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FRACTIONATED HEAVY METAL SEPARATION IN BIOMASS COMBUSTION PLANTS - POSSIBILITIES, TECHNOLOGICAL APPROACH, EXPERIENCES

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ABSTRACT

Previous research has shown that the natural cycle of minerals within the process of energy production from biomass is disturbed by deposition of heavy metals on the forest ecosystem. By separating a side stream rich in heavy metals (filter fly-ash) it should be possible to recycle the major part of the ashes produced (usable ash – a mixture of bottom ash and cyclone fly-ash). The aims of technological development are to reduce heavy-metal concentrations in the usable ash and to upgrade them in the filter fly-ash by implementing primary measures during the combustion process.

In the first phase of the present research project large-scale tests were carried out in a state-of-the-art biomass combustion plant. The results have shown that some variables have a significant influence on the Cd and Zn fluxes. These variables include the reducing potential of the gaseous phase around the ash particles, the temperature of ash precipitation in an oxidizing atmosphere and the size of the ash particles at temperatures below 800 °C.

Based on these results a new combustion technology with integrated fractionated heavy-metal separation was developed. In order to achieve reducing conditions in the primary combustion zone an "air staging" technology was implemented. Part of the fly-ash is precipitated at high temperatures in a relaxation zone in the secondary combustion chamber and in a high-temperature cyclone placed before the boiler. The filter fly-ash rich in heavy metals is efficiently precipitated in a flue-gas condensation unit followed by an aerosol electrostatic filter.

The new combustion technology was realized in a biomass district heating plant in Austria. The results of test runs carried out at the new plant show a high fractionation potential of Cd and Zn under reducing conditions. On an average the bottom ash produced in the new plant contains 27 times less Cd and 5 times less Zn than the respective ash fraction generated by state-of-the-art plants. In hot-precipitated fly-ashes the levels of Cd are 5 to 15 times lower than in fly ashes generated in multi-cyclones, whereas the fractionation potential of Zn is low. Furthermore, the amount of filter fly-ash with high heavy metal content increased due to the lower precipitation efficiency of the hot cyclone as compared to multi-cyclones. Therefore, hot cyclones are considered not efficient enough for fractionated heavy metal separation. Future

research and development will especially focus on the high fractionation potential for volatile heavy metals under reducing conditions.

INTRODUCTION

Coincident to forcing the thermal energy utilization of biomass (wood chips, sawdust, bark, straw, cereals), the amounts of combustion residues (ash) increase. Therefore, it is necessary to find ways of utilizing the ashes produced in a sustainable manner. Previous research has shown that the elementary cycle of nature within the process of thermal energy utilization from biomass is disturbed by dry and wet deposition of heavy metals on the forest ecosystem caused by environmental pollution. By separating a side stream rich in heavy metals (the so-called filter fly-ash - precipitated in electrostatic filters, fibrous filters or flue gas condensation units) it should be possible to recycle the major part of the ash produced, the so-called "usable ash". The usable ash represents a mixture of bottom ash and fly-ashes collected before filter fly-ash precipitation takes place (see Fig. 1).

The heavy metal levels measured in the usable ash fraction from state-of-the-art combustion plants show that the concentrations of Cd approach and in some cases even exceed the present Austrian limiting values for the utilization of biomass ashes on agricultural fields or forest soils [Bundesministerium für Land- und Forstwirtschaft, 1997; Salzburger Landesregierung, 1997]. The concentrations of Zn have also shown to be close to the limiting values.

Consequently, the aims of technological development are to reduce heavy metal concentrations in the usable ash and to upgrade them in the filter fly-ash, by designing a combustion technology that allows for efficient heavy metal separation during the combustion process. Such a primary measure has the advantage that no further ash treatment is necessary, which reduces the operating costs of the plant and meets the requirements for a decentralized closed-cycle economy within the system of energy production from biomass.

