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Full Length Article

Investigation of dust resistivity for a fractioned biomass fly ash sample during poor combustion conditions with regard to electrostatic precipitation

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ABSTRACT

It is well known that dust resistivity and particle size play a major role in electrostatic precipitation processes. The electrostatic precipitator design also has to be adapted for carbon rich fly ashes such as those found in heavy fuel oil combustion plants. In this work, an ash sample from an electrostatic precipitator downstream an industrial biomass boiler operated under poor combustion conditions was air classified into 5 particle size fractions. Those fractions were then analyzed regarding chemical composition, loss on ignition, particle size distribution and dust resistivity. Furthermore scanning electron as well as optical microscope images were taken to investigate particle structure and shape.

Diverse types of particles were found in the different fractions, varying from unburned coal particles to inorganic sand-like particles. It was also found that chemical composition as well as resistivity varied significantly with different size fractions. During resistivity measurements, fluctuating voltage and current values were recognized, similar to what can be seen during the back-corona phenomenon, but found at medium resistivity values. Furthermore, suggestions for an electrostatic precipitator design will be given based on findings in this study.

1. Introduction

Biomass combustion plants are commonly used to generate CO_2-neutral thermal energy for heating purposes or further conversion into electric power. Particulate emissions in those plants are typically controlled by centrifugal separators, electrostatic precipitators (ESPs) and bag filters. ESPs are commonly used on industrial biomass combustion systems due to their good separation efficiencies, low pressure drops and high availabilities.

ESPs are, especially on medium to small boiler systems in the power range of 1–10 $MW_{thermal}$, often faced with varying process conditions such as high number of start/stops or low-load operating conditions. These conditions usually lead to incomplete or poor combustion quality which results in increased amounts of unburnt carbon found in fly ash samples.

On the filters of gravimetric dust measurements, performed in the clean gas after the ESP of a biomass combustion boiler in Austria (Plant A), coal-like particles of a size up to 3 mm were found (Fig. 1) during above mentioned operation conditions.

It is known that the electrostatic precipitation process depends on dust resistivity and might be disturbed if resistivity is either too high or too low [1,2]. It was reported in Nussbaumer and Lauber [3] that dust resistivity of biomass fly ash is highly influenced by combustion conditions. They found separation efficiencies for soot particles of 16% by mass but 88% by number in a lab ESP and investigated that this is caused by re-entrained agglomerated particles.

In Ref. [4] tests with carbon-rich fly ashes in a lab-scale ESP it was concluded, that it is more difficult to collect carbon than mineral matter, but no detailed analysis of carbon particles were done and thus the effect of particle size might overrule the influence of resistivity of carbon particles in this case. Also Jedrusik and Swierczok concluded from their experiments with coal grate boiler fly ash samples in Ref. [5] a decrease of collection efficiency for high content of unburned carbon in the fly ash but this was also dependent on applied voltage on the test ESP. In Ref. [6] it was cited, that unburned coal content in particles lager than 100 µm was 10-times higher than in particles < 38 µm. Stretenovic et al. [7] investigated the influence of charred black liquor on dust resistivity of a recovery boiler ash sample but found only minor effect.

It was also investigated in previous works that chemical composition of fly ash from biomass combustion varies with particle size [8,9] and particle compositions of the same size may differ up- and

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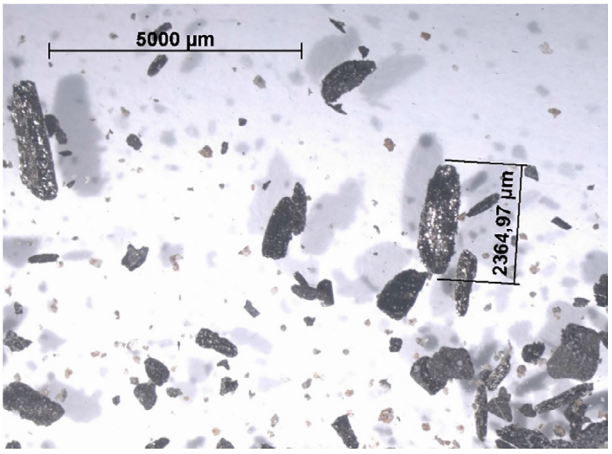

Fig. 1. Microscope image and particle size indication of a clean gas dust sample, precipitated during gravimetric dust measurement downstream a biomass boiler ESP.

downstream of an ESP [10].

In this study a biomass fly ash sample from an industrial ESP application was used to investigate the influence of particle size and dust resistivity to increase knowledge of the internal processes of electrostatic precipitation.

2. Material and methods

2.1. Materials

The ESP fly ash sample investigated in this study was collected from a woody biomass combustion plant in Finland (Plant B). The 4.5 $MW_{thermal}$ boiler was designed as a rotating grate with a conical primary combustion chamber as shown in Fig. 2.

