Reduction of Exposure to Ultrafine Particles by Kitchen Exhaust Fans of Varying Flow Rates

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SUMMARY

This study has investigated the effect of a kitchen exhaust hood on the reduction of exposure to ultrafine particles (UFP) from a gas stove. Size-resolved UFP ranging from 2 nm to 100 nm were monitored in a manufactured test house (volume of 340 m^3), using a Scanning Mobility Particle Sizer (SMPS). The flow rate of the range hood exhaust fan was varied from 100 m^3/h to 370 m^3/h. The majority of particles released from the gas stove were smaller than 14 nm. The effectiveness of the range hood for removing particles varies with the range hood flow rate, particle size and burner position. Higher particle removal efficiency for the gas stove was achieved with higher range hood flow rate and larger particles.

IMPLICATIONS

This study involves the first known measurements of UFP down to 2 nm for a gas stove and kitchen range hood with varying flow rates in residential environments. Results demonstrate that using a kitchen exhaust fan can reduce occupant exposure to UFP from a gas stove.

KEYWORDS

Ultrafine particles, Gas burner, Kitchen exhaust hood, Occupant Exposure, Particle removal efficiency

INTRODUCTION

Cooking is one of the most common combustion sources of ultrafine particles (UFPs, < 100 nm) in residential buildings (Wallace, 2006). Using a gas/electric stove and oven can contribute to elevated indoor UFP concentrations (Kuehn et al. 2009, Zhang et al. 2010, Wallace et al. 2008). The high emissions from the combustion sources have potential importance in inhalation exposure to UFP, which can lead to adverse health effects such as respiratory and cardiovascular mortality among susceptible individuals in the population (Brook et al. 2004). UFP deposition in human lungs has been associated with inflammation and impairment of the cells in the lung (Brown et al. 2002).

Kitchen range hoods can reduce exposure to UFP from cooking, even though the performance of the range hood can greatly vary with the aerodynamic design and ventilation rate of the range hood. The objective of the present study is to investigate the effect of using a kitchen range hood on reducing exposure to UFPs from gas stove. The study considers effects of range hood flow rate, particle size, and burner position.

METHODS

Size-resolved UFP ranging from 2 nm to 100 nm were measured in a manufactured test house (volume of 340 m^3). Continuous monitoring of UFP was conducted while operating a gas burner and kitchen range hood. The size-resolved UFP from the gas burner was monitored in a master bedroom, using a Scanning Mobility Particle Sizer (SMPS) which consists of an electrostatic classifier, nano-differential mobility analyzer (nano-DMA) and water-based condensation particle counter (WCPC). During the measurement, the forced-air heating and cooling system fan was turned on during the test to improve air mixing in the house. The uncertainty of measuring the number concentration reported by the manufacturer is estimated to be 12 % based on combining the individual uncertainties of flow rate, particle charge distribution, voltage adjustment, and particle charge efficiency in quadrature. The aerosol flow rates were measured three times and required to agree within 2 % before beginning each experiment.

The range hood was located in the kitchen above the stove top (Figure 1). In this study, two different range hoods were used: one with a relatively low flow rate (100 m^3/h) and the other with a higher flow rate (370 m^3/h). The particle laden air driven by the ranged hood fan was directly exhausted out of the building without recirculation. The tests were performed with a naked gas flame or when boiling water. The gas stove top burner was started simultaneously with the range hood fan. The gas stove was on for 15 minutes and the range hood fan was turned off simultaneously with the stove. The average gas flow rate was 4.2 L/min for the stove. UFP concentrations were monitored during the source emission and decay period. The effect of gas burner position on the UFP number concentration was examined with front and back burners.

