Fly ash resistivity and aerosol formation for non-woody biomass combustion applications related to electrostatic precipitation

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1. Introduction

Non-woody biomass fractions such as nut shells, coffee ground, olive pomace, sunflower hulls and many more often occur as waste in food and agricultural production processes. On the other hand these processes demand heat or electricity which can be supplied using the bio-based waste streams on site. Thus these non-woody biomass fractions became a frequent source of fuel in industrial scale combustion facilities the last years. Those fuels tend to have higher concentrations of aerosol forming elements (mainly K, Na, Zn, Pb) and consequently emit higher concentrations of particulates <1 µm than woody biomass [1]. Electrostatic precipitators (ESPs) are, beside fabric filters, state of the art technology for advanced particulate matter (PM) control on industrial biomass combustion applications. For the correct ESP design particle size distribution and aerosol concentration respectively has to be taken into account and predicted as accurate as possible based on fuel analysis.

Fly ash resistivity is a second important parameter for electrostatic precipitator design. A lot of study has been done on design and operation as well as dust resistivity behavior of woody biomass ash in ESPs in the past [2, 3, 4]. In particular the dependency of dust resistivity on combustion quality was investigated in detail [5, 6]. Most of the work in that context was based on woody biomass as fuel. No literature was found on detailed analysis of ash composition of non-woody biomass fuels in relation to the specific dust resistivity.

In this paper the results of recent study on the impact of fly ash composition on specific dust resistivity for non-woody biomass fuels will be presented. All samples were taken from industrial scale applications to get as realistic values as possible. Also an outlook on an ongoing study on the optimization of industrial scale ESPs for non-woody biomass combustion applications will be given.

2. Material and Methods

32 ash samples from industrial applications with boiler capacities > 1 MW fueled on various biomass fuels were taken.

The ash samples derived from ESPs where ever applicable. On plants only equipped with centrifugal separators samples were taken from multicyclone or cyclone discharge. An overview of the ash samples and corresponding fuels is given in Tabel 1.

Table 1. Overview on ash samples (no. of samples, fuels, sample location and country of origin)

Samples	*Fuel*	*Sample location*	*Country*
1	20% cork 80% particle board	ESP	CH
4	bark	ESP, MC+ESP	DE
4	bark with wood chips	ESP	AT, DE
1	cacao shells	C	CI
1	coffee spent ground	MC	BE
1	empty fruit bunches (EFB)	MC	CO
1	grape seeds	ESP	FR
1	grinding dust	MC	AT
1	gum tree	C	AU
2	particle board	ESP	DE
1	reed canary grass	C	CH
1	rubber wood	ESP	TH
3	sunflower hulls	ESP, MC+ESP	BG, FR
2	waste wood	ESP	CH
5	wood chips	ESP	AT, DE, SG
3	wood chips (prunings and trimmings)	MC, ESP	DE

ESP…Electrostatic Precipitator, MC…Multicyclone, C…Cyclone

Essential ions were determined by ion chromatography (IC). Relevant semi-metals and metals were quantitated by inductively coupled plasma optical emission spectrometry (ICP-OES). The determination of the carbon content was accomplished using a high-temperature-TOC/TNb-analyzer.

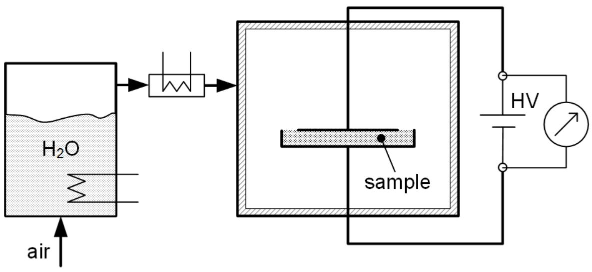

Figure 1. Basic layout of the dust resistivity setup

The system for the specific dust resistivity measurements was built by Scheuch GmbH. The basic layout can be seen in Fig. 1, a detailed description of the complete setup can be found in [7]. The resistivity measurements were done at a constant current density of 0.5 mA/m², which is a typical maximum value for industrial ESPs on biomass applications. When back corona was detected by recognizable fluctuations of the current values the current density was lowered till stable conditions were achieved again. Realistic current densities are required to determine back-corona phenomena in laboratory resistivity measurements as found in [8] and [9]. The measurements were performed in an atmosphere of air with a constant water dew point of 50°C. The temperature program started at 80°C with a constant temperature increase of 1 K/min until a temperature of 250°C was reached.

