

Fly ash from the combustion of post-consumer waste wood: distribution of heavy metals by particle size

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Abstract: - In industrialized countries considerable amounts of post-consumer waste wood are generated, which can be used as fuel in combustion processes. Because of the contamination of the waste wood with heavy metals, the ash produced contains higher amounts of some heavy metals. In the investigated fly ash the concentrations were within the published range. Generally, the enrichment of the heavy metals in the fine fraction was equal to or less compared to reported data for wood combustion fly ash. The main exception to this was Mn, which was enriched in the fine fractions in this study while in wood combustion fly ash the concentration was independent of the particle size. For the heavy metals Cd, Pb and Zn the dependence of the concentration on the particle size was similar to published data for wood combustion fly ash. The size dependence of the sulfate concentration was even more pronounced. The dry flue gas desulphurization unit operated in the investigated plant is likely to be responsible for this difference.

Key-Words: - Waste wood; combustion, fly ash; heavy metals, particle size, air classification

1 Introduction

Each year considerable amounts of post-consumer waste wood are generated [1,2]. This waste wood can be utilized as fuel in biomass combustion boilers. However, post-consumer waste wood is contaminated by increased amounts of chlorine and heavy metals (As, Cd, Cu, Cr, Pb, Sb, Zn) [3,4]. Negative impacts in the boiler system associated with waste wood combustion are increased formation of deposits and corrosion. Additionally, the ashes from the combustion of post-consumer waste wood contain increased amounts of heavy metals as a result of the contaminated fuel. Some data about the composition of fly ashes from waste wood combustion is available in the literature [5-7]. In comparison with typical heavy metals concentrations in fly ash from the combustion of untreated wood [8], the concentrations of P and Sb are one order of magnitude higher, while the concentrations of As, Cd, Cr, Cu, Ni and Zn are approximately twice as high. In the combustion process some components are volatilized and re-condense during the cooling of the off-gas. These components are enriched in the fine size fractions of the fly ash because of its higher specific surface area. For fly ash from wood combustion enrichment

in the fine fractions has been reported, especially for the heavy metals Cd, Cu, Pb and Zn [9,10].

In this study, fly ash from a biomass combustion plant which uses post-consumer waste wood as part of the fuel was investigated with respect to the distribution of the heavy metals and to the different size fractions of the fly ash.

2 Material and Methods

2.1 Material

A fly ash sample of about 2 dm³ was obtained from a 50 MW_{th} bubbling fluidized bed (BFB) combustion plant. It was collected from the discharge of the off-gas de-dusting filters. The fuel used in the plant consisted of approximately 30% of post-consumer waste wood and 70% of bark and saw mill residues. The off-gas system consisted of a dry sorption off-gas desulfurization process using hydrated lime as reactant with a subsequent fabric filter.

2.2 Air classification

A laboratory air classifier 100 MZR from Hosokawa Alpine was used for the sequential classification of

the fly ash sample. 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. In this classification the classifier was operated at reduced speed to split the material 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 [11]. The speed of the classifier selected in the four classification runs was 21,000 rpm, 11,000 rpm, 6,000 rpm and 3,000 rpm. The concentrations of Cr, Ni and Mo cannot be determined in the size fractions of the fly ash because of some erosion of stainless steel material from the classifier. For Fe this contamination can be disregarded because the Fe content of the fly ash is considerably higher. Therefore, the relative concentration increase of Fe caused by the erosion of classifier material is much smaller [12].

2.3 Sample Characterization

All chemical analyses were determined by testing each sample in duplicate. The average relative standard deviation calculated from the duplicate measurements was 5.2%. In the results the average values are presented. For determination of the concentration of metals and sulfate the samples were dissolved by aqua regia digestion prior to analysis. The concentrations of Na, K, Ca, Mg, and SO_4^{2-} were measured by ion chromatography (Dionex ICS-1000 system). The other metals were measured by inductively-coupled plasma optical emission spectroscopy (Horiba Jobin Yvon Ultima 2 system). The details of the analytical methods can be found elsewhere [8].

The particle size distribution of the samples was determined using a Sympatec HELOS/RODOS laser diffraction instrument with dry sample dispersion. The calibration of the instrument was checked with a Sympatec SiC-P600'06 standard.