OBJECTIVES

Based on previous biomass research [I.Obernberger, 1995] and the requirements for sustainable ash utilization, comprehensive investigations on the heavy metal fluxes and the influencing variables in biomass combustion plants were carried out. The research work covered the following points [F.Biedermann et.al., 1997; I.Obernberger et.al., 1997a]:

1. Test runs in a state-of-the-art grate-fired biomass combustion plant (Lofer, Austria) taking into account various operating parameters:
    - Tests with different kinds of bio-fuels (bark, wood chips).
    - Variation of the temperature in the combustion zones in order to check its influence on the heavy metal concentration in hot precipitated fly-ashes.
    - Tests at different plant loads in order to check the influence of different fly-ash production rates on the heavy metal fluxes.

2. Determination of the concentrations of heavy metals and nutrients in the different ash fractions produced and in the bio-fuels used.
3. Evaluation and interpretation of the results in order to examine the possibilities and the potential of a new combustion technology with integrated fractionated heavy metal separation.
4. Implementation of a new technology with integrated fractionated heavy metal separation in a biomass district heating plant.
5. Test runs in the new biomass combustion plant with integrated fractionated heavy metal separation.
6. Evaluation of the results achieved in comparison with the results obtained from the test runs performed in a state-of-the-art combustion plant in order to assess the potential of the new combustion technology as regards fractionated heavy metal separation.
7. Optimization of the new technology to enhance fractionation efficiency and to reduce investment costs.
8. Ecological evaluation of the ash quality produced using the new combustion technology.

METHODOLOGY

Altogether, 11 large-scale tests were carried out in a state-of-the-art biomass combustion plant (Lofer, Austria) equipped with a moving grate furnace, a multi cyclone and a flue-gas condensation unit. During the test periods, samples of 7 different ash fractions precipitated at different temperatures between 1000 and 40 °C and of the bio-fuel used were taken at regular intervals and analyzed for their contents of nutrients and heavy metals. Moreover, the amounts of biomass fired and ashes produced, the ash precipitation temperature, the amount of heat produced, the water content of the bio-fuel and the excess oxygen in the flue gas were measured.

Figure 1: Ash fractions sampled and respective precipitation temperatures
Explanations: The temperatures shown are average measurement data obtained during test runs.
Abbreviations: $T_{precip.}$ - precipitation temperature.