Measurements of dust resistivity for different ash fractions (ESP and Cyclone) out of one plant were conducted. Aim was to verify if ash fractions out of ESP, cyclone and multicyclone can be compared in terms of dust resistivity since sample location were also different for many plants. Especially installations for non-woody fuels or smaller facilities use only centrifugal separator as PM control device.

The ash composition and resistivity results were then computed using multivariate analysis to determine the influence of single elements on dust resistivity. Dust resistivity was assumed as being dependent on all ash composing elements. For this analysis dust resistivity value at 250°C was taken to eliminate surface conductivity effects and only taken volume conductivity into account.

3. Results and discussion

Ash fraction resistivity influence

Fig. 2 shows the dust resistivity curves for 3 different ash fractions of the same plant running on wood chips from prunings and trimmings as fuel.

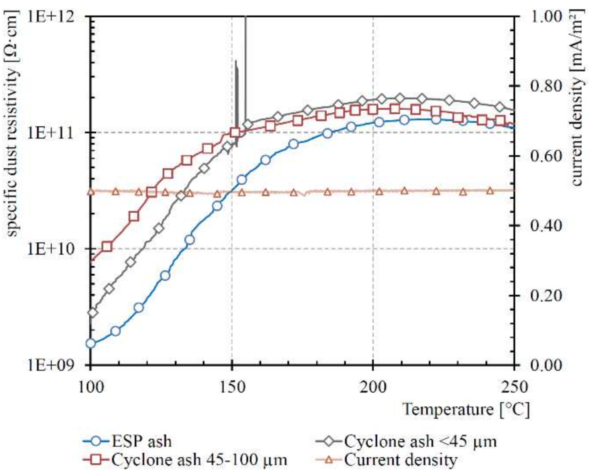

Figure 2. Dust resistivity for different ash fractions of one plant

The test was done to determine the comparability of dust resistivity for ash fractions out of centrifugal separators and ESPs. Measurements showed lowest resistivity for ESP ash while values increased with increasing particle sizes for temperatures up to about 150°C. For higher temperatures resistivity values were in the same range with minor variation. Especially on temperature of 250°C values of all 3 fraction were almost the same. It was concluded that even having different ash fractions the variation on volume conductivity is in a minor range and results from ESP ashes should be comparable to those from centrifugal separators.

Dust resistivity measurements

Dust resistivity measurements were performed for all samples. On 6 samples back corona was detected whereas 5 of those samples were fueled on woody biomass (bark, woodchips or prunings and trimmings). Highest resistivity was measured at 195°C with 1×10^{12} Ω·cm at current density of 0.08 mA/m² for a sample derived from a bark combustion facility. Fig. 3 shows dust resistivity curve for the reed canary grass sample which was the only non-woody biomass sample also showing slight back corona phenomenon. When reducing current density down to approx. 0.3 mA/m² measurement was stable and no back corona occurred.

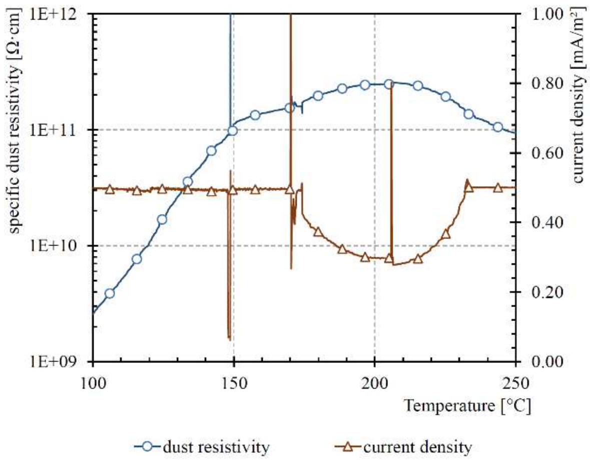

Figure 3. Dust resistivity for reed canary grass ash sample

For further correlation analysis the resistivity values at 250°C were taken as representative single values, only having volume conductivity influencing dust resistivity. Results vary between roughly 1×10^{9} and 3×10^{11} as shown in Fig. 4.