2.4 Calculations

When a volatile component is deposited onto fly ash particles the dependence of the concentration of this material is often described by the relation: $c \sim d^{-N}$ [13]. The exponent N results from the mechanism of condensation or reaction of the components on the particles. This relation was used to characterize the size dependence of the concentration of the various components in the fly ash. The mass median diameter d_{50} was used as the characteristic particle size of the size fractions. The higher the value of the exponent N , the more pronounced is the increase in

the concentration of this component in the fine size fractions and the depletion of this component in the coarse size fractions.

The mass concentration $c_{m,i,j}$ of a component i in size fraction j can be expressed by Eq.(1):

$$c_{m,i,j}(d_{50}) = K_i \cdot (d_{50,j})^{-N_i} \quad (1).$$

The exponent N_i for each component was obtained by linear regression.

3 Results and Discussion

3.1 Particle size distribution

The particle size distributions of the size fractions produced are shown in Figure 1. The mass median diameters of the five size fractions were 2.1 μm , 3.6 μm , 7.9 μm , 20 μm and 63 μm . The mass median diameter of the original fly ash was 16.0 μm .

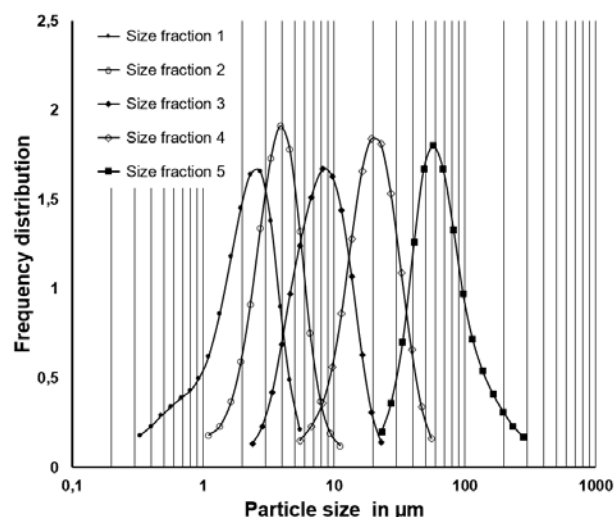


Fig. 1 Particle size distribution of the fly ash size fractions produced

3.2 Composition of Fly Ash

The chemical analysis of the fly ash fractions is shown in Table 1. The highest concentrations were found for the heavy metals Zn and Pb. For both elements the dependence of the concentration on the particle size was quite pronounced (Fig. 2). The exponent N was 0.45 for both elements. Compared to data published for wood combustion fly ash the exponents were slightly lower [9]. For Cu the results differ. In this study the concentration of Cu was practically independent of the particle size while in the study with wood combustion fly ash a moderate enrichment in the fine size fractions was found [9].

Table 1 Chemical composition of the fly ash size fractions (in mg/kg d.w.)

	Fly ash	Size Fraction 1	Size Fraction 2	Size Fraction 3	Size Fraction 4	Size Fraction 5	N
Al	22,700	6270	10,300	18,100	24,200	35,600	-0.49
As	66	38	39	49	57	110	-0.30
B	177	316	246	169	98	66	0.47
Ba	555	418	350	499	848	1,460	-0.42
Cd	14	21	18	14	8	2	0.63
Co	15	17	16	15	13	10	0.15
Cu	245	240	237	260	255	279	-0.05
Fe	11,100	5,440	7,580	11,500	13,600	12,500	-0.25
Mn	5,000	8,850	6,410	4,280	2,670	1,620	0.50
Pb	975	1,300	1,170	996	628	278	0.45
Sb	52	72	55	39	30	34	0.23
Sr	343	515	429	374	272	157	0.34
Ti	1,400	1,980	2,060	2,500	1,740	1,330	0.13
V	31	18	20	30	36	33	-0.19
Zn	4,310	6,400	5,580	3,880	2,550	1,420	0.45
SO4	25,100	90,200	46,100	26,600	11,700	4,700	0.85
Na	4,020	3,920	4,120	4,790	4,800	2,940	0.06
K	23,300	35,600	31,300	24,500	21,000	11,700	0.31
Mg	18,500	18,800	16,300	18,400	23,100	14,600	0.03
Ca	192,000	260,000	268,000	234,900	174,800	88,000	-