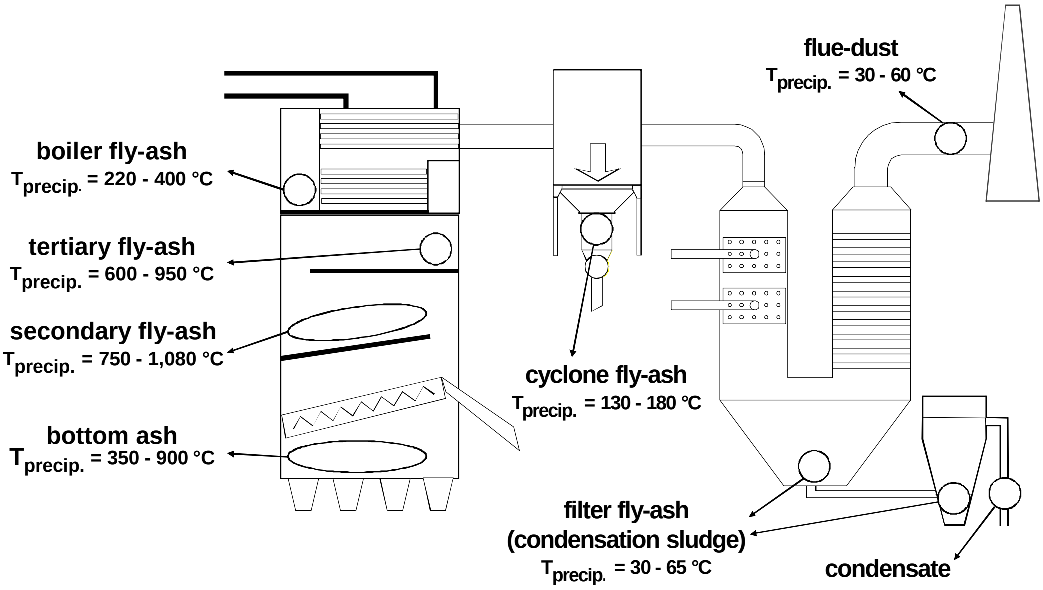


Figure 1 shows a scheme of the biomass combustion plant where the test runs were performed. Every test period lasted 3 days. The first day was necessary to adjust the combustion unit to the specified side constraints. After a pre-run of 24 hours the boiler, the combustion unit and the fly-ash precipitation units were carefully cleaned for the subsequent 48-hour test period.

In the autumn of 1996 a series of 8 test runs was performed at the new biomass combustion plant with integrated fractionated heavy metal separation (Straßwalchen, Austria). The sampling methodology and the recording of operating data were similar to the ones already described. The different ash samples taken during the test runs in Straßwalchen and the respective precipitation temperatures are shown in Fig. 2.

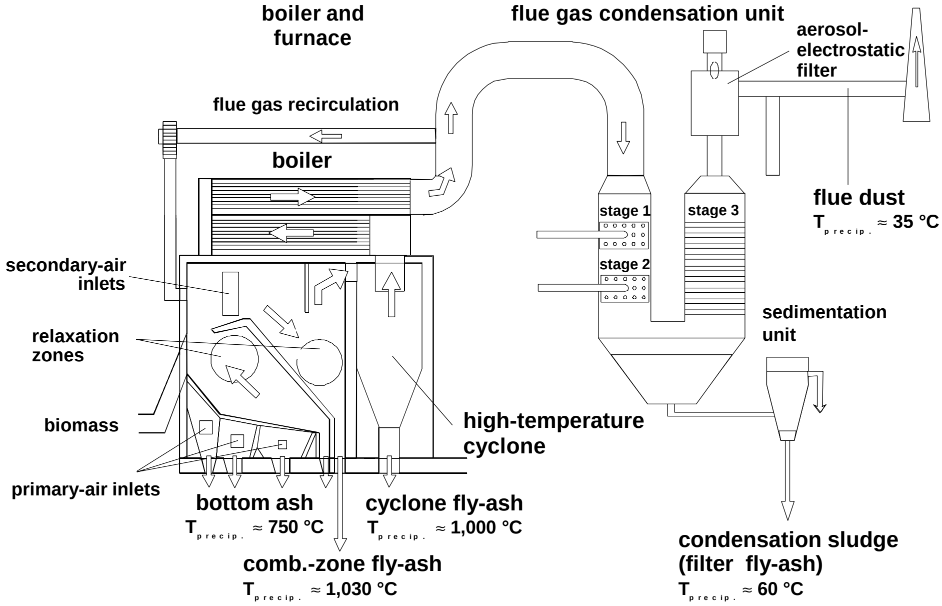
DESCRIPTION OF THE NEW COMBUSTION TECHNOLOGY WITH INTEGRATED FRACTIONATED HEAVY METAL SEPARATION

Based on the research results achieved, the following points were considered for the design and development of a new combustion technology with integrated fractionated heavy metal separation [F.Biedermann et.al., 1997] (for details see section "Results"):

- The amount of bottom ash should be increased as much as possible.
- The major part of the fly-ash (particle size >15 µm) should be precipitated at temperatures above 850 °C.
- The precipitation of the fine fly-ash remaining in the flue gas should be carried out in an efficient way to avoid an increase of heavy metal emissions.

Figure 2: Schematic illustration of the new technology with integrated fractionated heavy metal separation and the ash fractions sampled

Explanations: The temperatures shown are average measurement data from the test runs.
Abbreviations: $T_{precip.}$ - precipitation temperature.



