Biomass for Energy and Industry, 10th European Conference and Technology Exhibition
June 8–11 1998, Würzburg (Germany)

PARTICLE SIZE DISTRIBUTION OF THE FLY ASH FROM BIOMASS COMBUSTION

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ABSTRACT: The particle size distributions of the fly ash have been determined with an Andersen cascade impactor for various biomass fuels in different furnaces and under different operating conditions. Particle diameters are calculated as aerodynamic diameters (unit particle density of ρ = 1.0 kg/dm^3). For native wood, chipboard fuel, urban waste wood and hay, unimodal particle size distributions were found with mean diameters <0.25 μm. More than 80 weight% of the particle mass was found as aerosol with diameters < 1 μm. Bark is the only fuel found so far which exhibits a bimodal particle size distribution. Flue gas recirculation leads to lower amounts of aerosol particles in under stoker furnaces.
Keywords: Biomass, combustion, particles, size, distribution, aerosol, impactor, properties

1. INTRODUCTION

For the combustion of wood fuel in Switzerland, the particle emissions are limited to 150 mg/Nm^3 (for <1 MW at 13 vol.-% O_2; for > 1MW at 11 vol.-% O_2). For urban waste wood, the particle emission limit is 50 mg/Nm^3 (at 11 vol.-% O_2). In some areas or in other countries, lower limits such as 100 mg/Nm^3 or 50 mg/Nm^3 are set.
Multi cyclones are normally used for particle separation. With native wood chips, the particle loading of the flue gas is between 100 and 150 mg/Nm^3. With urban waste wood, chipboard or agricultural fuels such as hay or miscanthus, the dust level after the multi cyclone generally exceeds the emission limits substantially.
With fabric filters or electrostatic precipitators, particle emissions below <10 mg/Nm^3 can easily be obtained, but investment cost are considerably high.
The design and assessment of dedusting units require information of the particle properties such as the size distribution. Up to date, few particle size distribution data from wood combustion are available. The available data indicate that most of the particles have diameters less than 1 μm [1], [2], [3]. To get more detailed data of the particle properties from biomass combustion, particle size distributions of the fly ash have been measured for various biomass fuels in different furnaces and with different operating conditions.

2. EXPERIMENTAL

The particle size distribution can be measured with techniques which determine the number or the mass of particles of a given size [4].
The national emission limits are usually set in mass concentration and hence a weight based sampling system has been selected. Cascade impactors are widely used for mass based particle size distributions.
For the results presented in this paper, an Andersen cascade impactor with eight stages and a total filter at the end has been used (figure 1). Most of the samples were taken in the flue gas after a multi cyclone, some were taken in the raw gas. Particle diameters are calculated as aerodynamic diameters (unit particle density of ρ = 1.0 kg/dm^3).
The impactor can be placed either directly in the stack gas or externally. For the external arrangement, separate heating of the sampling tubes and impactor is necessary. Both arrangements were used, but the results were comparable.

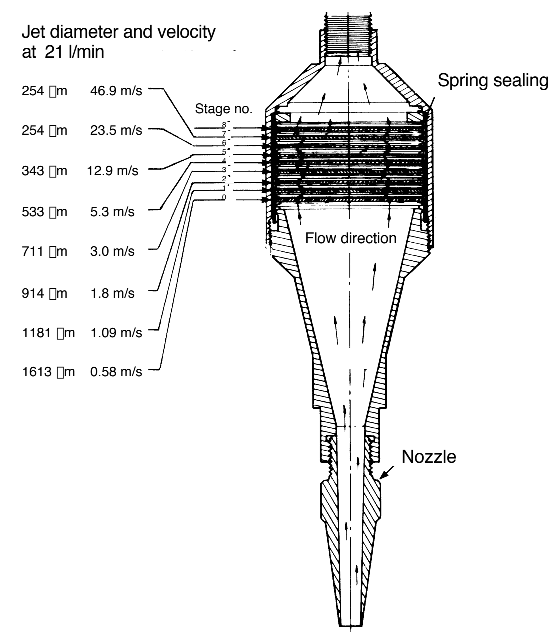

Figure 1: Andersen cascade impactor (stack arrangement)

Depending on the chosen sampling flow rate, nine particle size classes ranging from approximately 0.2 µm to 10 µm can be determined. Particle blow off has not been observed, although jet velocities up to 170 m/s were used.
After sampling, the amount of particles deposited on each plate is determined gravimetrically.
The results from an impactor measurement can be expressed as histograms or as particle density functions (figure 1).