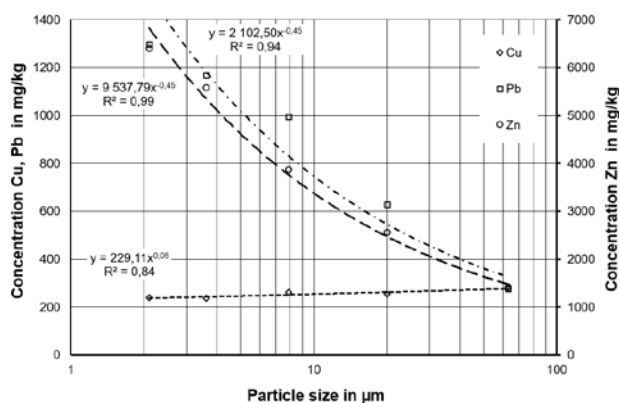


Fig. 2 Size dependence of the concentration of the heavy metals Cu, Pb and Zn

The enrichment of Cd in the fine size fractions was even more significant, which resulted in an exponent of $N=0.63$ (Fig. 3). In the study with wood combustion fly ash the enrichment for Cd was the same ($N=0.62$) [9]. For Co and Sb only slight enrichment was found in this study. The respective exponents were 0.15 and 0.23. In contrast, in wood combustion fly ash the concentration of these elements was independent of the particle size [9]. The heavy metals As and V were depleted in the fine size fractions of the waste wood combustion fly

ash. Thus, the exponents were negative for these elements. For wood combustion fly ash similar behavior of As and V was found. The respective exponents were quite similar [9].

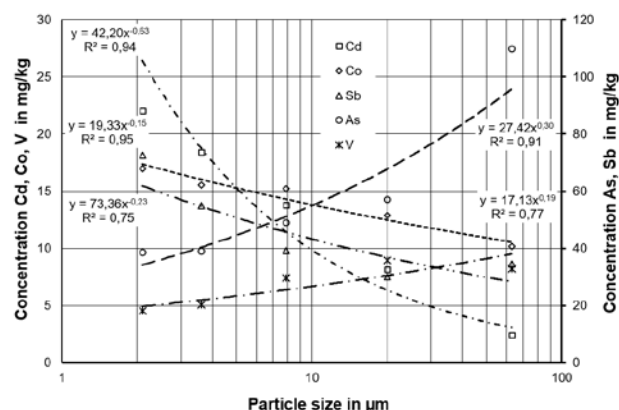


Fig. 3 Size dependence of the concentration of the heavy metals As, Cd, Co, Sb and V

Surprisingly, for Mn (Fig. 4) considerable enrichment in the fine size fractions was found in this study ($N=0.50$), while in wood combustion fly ash the Mn concentration was independent of the particle size [9].

The highest value of the exponent ($N=0.85$) was found for sulfate (Fig. 4). This value is higher than has been reported for the enrichment of sulfate in fly ash from wood combustion [9]. An explanation for this high value is the flue gas desulphurization process operated in the investigated plant. The SO_2 contained in the off-gas reacts with the lime powder added to the flue gas. As most of the reaction takes place at the surface of the lime particles the separated SO_2 is nearly proportional to the surface of the particles, which is proportional to $d^{-1.0}$.

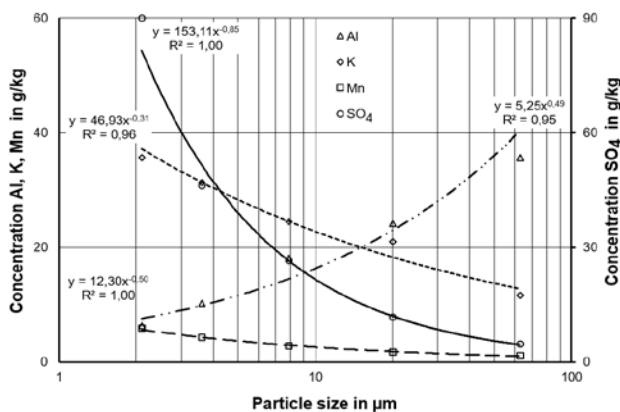


Fig. 4 Size dependence of the concentration of sulfate and the elements Al, K and Mn

The element K is enriched in the fine size fractions, while Al (Fig. 4) and Fe (Fig 5) are depleted. For Mg and Na no distinct size dependence of the concentrations was found (Fig. 5). This is in accordance with the results published for wood combustion fly ash [9].

For Ca the distribution in the different size fractions is strongly influenced by the size distribution of the added lime powder. Thus, a different type of approximation function was used.