These objectives were to be achieved by a new design and process control of the furnace and a new fly-ash precipitation technology (see Fig. 2). A new geometry of the primary combustion chamber decreases the chamber volume over the last grate section and consequently raises the temperature in this section (influence of radiation). Furthermore, a relaxation zone in the primary combustion zone increases the residence time of the flue gas and enhances fly-ash precipitation on the grate. Moreover, a reducing atmosphere is achieved and the entrainment of ash particles decreased by means of section-separated and well-controlled distribution of the primary air over the grate. A second and bigger relaxation zone is situated in the secondary combustion chamber. Larger fly-ash particles are precipitated there at temperatures between 900 and 1,100 °C.

The furnace is equipped with "air staging" technology, which means that the gasification of wood and the combustion of the gases produced take place in different combustion chambers. The reducing atmosphere in the primary combustion zone should both increase heavy metal evaporation and reduce nitric oxide emissions. Furthermore, a high-temperature cyclone was placed behind the furnace. The precipitation temperature in this cyclone varies between 950 and 1,050 °C to guarantee low concentrations of volatile heavy metals (especially Cd) in the ash fraction produced.

The usable ash consists of a mixture of bottom ash and hot-precipitated fly-ashes. The fine fly-ash particles leaving the boiler are effectively precipitated in a flue gas condensation unit with an aerosol electrostatic filter installed behind it for low-temperature precipitation (about 40 °C). This filter fly-ash fraction has to be disposed of or industrially utilized.

The new technology was implemented in an Austrian biomass combustion plant (nominal boiler capacity 3 MW_{th}) which was put into operation in the spring of 1996.

RESULTS – IMPORTANT INFLUENCING VARIABLES FOR FRACTIONATED HEAVY METAL SEPARATION IN BIOMASS COMBUSTION PLANTS

The following section discusses and compares the results of the test runs carried out in the state-of-the-art combustion plant (Lofer) and the plant with integrated fractionated heavy metal separation (Straßwalchen). The discussion focuses on the environmentally most relevant heavy metals in bio-fuels and ashes, which are primarily Cd and secondarily Zn.

Cd and Zn concentrations in the different ash fractions sampled – influence of temperature on heavy metal behavior

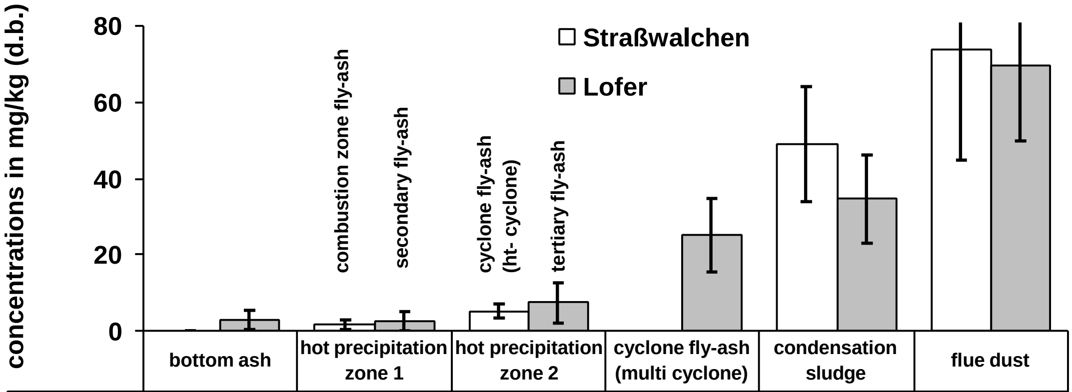
Figure 3 and 4 show the average concentrations of Cd and Zn in the different ash fractions examined. The concentrations increase significantly with decreasing temperature of precipitation and decreasing ash particle size. The flue dust contains about 700 times as much Cd and 200 times as much Zn as the bottom ash.