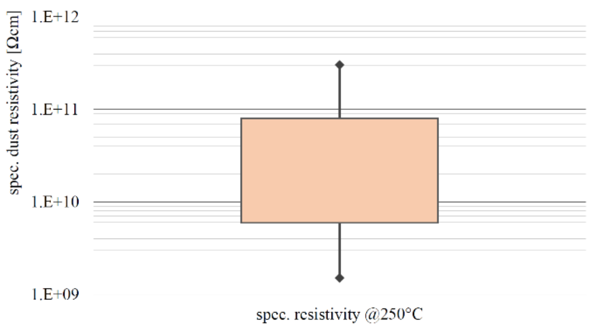

Figure 4. Dust resistivity values @250°C of all samples (25 and 75% percentile, min. and max. values)

Ash analysis

Following ash elements and parameters were analysed for all samples: Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sn, Zn, Al, PO_4, SO_4, Na, K, Mg, Ca, Total Carbon (TC) and Total Organic Carbon (TOC).

Fig. 5 shows the range of concentration for major aerosol forming elements K, Na, Zn and Pb. It was found that Potassium is by far the most important aerosol forming species. Zn and Pb were found in significant concentrations in waste wood fly ash and bark fly ash respectively. Na concentrations above 1% in fly ash were found in some woody biomass samples, all samples from non-woody biomass hat concentrations < 1%.

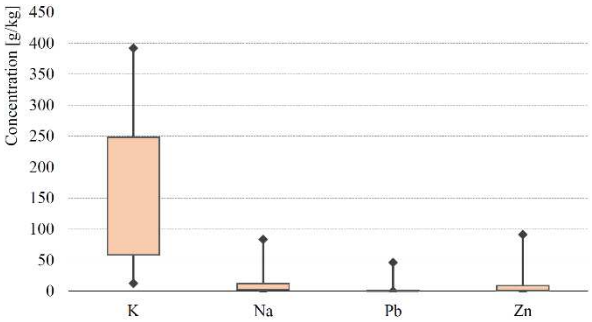

Figure 5. K, Na, Pb and Zn content of all samples (25 and 75% percentile, min. and max. values)

<u>Correlation of specific resistivity on ash composing elements</u>

The results of dust resistivity measurements at 250°C and chemical analysis were used for correlation analysis. The correlation matrix was visualized in a correlogram and can be seen in Fig. 6. For more information please refer to [10].

Highest values for Pearson product-moment correlation coefficient (PCC) for dust resistivity (*Re*) were found for Al (0.474) and K (–0.434). Regression analysis showed an influence of both components in the range of 1.5 decimal powers over the whole spectrum of 0.1 – 33.5 g/kg for Al and 12.6 – 392 g/kg for K.

Most other components had no or only minor statistical influence on biomass ash resistivity. Similar tendencies can be found in literature [11] reported decreasing resistivity with increasing concentrations of SO_3, Mg (MgO), Ca (CaO), K (K_2O), and Na (Na_2O) in coal fly ash. Mohanty et. al. [12] published increasing resistivity with increasing Al (as Al_2O_3) content in fly ash.

Wheland et. al. [11] reported variation in resistivity in the range of 1.5 decimal powers when varying K_2O concentration in coal fly ash from 0.3% to 0.7% or Na_2O concentrations from 0.05% to 1.1% whereas Mohanty et. al. [12] published influence of Na_2O in the range from 0.5% to 3% on resistivity with 0 – 4000×10^{10} Ωcm and for Al_2O_3 from 1% to 30% in the range of 0 – 8000×10^7 Ωcm.

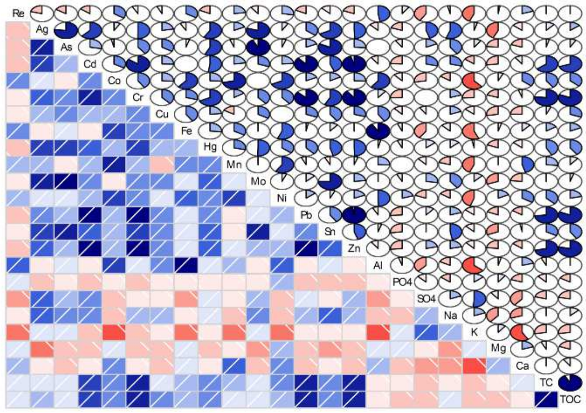

Figure 6. Correlogram for PCC dust resistivity (*Re*) and ash components (blue = positive, red = negative correlation; filling degree = strength of correlation)

Strong correlations of other ash components were found such as Zn and Pb as shown in Fig. 7 below.