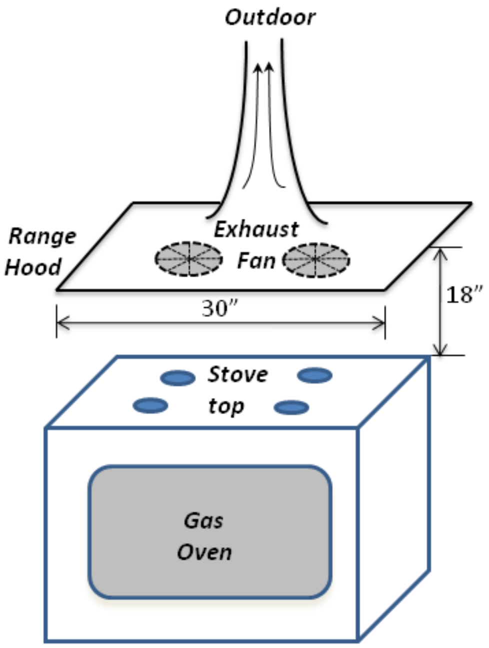

Figure 1 Schematic diagram of the gas stove/oven and kitchen range hood.

Particle Removal Efficiency

Size-resolved particle removal efficiency was calculated for the 1-h period following the start of gas burning. For each particle size bin, the particle concentration integrated over the 1-h decay period was calculated. Using the ratio of the 1-h integrated particle concentrations between fan off and fan on period, the removal efficiency was calculated as

$$Efficiency = 1 - \frac{\int^{1h} C_{Fan\_On}\,dt}{\int^{1h} C_{Fan\_Off}\,dt} \qquad (1)$$

where C_{Fan_On} is the particle number concentration measured with the range hood on, C_{Fan_Off} is the number concentration with the range hood off.

Equation (1) worked for particles smaller than 14 nm, below which 95 % of the particles released from the gas stove were found. The efficiencies decrease to zero or negative values for particles larger than 14 nm because the fan off situation resulted in major coagulation leading to increased numbers in the 14 nm to 30 nm range. The numbers from 20 nm to 100 nm are close to background in both cases leading to random errors. The uncertainty of the efficiency for each particle size was estimated as the standard error of the efficiencies obtained from repetitive tests, which is relatively larger than the error propagated from each term in Equation (1).

RESULTS

Figure 2 shows the particle size distribution during the decay period following the peak for the gas stove. In this case, the range hood was turned off. The peak concentration occurs at a particle diameter at about 5 nm. During the decay, the total number concentration decreases with time and the particle size distribution moves toward larger particle size due to particle coagulation.

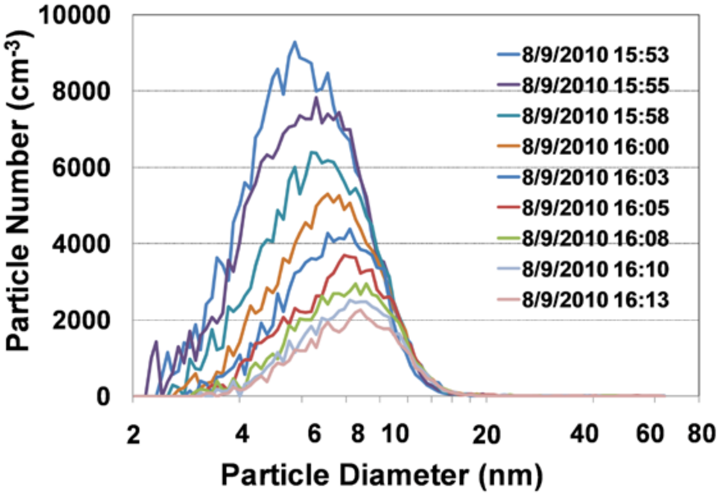

Figure 2 Particle Size Distribution: Gas Stove Test with No Range Hood Operating.

Figure 3 illustrates the particle size distribution during the decay period with the range hood flow rate of 370 m^3/h. The graph shows that the particle peak is reduced with the range hood. Figure 3 also indicates that the particle reduction due to the range hood is a function of gas burner position. Comparing the peaks between range hood off (Figure 2) and hood on (Figure 3) period, the peak concentration is about half and a quarter of the concentration observed with the range hood off condition for the front burner (Figure 3a) and back burner (Figure 3b), respectively.