The new combustion technology shows a considerable reduction potential for Cd and Zn in the bottom ash. Compared to state-of-the-art combustion plants the Cd concentrations in the bottom ashes produced in the new plant equipped with integrated fractionated heavy metal separation are about 20 times lower. The Cd levels in the combustion zone fly-ash and in the fly-ash precipitated in the high-temperature cyclone are slightly lower than in fly-ashes precipitated at similar conditions in state-of-the-art combustion plants (see Fig. 3).

Figure 3: Average Cd concentrations in different ash fractions produced by different combustion technologies

Explanations: comparison of state-of-the-art technology (Lofer) and technology with integrated fractionated heavy metal separation (Straßwalchen), the ashes precipitated in comparable locations and at similar temperatures are compared.

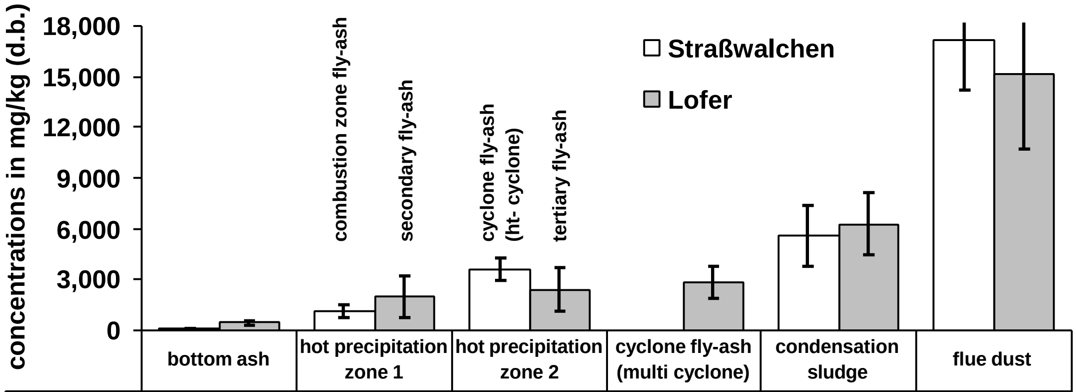
Abbreviations: ht – high temperature.



	bottom ash	hot precipitation zone 1	hot precipitation zone 2	cyclone fly-ash (multi cyclone)	condensation sludge	flue dust
Straßwalchen	0.1	1.7	5.2		49.0	73.8
Lofer	2.8	2.5	7.4	25.2	34.6	69.4

Figure 4: Average Zn concentrations in different ash fractions produced by different combustion technologies

Explanations and abbreviations: see Fig. 3.



	bottom ash	hot precipitation zone 1	hot precipitation zone 2	cyclone fly-ash (multi cyclone)	condensation sludge	flue dust
Straßwalchen	87	1,113	3,606		5,631	17,173
Lofer	438	1,973	2,398	2,855	6,295	15,170

Furthermore, the investigations showed a significant dependence of the Cd concentrations in hot-precipitated fly-ashes on the temperature of precipitation (see Fig. 5). The Cd concentrations increased with decreasing temperature of ash precipitation. According to high-temperature equilibria calculations, Cd should be completely in the gaseous phase at temperatures measured in secondary combustion chambers of biomass combustion plants. At temperatures above 700 °C no correlation between temperature and Cd concentrations should be observed under oxidizing conditions [J.Dahl et.al., 1997]. This result of equilibrium calculations is in contradiction to the data achieved from the test runs and probably indicates the existence of a non-volatile Cd compound formed by surface reactions of the ash particles with the metal vapors, which was not taken into account in the equilibrium calculations [T.Lind et.al., 1997]. This open problem is the subject of ongoing investigations [I.Obernberger et.al., 1997b].

Figure 5: Cd concentrations in the hot-precipitated fly-ashes versus temperature of precipitation
Explanations: regression function: $y=31.56+1,072/x^{0.5}$, $r^2=0.65$, F_{stat}-value=58.3.

