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Residential Biomass Combustion Aerosols – Influence of Combustion Conditions on Physical and Chemical Particle Characteristics

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INTRODUCTION

Combustion of biomass occurs on many scales from small residential fire places indoors to well controlled large boilers for energy production and biomass burning during deforestation. Particle emissions from such sources may affect both human health and global climate. It is well established that the particle emissions during less optimised combustion in small scale fire places and during deforestation are most often dominated by products of incomplete combustion, i.e. organic and elemental carbon (OC/EC). In contrast during optimised combustion in large boilers and modern domestic pellets combustion systems the aerosol can be dominated by ash compounds, especially KCl and K₂SO₄ formed via heterogeneous reactions in the gas-phase. However, surprisingly little research has focused on the variations in physical and chemical particle properties between different combustion technologies or when varying the combustion conditions within the same unit. The aim of this work was to study the physical and chemical properties of particles emitted during combustion of woody biomass pellets at different operation conditions.

METHODS

A modern residential wood pellet boiler fired with a typical softwood pellet fuel was used at several operating conditions including; A) Efficient "complete" combustion at high load, B) Hot air-starved combustion and C) Combustion at lower temperature using moist fuel (~18 %) and reduced air/fuel mixing to simulate poor residential wood log combustion (i.e. "wood smoke"). The aerosol was diluted in two to three stages and fed into a 18 m³ chamber from which sampling was performed. The chamber was also used with similar aerosols for controlled human exposures and respiratory deposition measurements as described by Boman *et al.* (2006) and Löndahl *et al.* (2006). Particle number size distributions and resulting number concentrations were determined using an Electrical Mobility Spectrometer (SMPS; 15-1000 nm) and mass concentrations were determined using a Tapered Element Oscillating Microbalance (TEOM). The mean effective density, weighted by the third power of the mobility diameter was determined by combining TEOM and SMPS measurements, which first passed a

common PM₁ impactor. Particles were classified according to hygroscopic growth and volatility using Tandem Differential Mobility Analyzers (TDMA) to get information about the mixing status. Samples for Transmission Electron Microscopy (TEM) were collected on copper grids using either an electrostatic precipitator (ESP) for the integral aerosol or with mobility selected particles using a Low Pressure cascade Impactor (LPI). Samples for chemical analysis (including elemental composition, major inorganic ions, inorganic phase composition, EC/OC and PAH) were collected using multiple filter samplers and an LPI.

RESULTS AND DISCUSSION

The aerosol was diluted down to concentrations below 200.000 cm⁻³ to decrease the influence of coagulation during the 5 min residence time in the chamber. The number weighted Geometric Mean Diameter (GMD) of the aerosols ranged from 70 nm during efficient combustion to 300 nm during hot air-starved combustion. Typical CO and PM₁ emission factors were 90 mg/MJ (100-300 ppm) and 15 mg/MJ, respectively during efficient combustion (A), 1100 mg/MJ (500-10000 ppm) and 45 mg/MJ during hot air-starved combustion (B) and 1300 mg/MJ (1000-8000 ppm) and 30 mg/MJ, during low temperature combustion (C). The elemental composition (atomic number > 12) was dominated by K, S, Cl and Zn.

During efficient combustion (A) the aerosol was internally well mixed in terms of hygroscopicity and volatility. Particles were non-volatile up to 425° C and the hygroscopic growth factor ranged between 1.6-1.8 (at 90% RH), in the range of the pure potassium salts if taking the limited solubility of K₂SO₄ into account (Rissler *et al.* 2005). The effective density was 2.1 ±0.2 g/cm³ indicating compact particles (bulk densities of KCl and K₂SO₄ are 1.98 and 2.66 g/cm³, respectively).

In contrast particles emitted during hot air-starved combustion (B) showed different characteristics. These particles were non-volatile up to 425° C, nearly hydrophobic and the effective density was 0.3 (±0.2) g/cm³. During air-starved combustion at 900-1000 °C emissions of agglomerated elemental carbon particles is favoured in agreement with the presently measured properties.

The aerosol during low temp. combustion (C) was more complex and presumably a mixture of different particle types. The effective density of the particles in the chamber was typically around 1.0 g/cm³ with intermediate hygroscopic growth factors. As the particle size increased, the hygroscopic growth factors decreased, which we interpret as smaller particles having a higher content of potassium salts.

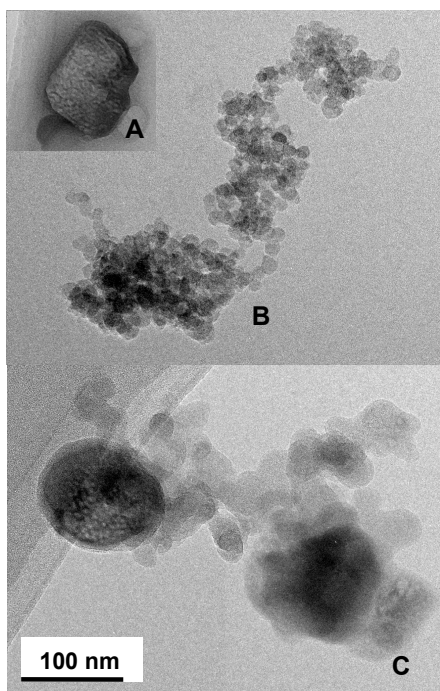


Figure 1. TEM-images of particles collected with the ESP sampler. A, B and C refers to different combustion conditions.

In Figure 1 representative TEM-pictures from samples collected with the ESP sampler are shown for the three combustion conditions studied. Particles from efficient combustion (A) were typically compact with diameters in the range of those determined with the SMPS. The material was beam-sensitive similar to observations described by Wierzbicka *et al.* (2005) during efficient combustion in a 12 MW grate boiler. Scanning TEM-EDX analysis showed these particles to be rich in potassium, sulphur and chloride.

During hot air-starved combustion (B) agglomerated particles with clearly distinguishable primary particles of 20-30 nm were found. This is consistent with the observed low effective density and particles being dominated by elemental carbon (i.e. soot). The primary particle diameter is similar to that from diesel engines, but the number of primary particles and the mobility sizes were typically larger for the air-starved wood pellet combustion.

For the low temperature combustion (C), the morphology was more complex with larger particle to particle variations. Primary particles were identified but not as easily distinguished, indicating the presence of other compounds, for example potassium salts and/or organic carbon. Areas similar to the two larger entities were rich in potassium, sulphur and chloride.

CONCLUSIONS

The physical and chemical aerosol properties are strongly influenced by the combustion and operating performance during residential biomass pellet combustion. Similar variations will most likely occur also during batch-wise combustion of wood logs. Results from on-line measurements of particle size, hygroscopic growth, volatility and effective density were consistent with results from off-line characterisation of morphology and chemical composition.

Keywords: Biomass Combustion, TEM, Physical Properties

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