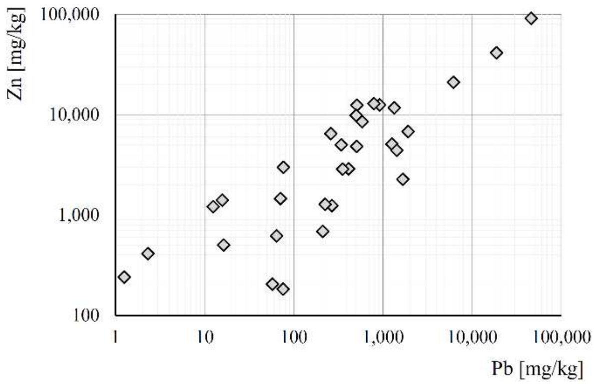

Figure 7. Scatterplot of Pb versus Zn concentration in biomass fly ashes

As mentioned above also Total Carbon and Total Organic Carbon was analysed for all samples (see Fig. 8).

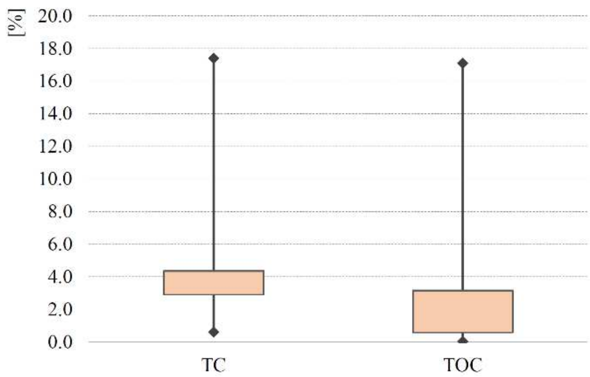

Figure 8. Total Carbon (TC) and Total Organic Carbon (TOC) content of all samples (25 and 75% percentile, min. and max. values)

Work from Nussbaumer and Lauber [5, 6] showed a variation of specific dust resistivity dependent on combustion conditions of up to 6 decimal powers. Accordingly carbon content in fly ash can either increase (as Condensable Organic Compounds – COC) or decrease (as soot) dust resistivity.

Taking the wide variation of TOC levels of 0.03% up to 17% in the samples into consideration it is most likely that carbon content – either as COC or soot – has the highest influence on specific dust resistivity.

4. Outlook

Based on the findings in this work two essential topics will be investigated in a follow-up project. The prediction of aerosol forming potential dependent on fuel analysis and better understanding of the behavior of different particle species (salt, soot, COC) in the electrostatic precipitation process will be investigated in a cooperation between Scheuch GmbH and BIOS BIOENERGIESYSTEME GmbH, Graz, Austria.

First results of aerosol forming potential analysis are given in Figure 1. Aerosol concentration in flue gas after biomass combustion application can vary in a range of 1:38 and has to be considered in ESP design.

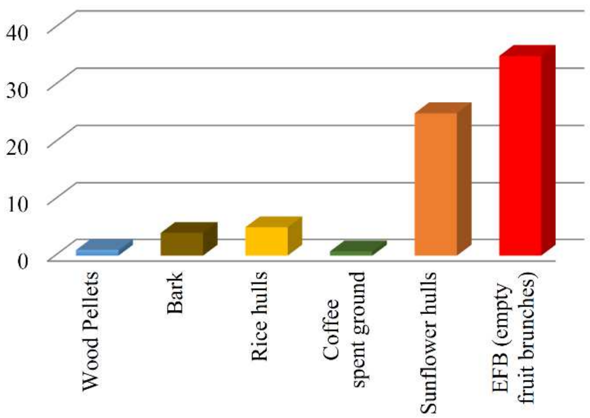

Figure 1. Relative aerosol forming potential (wood pellets = 1) of different biomass fuels; [1] and Scheuch/BIOS

A CFD model [13] developed by BIOS BIOENERGIE-SYSTEME GmbH will be used to investigate the behavior of the different aerosol fractions (salts, soot and COC) in the electrostatic precipitation process with verification in a lab-scale ESP downstream a biomass boiler.

5. Conclusion

It was found that fly ash resistivity for non-woody biomass is in the same range as for woody biomass fuels. Ashes derived from fuels with high potassium contents tend to have slightly lower specific resistivity. Higher resistivity values and thus back corona phenomenon in ESPs are more determined by combustion process and combustion quality than influenced from ash composition itself.

Due to very high aerosol formation potential for some non-woody biomass fuels ESP design is more critical than for woody biomass. Reason is the wide range of aerosol concentrations derived from such fuels.

Nevertheless more work has to be done to predict aerosol concentrations based on fuel analysis more precisely. Also a better understanding of aerosol formation process during incomplete combustion and behaviour in the electrostatic precipitation process is necessary to further enhance ESP design for those applications.

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