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Physical and Chemical Properties of Fine Particles Emitted from Candles

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Candles have appeared as a source of fine and ultrafine particles in indoor air (e.g. Hussein et al. 2006). Fine et al. (1999), found high Organic Carbon (OC) emissions connected to the extinction of the candle and high EC concentrations when the flame was burning unsteady. Zai et al. (2006) identified three different particle types from size distribution analysis. However, the connection between the chemical composition and the physical particle properties remains unclear. The aim of this work was to gain more insight into the physical and chemical properties and the formation mechanisms of the different particle types emitted from candles.

The experiments comprised candles of ten different brands, including paraffin, stearin, bees wax and scented fuels. Emissions were studied in a 25 m³ air-tight steel-chamber where the background particle concentration was lower than 100 cm⁻³. The air exchange ratio was 2 h⁻¹. A fan was used to ensure mixing in the chamber. In a typical experiment a candle was lighted and let burn continuously for approximately 3 hours. Particle size distributions in the room were measured using two SMPS system (10-1000 nm). A TEOM was used to determine the average effective density by combining the SMPS and TEOM data. Samples for morphology were collected using an electrostatic precipitator and the morphology was studied with Transmission Electron Microscopy. Particles were separated according to volatility and hygroscopicity using Tandem Differential Mobility Analyzers (TDMAs). The chemical composition was determined from filter and low pressure impactor samples analyzed using Ion Chromatography (IC; water soluble ions), Particle Induced X-ray Emission (PIXE; metals) and Evolving Gas Analysis (OC/EC).

High concentrations (~10⁶ cm⁻³) of ultrafine particles were detected during steady burning of a single candle. Particles aged 2-5 min were in the range of 10 to 25 nm. These particles acted as coagulation sink and a bimodal size distribution developed with one mode of fresh particles and a mode of larger aged particles (up to 100 nm). Dependent on candle type, two different categories of particles were detected during steady burning using the volatility and hygroscopicity analysis.

Type 1a particles had hygroscopic growth factors (*G_f*) of around 1.8 at 90% RH and were volatilized at 400°C in the Thermodesorber in the VTDMA analysis. These particles were rich in Potassium and

Nitrate and contained relatively high concentrations of metals such as Cu and Sn.

Type 1b particles had hygroscopic growth factors of around 1.6 at 90% RH and were volatilized at 150°C in the VTDMA analysis. These particles were rich in phosphate and contained less metals.

Table 1. Physical and chemical properties of the different particle types emitted from candles.

Type	Mean Particle Size (nm)	G _f (90%)	Evaporation in TD (°C)	Main Components	Morphology
1a	15-30	1.8	400	K ⁺ , NO ₃ ⁻	Compact
1b	10-25	1.6	150	K ⁺ , PO ₄ ³⁻	Compact
2	200-250	<1.05	>600	Soot	Aggregate
3	30-100	Low	70	OC	Compact

When the flame was exposed to increased air flows, the flame started flickering. A larger sized mode appeared in the size distribution. These particles (Type 2) were essentially non volatile (up to 600° C) and hydrophobic. TEM analysis revealed highly agglomerated carbon rich particles. The average effective density was 0.3 g/cm³. These are features similar to soot from other sources such as diesel exhaust.

As the candle was extinguished white smoke appeared. These particles (Type 3) were volatile at around 70°C. This indicates organic components from evaporation and condensation of the fuel, as has been described previously (Fine et al. 1999).

In conclusion distinctly different particle types are emitted from candles. The water soluble particles emitted during steady (optimal) combustion may need to be treated differently from soot particles in future health risk estimates of fine and ultrafine particles in indoor air.

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