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IN-SITU CHARACTERISTICS OF PARTICLE EMISSIONS FROM BIOMASS COMBUSTION

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KEYWORDS: BIOMASS COMBUSTION, PARTICLE MORPHOLOGY, TIME-VARIATIONS

INTRODUCTION

Fine and ultrafine particles from combustion sources have been suggested to be responsible for the associations between adverse effects on human health and the outdoor concentration (e.g. PM_{2.5}) of aerosol particles. The characteristics of fine particles from biomass combustion vary largely from being totally dominated by products of incomplete combustion in wild fires and in some cases in residential combustion, to purely inorganic particles mainly consisting of potassium salts with a significant metal content (e.g. Zn), during large-scale combustion. The size- and time variations of these two classes of particle components have been relatively little studied.

Previous electron microscopy analyses have shown a large spread in detected morphologies. Hygroscopic Tandem-DMA measurements in a 1.5 MW moving grate boiler (Rissler et al. 2004) showed that particles sampled with heated dilution air typically experience a reduced drag-force (decreased mobility diameter) at RH between 60 and 70%. It is not known how such particle-water vapour interactions influence the particle morphology during sampling and dilution.

In this work we used a Scanning Mobility Particle Sizer and an Electrical Low-pressure Impactor to: a) Derive information of the particle morphology through air-borne analysis and b) Identify time- and size variations of particle phase components from incomplete combustion and ash-components.

METHODS

The results presented here covers measurements in two moving grate boilers (12 MW operating on moist forest residue and 1.5 MW operating on wood pellets). For more details of emission characteristics from these types of boiler-systems see e.g. Pagels et al. (2003) and Strand et al. (2002). The particles were sampled using a two-stage ejector dilution system. Air to the first stage was heated to 150° C. A stainless steel tube (residence time~1 s), where we reduced the temperature was inserted prior to dilution. We varied the temperature in the first part of the tube between 60° and 120° C to study the influence on particle morphology. With “humid” and “dry” sampling we refer to particles sampled with a minimum temperature of 70° C or lower (close to the dew point) and 100° C or higher respectively. An electrical mobility spectrometer (SMPS, 3934, TSI. Inc., USA) was used to determine the mobility size distribution. An Electrical Low-Pressure Impactor (ELPI, Dekati Ltd, Finland) was used to study the aerodynamic size-distribution. Effective density profiles and fractal dimensions were fitted to the SMPS and ELPI data with a method similar to that described by Virtanen et al. (2004). In the method ELPI current distributions are simulated from the SMPS-data by taking the ELPI charger efficiency and impactor Kernel-functions into account. Particle phase organic and elemental carbon (OC/EC) was determined using a thermal-optical method (Wierzbicka et al., 2004). Ion Chromatography (IC) and PIXE was used to quantify 6 major ions and elements with $Z > 12$.

RESULTS AND CONCLUSIONS

Fitted effective density profiles and fractal dimensions are compared with calculated densities from the chemical analysis (figure 1). The calculated density agrees well with effective densities fitted for “humid” sampling (assuming spherical particles). However, effective densities during dry sampling are significantly lower. Effective density (ρ_{eff}) is a property dependent on both the material density and the particle morphology. Less compact particles have a reduced ρ_{eff} . The (mass-)fractal dimension (D_f) scales the particle mass with the mobility diameter, d_b (1) and determines the slope of the effective

density profile (2). A D_f of 3.0 (humid sampling) indicates compact particles with constant effective density. A D_f of 2.6 (dry sampling) indicates agglomerated particles, which become more open with increasing size. A partial restructuring due to coalescence appeared above 300° C in experiments with a Thermo-desorber in front of the DMA, therefore we believe the detected agglomeration process occurs due to coagulation at the end of the heat-exchanger and in the following flue-gas system.

$$m \sim d_b^{D_f} \quad (1)$$

$$\rho_{eff} \sim d_b^{D_f-3} \quad (2)$$

The agglomeration likely also disappears during “natural” humid dilution after the stack. The particle-water interaction may also explain some of the variations in previous electron microscopy characterisation. The variations in ρ_{eff} and D_f give information about particle formation mechanisms and influences particle measurement techniques (e.g. number concentration with the ELPI).

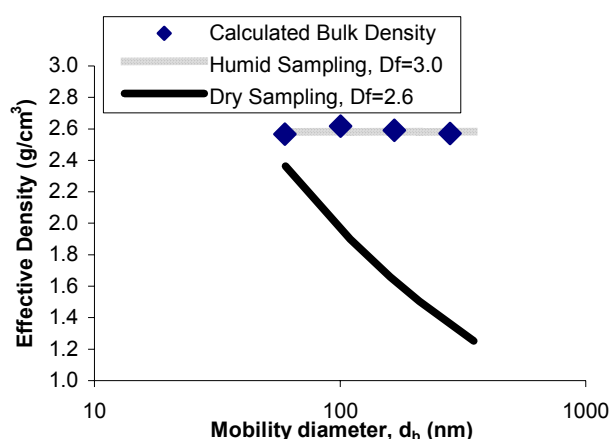


Figure 1. Fitted effective density profiles and calculated bulk density in the 12 MW boiler.

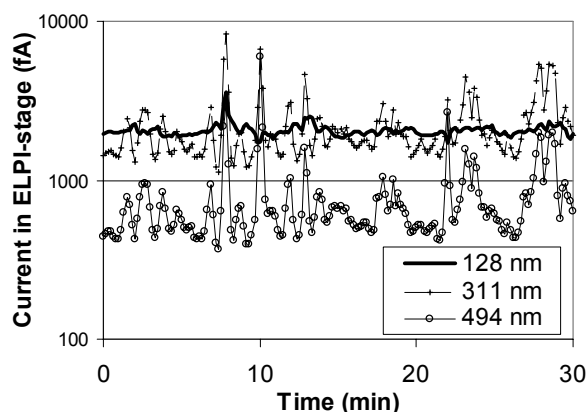


Figure 2. Time-variations of the detected current in three ELPI-stages, 1.5 MW boiler.

We have previously shown that PM1 estimated from ELPI-measurements consisted of a rather constant background with peaks correlating with CO and OGC peaks (Szpila et al. 2003). In the 1.5 MW boiler EC contributed to 34% of PM1, while in the 12 MW boiler EC was below 0.5%. Figure 2 shows time variations in the 1.5 MW boiler as the current in three stages of the ELPI-impactor. Note that time-variations increase strongly with particle size. The fraction of the gravimetric mass detected as water-soluble ions (IC) decreased from ~ 70% for d_{ac} = 78 and 133 nm to ~25% for 322 and 510 nm particles and increased to around 50% for particles larger than 1 μ m. In the 12 MW boiler time-variations were as low as for 128 nm particles and IC recovery was high for all studied particle sizes. Based on these data we conclude that PM consisting of ash-components are formed with small time-variations mainly in mobility-sizes below 250 nm, while Elemental Carbon is emitted at high concentrations during peaks on the time-scale 10 - 30s, mainly in particle sizes larger than 150 nm. However, the detailed mixing status of these two particle types/materials is still not known.

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