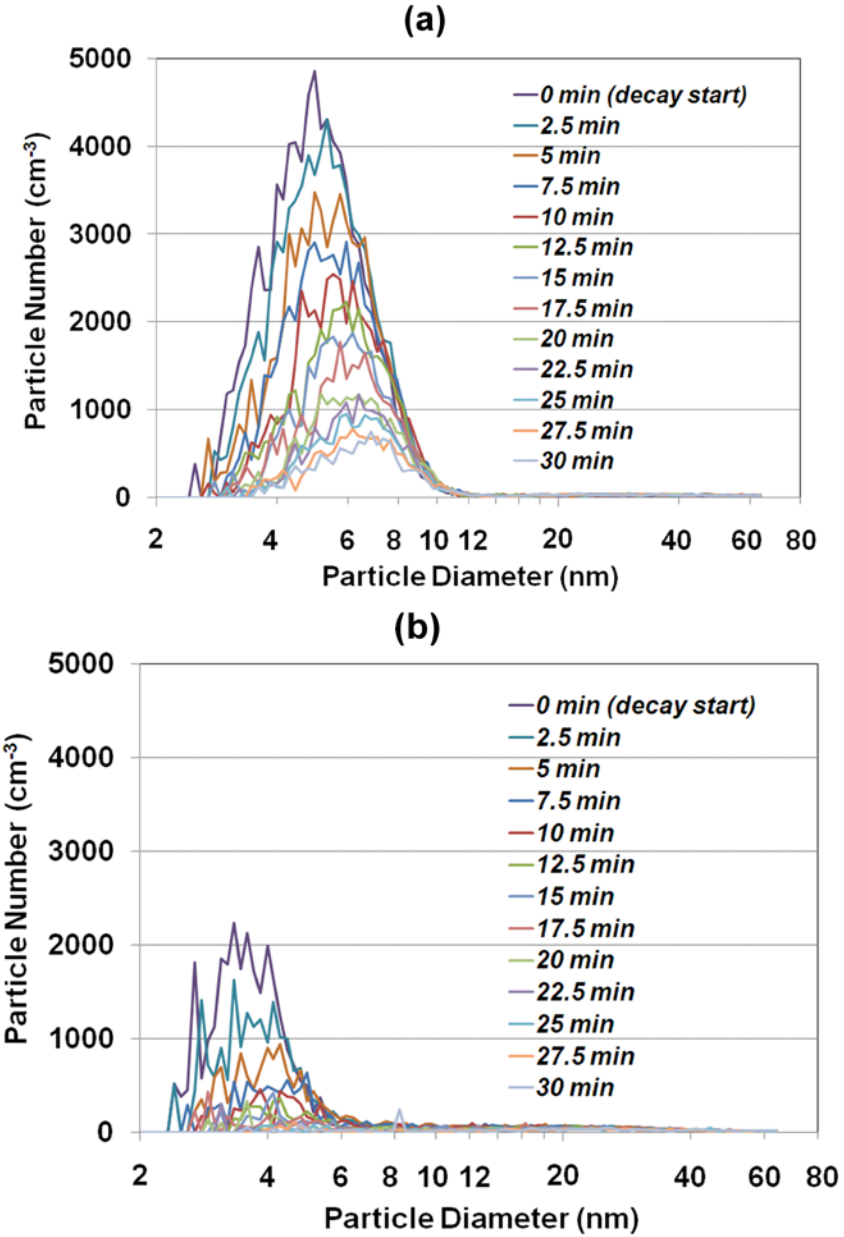

Figure 3 Particle size distribution with 370 m^3/h of range hood fan flow: (a) front burner; (b) back burner.

Figure 4a and 4b present size-resolved particle removal efficiency for two range hood flow rates(100 m^3/h and 370 m^3/h) for the particles smaller than 14 nm. The efficiency of the range hood increases when the flow rate increases from 100 m^3/h to 370 m^3/h. The particle removal efficiency at 370 m^3/h is up to 70 % larger compared to that at 100 m^3/h. At 100 m^3/h, the efficiency is very small or almost zero for particles smaller than 5 nm, indicating that this low range hood flow rate is not effective for removing the smallest nanoparticles. At 370 m^3/h, the removal efficiency is up to 90 % for the front burner and up to 100 % for the back burner. In general, the efficiency is higher with larger particles, suggesting that with the same flow rate, larger particles are easier to remove than smaller particles.