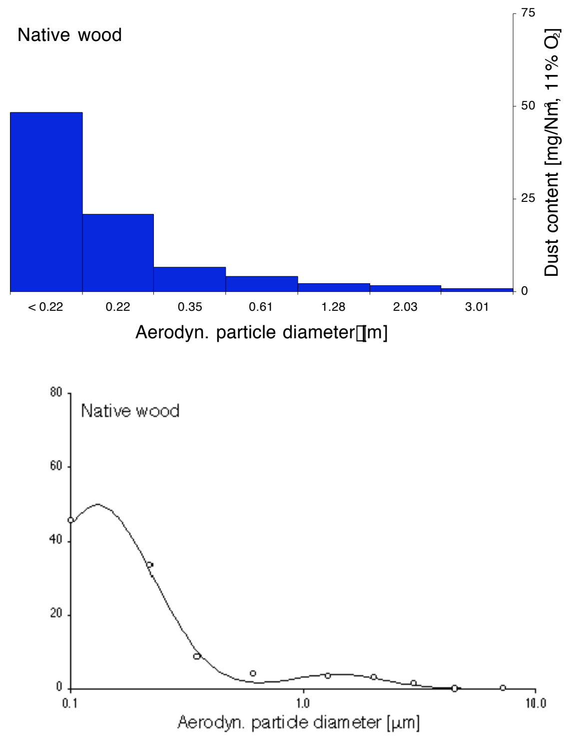

Figure 2: Presentation of particle size data as histogram (upper figure) and particle density function (lower figure)

The histogram presentation does not require data manipulation whereas for the density function, discrete values of the particle density function are derived from the impactor measurement data. The density function can be approximated with log normal distribution function.
For particles from wood combustion, the data presentation as a particle density function must be viewed critical since the impactor measurement solely generates 3 to 4 discrete density values in the range where most of the particle mass is found.

3. RESULTS AND DISCUSSION

Particle size distributions were measured during the combustion of native wood, a wood/bark mixture, urban waste wood, chipboard residues and hay pellets in a 450 kW moving grate furnace. The operating conditions were comparable for all fuels. The combustion quality is optimal and CO values are below 4 mg/Nm^3 (at 11 % O_2).
With native wood, only minor differences in the particle size distributions have been observed before and after cyclone (figure 3).
The particle size distributions with various biofuels are shown in figure 4. Except for the wood/bark mixture, unimodal particle size distributions were found during the test runs for all fuels investigated [5]. Bark is the only fuel found which exhibited a bimodal size distribution. The particle size maxima for bark are <0.2 µm and approximately 5 µm. With bark, 50% or 30 mg/Nm^3 of the particles are found in the aerosol size fractions below 1 µm.

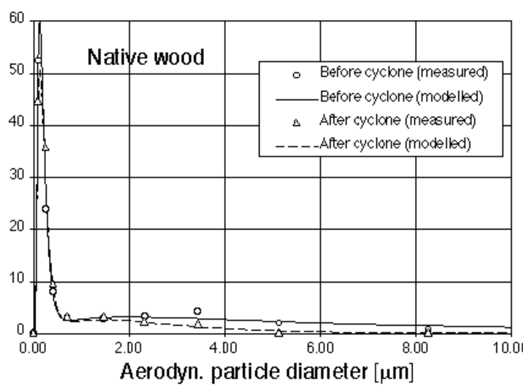

Figure 3: Particle size distribution before and after the multi cyclone during the combustion of native wood in a 450 kW moving grate furnace at full load