The plant design is for a moisture content of the biomass fuel of 35–60 wt% and the design velocity of the ESP is < 0.8 m/s with an aspect ratio (length to height) of 1.7. The carbon monoxide design concentration for this plant was given with < 500 ppm based on dry gas and an excess oxygen concentration of 4%$_{Vol}$ (wet basis). This plant was selected for ash sampling because the ESP is installed directly downstream the boiler without a pre-separator and thus collects the full particle size range out of the boiler. The given CO design concentration is in a higher range, which might indicate a somewhat limited combustion efficiency of the system. In comparison, the current Austrian emission limit for similar sized boilers is 250 mg/m^3 (STP, dry at 11% O_2), which is equivalent to 200 ppm [11].

A fly ash sample of approximately 10 dm^3 was collected at the discharge of the ESP. No detailed process data were available during ash sampling period. The volume of the collected ash sample was reduced to a volume suitable for the various laboratory tests using sample dividers which were applied repeatedly (Haver & Boecker HAVER RT, Quantachrome Micro Riffler).

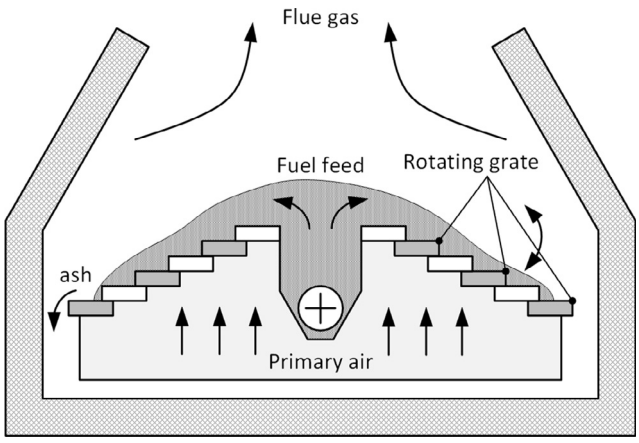

Fig. 2. Principle drawing of the grate system of Plant B.

2.2. Methods

A portion of the sample was taken without any further classification and used as a reference sample, referred to as the original sample. For sequential dry classification of the ESP fly ash sample a Hosokawa Alpine laboratory classifier 100 MZR was used. In a first step the larger particles were separated by sieving with a 500 µm sieve. In the first classification step size fraction 1, the finest size fraction, was separated from the bulk. The remaining coarse fraction was used as feed material in the second classification step, in which the classifier was operated at reduced speed. In this classification step the material was split into size fraction 2 and a new coarse fraction. This procedure was repeated twice. The details for such a sequential classification are described in the literature [12]. The speed of the classifier selected in the four classification runs was 21,000 rpm, 11,000 rpm, 6000 rpm and 3000 rpm. The coarsest size fraction was split into two size fractions by sieving with a 100 mm sieve.

The particle size distribution of the samples was measured using a laser diffraction instrument Sympatec HELOS/RODOS with dry sample dispersion. Microscopic images of particles from the various particle classes were taken with a Zeiss Stemi 2000-C microscope with an AcioCam MRc5 as well as a scanning electron microscope TESCAN, type VEGA LM.

The loss on ignition (LOI) was determined at 850 °C for 1 h after predrying the samples at 105 °C for 3 h.

All chemical analyses were determined by testing each sample in duplicate. In the results the average values are presented. For all elements the average relative standard deviation for the duplicates was less than 10%, except for As, Ba, Co and V where it was up to approximately 15%. The total carbon content (TC) was determined with a LiquiTOC system from Elementar Analysensysteme. For chemical analysis the samples were dissolved by an aqua regia digestion procedure according to ISO 11466. The concentration of most metals (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Sr, Ti, V and Zn) was measured by inductively coupled plasma optical emission spectroscopy (ICP-OES) using an Ultima 2 instrument from Horiba Jobin Yvon. For analyses of Na, K, Ca, Mg and SO_4^{2-} ion chromatography was used (Dionex ICS-1000). Details of the analytical procedure can be found elsewhere [13].

The dust resistivity of the various size fractions produced by air classification was measured in ambient air at constant gas humidity (water dew point was maintained at 50 °C). The resistivity was determined with increasing gas temperature – from 100 °C up to 300 °C with a constant temperature increase of 1 K/min. Measurements were generally done with constant current density of 0.5 mA/m^2. Current density had to be lowered for original sample as well as for size fraction 4 and 5 due to heavily fluctuating measurements to get stable values. The dust resistivity measurement setup is shown in Fig. 3. The dust measurement tray was designed with a height of 4 mm and a diameter of 100 mm. To ensure temperature and humidity equilibrium the electrodes were made of porous sinter material. The total accuracy of the measurement system was calculated with ± 7.8%.

The single particle resistivity was measured with a standard ohmmeter GW Instek GDM-396.

3. Results and discussion

3.1. Particle size and optical analysis

The oversize fraction > 500 µm of the ESP fly ash accounted for 24.9% of the total mass, while 75.1% passed the sieve. This material