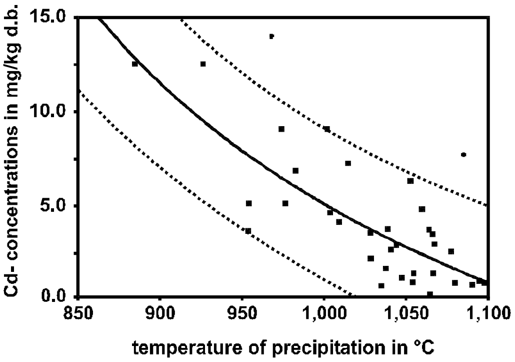


Figure 6: Zn concentrations in the hot-precipitated fly-ashes versus temperature of precipitation
Explanations: hot-precipitated fly-ashes from the test runs in Lofer were evaluated.

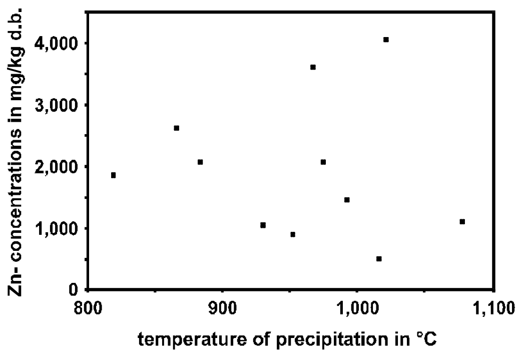


Figure 7: Zn concentrations in the cyclone fly-ash (hot-cyclone) versus temperature of precipitation
Explanations: regression function: $y=\exp(6.41+1.8\cdot10^{-6}\cdot x^2)$, $r^2=0.96$, F_{stat}-value=113.1.

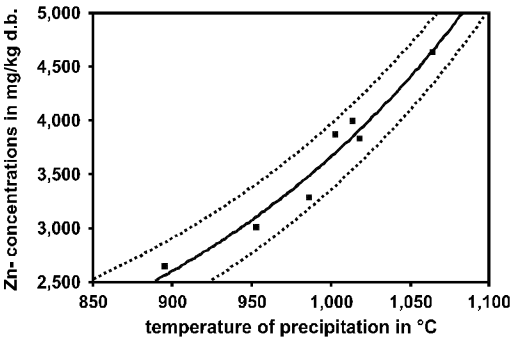
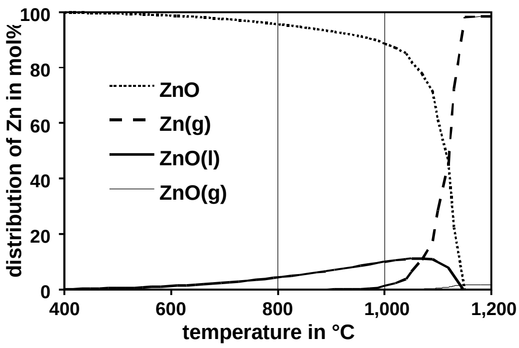


Figure 8: Results of high-temperature equilibria calculations for Zn and Zn compounds in the secondary combustion zone
Explanations: input data: air ratio $\lambda=1.7$, fuel used – wood chips.



The average Zn concentrations in the bottom ash produced in the new plant with integrated fractionated heavy metal separation (Straßwalchen) are 5 times lower than in the respective ash fraction from state-of-the-art combustion plants (see Fig. 4). The levels of Zn in the combustion zone fly-ash are lower than in hot-precipitated fly ashes produced in the state-of-the-art combustion plant (Lofer), whereas the Zn concentrations in the fly ash precipitated in the high-temperature cyclone are considerably higher. On an average they even exceed the respective concentrations found in the multi-cyclone fly-ash of the state-of-the-art combustion plant.