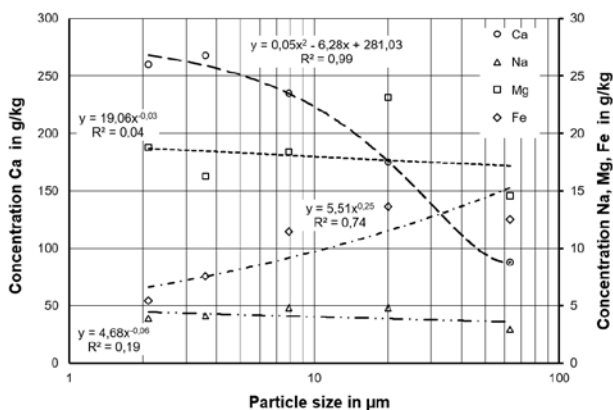


Fig. 5 Size dependence of the concentration of the elements Ca, Fe, Mg and Na

4 Conclusion

The heavy metal concentrations in fly ash from waste wood combustion are higher than in the fly ash from the combustion of untreated wood. In the investigated fly ash the concentrations of the investigated heavy metals were within the published range.

For the heavy metals Cd, Pb and Zn a considerable dependence of the concentration on the particle size was found. The calculated exponents in the approximation equation were in a similar range as that published for wood combustion fly ash.

The size dependence of the sulfate concentration was even more pronounced than reported for wood combustion fly ash. The dry flue gas desulfurization unit operated in the investigated plant is probably responsible for this difference.

Generally, the enrichment in the fine fraction was less for most components investigated compared to reported data for wood combustion fly ash. The main exception to this was the distribution of Mn, which was enriched in the fine fractions in this study, while in the reported data the concentration was independent of the particle size.

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References:

- [1] Frühwirth, W., Stark, W., Pilz, H., Schweighofer, J., *Vermeidung und Verwertung von getrennt gesammelten Abfällen und hausmüllähnlichen Abfällen aus Gewerbe und Industrie in Österreich*, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien, 2005
- [2] McKeever, D.B., Falk, R.H., *Woody residues and solid waste wood available for recovery in the United States, 2002*, Management of Recovered Wood, Recycling, Bioenergy other Options, University Studio Press, Thessaloniki, 2004.
- [3] Thrän, D., *Holzartige Biomasse*, in: Kaltschmitt, M., Hartmann, H., Hofbauer, H. (Eds.), *Energie aus Biomasse, Grundlagen, Techniken und Verfahren*, 2nd Ed., Springer Verlag, Berlin, pp. 135-170, 2009.
- [4] Nzihou, A., Stanmore, B., The fate of heavy metals during combustion and gasification of contaminated biomass—A brief review,

Journal of Hazardous Materials, Vol.256– 257, No.1, 2013, pp. 56– 66.

- [5] H Lanzerstorfer, C., *Characterization of fly ashes from the combustion of post-consumer waste wood*. Proceedings of the 4th European Conference on Renewable Energy Systems, Aug. 28.-31., Istanbul, pp. 925-930, 2016.
- [6] van Loo, S., Koppejan, J., *The Handbook of Biomass Combustion and Co-firing*, Earthscan, London, 2008.
- [7] Berg, M., *Combustion of Waste Wood: Swedish Experiences and Research*, Joint Meeting IEA Bioenergy Task 32,33 and 36, Oct. 28t., Tokyo, 2003.
- [8] Lanzerstorfer, C., Chemical composition and physical properties of filter fly ashes from eight grate-fired biomass combustion plants, *Journal of Environmental Sciences*, Vol.30, No.1, 2015, pp. 191-197.
- [9] Lanzerstorfer, C., Cyclone fly ash from a grate-fired biomass combustion plant: dependence of the concentration of various components on the particle size, *Fuel Processing Technology*, Vol.131, No.1, 2015, pp. 382-388
- [10] Lanzerstorfer, C., Model based prediction of required cut size diameter for fractionation of fly ash from a grate-fired wood chips incineration plant, *Fuel Processing Technology*, Vol.92, No.5, 2011, pp. 1095-1100.
- [11] Lanzerstorfer, C., Kröppel, M., Air classification of blast furnace dust collected in a fabric filter for recycling to the sinter process. *Resources, Conservation and Recycling*, Vol.86, No.1, 2014, pp. 132-137.
- [12] Lanzerstorfer, C., Investigation of the contamination of a fly ash sample during sample preparation by classification, *International Journal of Environmental Science and Technology*, Vo.12, No.4, 2015, pp. 1437-1442.
- [13] Linak, W.P., Wendt, J.O.L., Toxic metal emissions from incineration: Mechanisms and control, *Progress in Energy and Combustion Science*, Vol.19, No.2, 1993, 145-185.