower oils reduced the $PM_{2.5}$ concentration by 90% and ultrafine particle (UPF) number concentration by 95% as compared with coconut, olive, peanut and corn oils. Reducing the surface area of the oil also reduced emissions with the emission rate directly proportional to the oil surface area (Amouei Torkmahalleh et al., 2012). Thus, the emission flux (mass time^{-1} area^{-1}) can be calculated by dividing the emission rate by the surface area.

Often, additives are added during frying and cooking to improve the taste of the cooked foods. Black pepper, table salt and sea salt are commonly used additives in many cultures. Turmeric is a yellow ingredient used extensively in the Middle Eastern and South Asian countries such as Iran and India and is also commonly available in the western countries. The yellow active constituent of turmeric is curcumin that has shown antimutagenic and anticarcinogenic activity (Shukla et al., 2002; Nagabhushan and Bhide, 1992). Karadas and Kara (2012) performed an elemental analysis of turmeric and determined the elemental compounds of turmeric to be Ca, Mg, Fe, Sr, Mn, Zn, Ba, Cu, Ni, Cr, Co, As, Cd. Among these elements, Ca was found to have the highest concentration following with Mg.

In western style food, garlic is often added during cooking and frying. The main compound of garlic is diallyl disulfide (DADS), which improves digestibility and energy use efficiency (Klevenhusen et al., 2011). Garlic and black pepper contain variety of elements such as Ca, Fe, Mn, Zn, Cu, Cd, Pb, P, Cl, S, Na, Mg, Al, P, K, Ti, Cr, Co, Ni, Se, Rb, Sr and Sn (Al-Bataina et al., 2003; Gonzalvez et al., 2008). Potassium was found to be the element in garlic and black pepper with the highest concentration ranging from 0.16 to 2.1% (w/w) (Gonzalvez et al., 2008).

The objective of the present study is to systematically investigate the particle number and mass concentrations and emission rates from major cooking oils in the presence of additives such as table salt, sea salt, black pepper, garlic powder and turmeric. The results from this study can provide guidance on choosing proper combinations of oil and additives that result in lower emission fluxes when heated.

2. Materials and methods

2.1. Particle emission experiments for different oils

Two commercial cooking oils, soybean oil and canola oil, were investigated to determine the $PM_{2.5}$ and total particle number concentration and emission fluxes in the presence of five additives: table salt, sea salt, black pepper, garlic powder and turmeric. Soybean and canola oil were selected because they are among the oils with the lowest emission rates when heated (Amouei Torkmahalleh et al., 2012). The oils and additives were purchased locally and stored in the laboratory without refrigeration. The oils were used within approximately one month of the date of purchase.

All of the experiments were conducted in a 0.81 m^3 laboratory hood operating at 80 air changes per hour to standardize environmental conditions. The laboratory hood was partitioned into two sections. In one section, 200 mL of oil was heated in a 1 L beaker over the hot plate to a temperature of 205 °C, which is below the smoke temperature (T_s) of canola oil ($T_s = 210 \pm 11$ °C) and soybean oil ($T_s = 211 \pm 3$ °C) (Amouei Torkmahalleh et al., 2012). Consequently, the emissions were not visible to the eye during the experiments. One hundred milligrams of the additive were added to the oil without stirring such that material floated on top of the oil and partially penetrated the surface of the oil. For both table and sea salts with canola oil, 50 and 200 mg were also tested to observe the sensitivity of the results to the additive concentration. After the additive was placed in the beaker, the beaker was quickly transferred to the adjacent part of the hood to physically separate particles emitted by the hot plate heating element from those emitted from the oil. The particle number and mass concentrations were monitored at a point 0.35 m above the oil surface as the temperature of the oil decreased with time. The surface area of the oil was determined to be 0.0094 m^2.

Particle concentration and temperature monitoring continued until the oil temperature decreased to 150 °C. The beaker was washed with soap and rinsed with DI water to remove any residual oil between the experiments. The experiments were conducted at laboratory temperature and relative humidity (23.6 ± 1 °C and 42.3 ± 3%). The sampling time for the monitoring instruments was 1–2 min. Therefore, the oils cooled substantially between measurements at a rate of 0.13 ± 0.01 °C s^{-1}. The measured temperature of the oils at the time of the first particle measurements was 200 ± 1 °C.

During the time of the experiment (~10 min), the table salt and sea salt were observed to dissolve in the oil, with little residue on top of the oil at the end of the experiment. However the other additives were observed to remain primarily unmixed on the surface of the oil.

2.2. Instrumentation

A TSI (St. Paul, MN) DustTrak Model 8520 Aerosol Monitor with a $PM_{2.5}$ inlet was utilized with 1 min integrating times to determine the mass concentration of particles emitted during the experiments. Although the DustTrak captures only a limited size range of the particle number distribution (approximately 100–2500 nm), particles >500 nm in diameter constitute the majority of the estimated mass. Particle number and size distributions ranging from 10 nm to 500 nm were monitored with an MSP (Shoreview, MN) Wide-range Particle Spectrometer™ (WPS) using a scan time of 2 min. The temperature of the oils was monitored by placing a thermometer into the oils without touching the beaker. The thermometer was new and calibrated by the manufacturer. The additives were weighed using a Cahn C-33 microbalance (Thermo Electron Corp, Beverly, MA).

2.3. Emission flux estimation

The concentration–time series was analyzed to calculate the emission rate and emission fluxes. The detailed experimental and mathematical approach to calculate the emission rate, air exchange rate and particle decay rate were described by Amouei Torkmahalleh et al. (2012). Briefly, the emission rate was assumed to be constant over the sample duration, and the steady-state solution of the mass balance equation was used to calculate as shown in Eq. (1).

$$S = (a + k)VC_{\text{in}} \qquad (1)$$

where S is the particle emission rate, V is the chamber/hood volume, a is the air change rate and k is the decay rate coefficient for the combined non-ventilation removal mechanisms. The emission flux was calculated as the emission rate divided by the surface area of the oil.