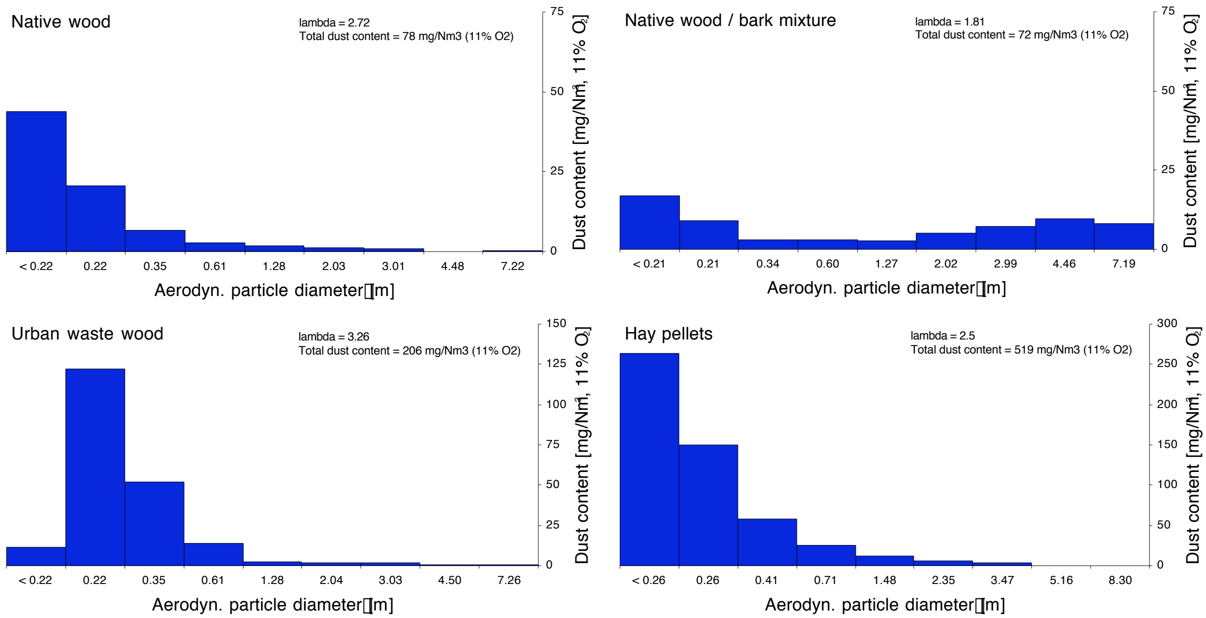

Figure 3: Particle size distribution during the combustion of native wood, a mixture of native wood and bark, urban waste wood and hay pellets in a 450 kW moving grate furnace at full load
Remarks: For the wood/bark mixture, the particle size measurement was done before the multi cyclone, for native wood, urban waste wood and hay after the cyclone.

For the other fuels investigated, 83 to 99 weigth % of the particles in the flue gas after the cyclone are found in the aerosol size fractions below 1 µm. The particle mass below 1 µm amounts to approximately 70 to 90 mg/Nm^3 (at 11% O_2) for native wood and increases up to 500 mg/Nm^3 for hay. For native wood, chipboard residues and hay pellets, the relative particle size distributions do not change significantly. With urban waste wood, the mean areosol particle size diameter is slightly higher than for the other fuels.
The fuel has an influence on the total mass of particles in the flue gas. A linear correlation has been found between fuel ash content and total particle mass in the flue gas.
In a 250 kW understoker furnace with flue gas recirculation, the influence on the particle size distribution was investigated by a variation of the primary excess air ratio, the overall excess air ratio as well as of the amount of re-circulated flue gas. The investigated understoker furnace allows Low-NO_x operation by substoichiometric combustion conditions in the primary combustion chamber.
All particle size measurements have been made in the flue gas after the cyclone. Native wood chips with 20 wt% humidity (mf basis) were used as fuel. The combustion quality was excellent with CO values below 20 mg/Nm^3.

An example of the particle size distribution is given in figure 5. The parameter variation in the understoker furnace showed no influence on the (relative) particle size distributions. However, flue gas recirculation leads to a significant decrease in the total particle mass in the flue gas (table I). In a moving grate furnace, the same effect has not been observed. During Low-NO_x operation without flue gas recirculation, increased total particle emissions were observed.

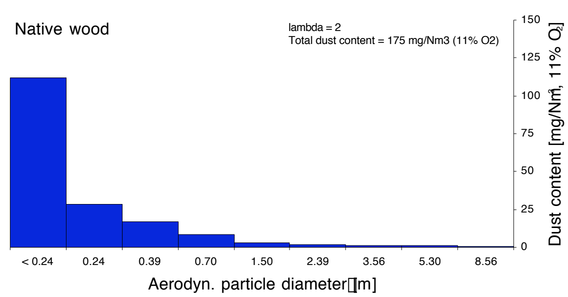

Figure 4: Particle size distribution during the combustion of native wood in a 250 kW understoker furnace operated at 170 kW

Table I: Results from the particle size measurements in the 250 kW understoker furnace
Remarks: R = recirculation rate (mass of recirculated flue gas / total mass of combustion air); CO, NO_x and dust at 11 vol.-% O_2.

no.	Heat output [kW]	R [%]	λ_{prim} [–]	λ_{tot} [–]	CO [mg/Nm^3]	NO_x [mg/Nm^3]	Particles [mg/Nm^3]
23	203	0	0.7	1.6	11	144	162
24	174	0	1.0	2.0	14	167	171
25	161	0	1.3	2.3	18	213	70
26	195	31	0.7	1.6	19	150	57
27	197	30	0.7	1.6	20	181	49
28	189	27	0.4	1.6	18	163	45
29	122	38	0.7	1.6	10	148	28
30	138	0	0.7	1.6	21	119	112

4. CONCLUSIONS

Except for bark, more than 80 weight% of the particles have diameters < 1μm. For native wood, chipboard, urban waste wood and hay, the mean particle diameter is <0.25 μm. Since conventional cyclones have very low separation efficiencies for particles below 2 μm, no significant reduction of the particle emissions will be achieved with cyclones.
Bark is the only fuel tested so far which exhibits a bimodal size distribution. Here only 50% or 30 mg/Nm^3 of the particle are found in the aerosol size fractions below 1 μm.
Flue gas recirculation in a understoker furnace leads to lower amounts of aerosol particles, but the particle size distribution can not be shifted to higher mean particle size diameters. The potential of reducing the amount of aerosol particles by primary measures needs further investigations.

ACKNOWLEDGMENTS

The present investigation was carried out in cooperation with the wood furnace manufacturers SCHMID AG (Eschlikon) and TIBA-MUELLER AG (Balsthal) and it was funded by the Swiss Federal Office of Energy. We express our thanks to ALUSUISSE (Schaffhausen) for the disposition of the aerosol measurement equipment.

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