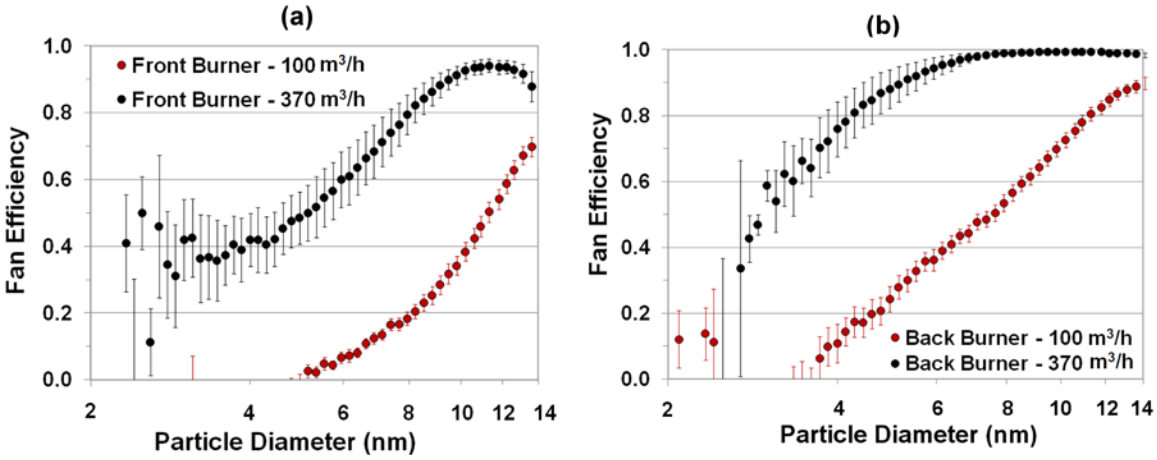

Figure 4 Particle removal efficiency for 1-h decay period for two burner positions: (a) front burner; (b) back burner. Error bars are standard errors: a) *N*=5 and b) *N*=4

DISCUSSION

Nanoparticle removal efficiency due to a kitchen range hood is a function of range hood flow rate, particle size, and burner position. The range hood flow rate is a significant factor in particle reduction and the results suggest that occupant exposure to UFP can be reduced a large extent using a range hood exhaust. For example, the peak occurs at about 5 nm when burning the gas stove, and up to 90 % removal for 5 nm particles can be achieved at a fan flow rate of 370 m^3/h whereas only up to 20 % removal is achieved at 100 m^3/h (Figure 4b). In general, a higher flow rate results in larger particle removal. However, the increase of noise level with higher flow rate might affect the comfort level and behavior of an occupant in using the range hood (ASHRAE 2010).

With the same flow rate, the removal efficiency is lower for smaller particles than larger particles (Figure 4). The higher molecular and turbulent diffusion occurring with smaller particles may allow them to escape from the combustion plume.

Gas burner position also influences on the removal efficiency of the range hood. The efficiency is generally higher with the back burner than with the front burner. For instance, for 5 nm particles at 370 m^3/h, the removal efficiency is 40 % for the front burner whereas it is 80 % for the back burner (Figure 4).

Wallace et al. (2008) reported that majority of particles from gas and electric burner are less than 10 nm and these indoor sources substantially contribute to occupant exposure to UFP. Zhang et al. (2010) indicated that the kitchen exhaust fan can achieve up to 5 times faster particle decay rate compared to fan off period, even though the study did not report the fan flow rate and size-resolved removal efficiency. This study shows that using a kitchen range hood can be effective in removing UFP released from the gas stove. However, particle diameters, aerodynamic characteristics associated with range hood flow rate, and burner position have measurable influence on the particle removal efficiency. Also, there needs to be a consideration of compromise between the range hood flow rate and the flow induced noise.

CONCLUSIONS

This study establishes that using a kitchen range hood can reduce human exposure to UFP due to cooking. The results show that range hood flow rate, particle size, and aerodynamic flow characteristics associated with burner position can have measureable effect on reduction of UFP smaller than 14 nm released from a gas burner.

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