For hot-precipitated fly-ashes produced in the state-of-the-art combustion plant (Lofer) and for the combustion zone fly-ash (Straßwalchen) the investigations revealed no significant dependence of Zn concentrations on the temperature of precipitation (see

Fig. 6). These results show that Zn compounds formed under oxidizing conditions should be in the solid or liquid phase. On the contrary, the Zn concentrations in fly ashes precipitated in the high-temperature cyclone increase considerably with increasing temperatures of precipitation (see Fig. 7).

High-temperature equilibria calculations for Zn under oxidizing conditions show that at temperatures below 1,100 °C ZnO should be formed, which is partly in the liquid phase (above 600 °C) and mainly in the solid phase (see Fig. 8) [J.Dahl et.al., 1997]. If the results of these equilibrium calculations and the low-pressure impactor measurements with subsequent particle analysis (see section " Influence of particle size on the heavy metal concentrations in fly-ash fractions") are considered along with the behavior of Zn in a reducing atmosphere (see section "Influence of the gaseous phase around ash particles on the heavy metal fluxes"), the Zn vapors released in the primary combustion zone should partly condense (forming aerosols) and partly undergo surface reactions with fly-ash particles. These surface reactions, which are not known at present, are likely to increase with temperature. Increasing agglomeration of particles in the high-temperature cyclone (due to sintering and melting processes) could also be a reason for a rise in heavy metal concentrations. The exact behavior of Zn in the hot cyclone is not yet fully understood.

The concentrations of Cd and Zn in the condensation sludge (filter fly-ash) considerably exceed the respective Austrian limiting values for the utilization of biomass ashes on agricultural fields or forest soils. Consequently, this ash fraction has to be collected separately for subsequent disposal or industrial utilization. The highest heavy metal concentrations are found in the flue dust which shows the importance of an efficient dust precipitation technology.

Influence of the gaseous phase around ash particles on the heavy metal behavior

Figure 9 and 10 show the results of high-temperature equilibria calculations for Cd, Zn and their compounds in a reducing atmosphere (primary combustion zone) for moving grate furnaces burning wood chips.

These calculations show that under reducing conditions high amounts of Cd are expected to be volatilized at relatively low temperatures due to the fact that elemental Cd has a high vapor pressure [I.Obernberger, 1997; J.Dahl, 1995, A.Nordin, 1993; A.D.Tillmann, 1994] (see Fig. 9). Elemental Zn is expected to be volatilized as well, but the volatilization temperatures are higher than for Cd (see Fig. 10).

The equilibrium calculations tie in well with the results achieved from the test runs. The levels of Cd and Zn in the bottom ash are very low (see Fig. 11 and 12). This ash fraction is formed under reducing conditions on the grate. Furthermore, the Cd and Zn concentrations in the bottom ash have a significant influence on the combustion air ratio in the primary combustion zone (see Fig. 11 and 12). The concentrations decrease with decreasing primary air ratio (increasing reduction potential).

Figure 9: Results of high-temperature equilibria calculations for Cd and Cd compounds in the primary combustion zone

Explanations: input data: air ratio λ=0.7, fuel used – wood chips.

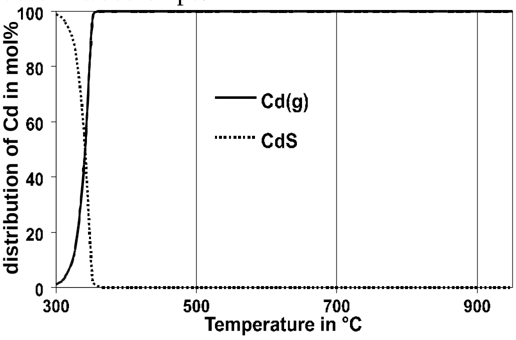


Figure 10: Results of high-temperature equilibria calculations for Zn and Zn compounds in the primary combustion zone

Explanations: input data: air ratio λ=0.7, fuel used - wood chips.

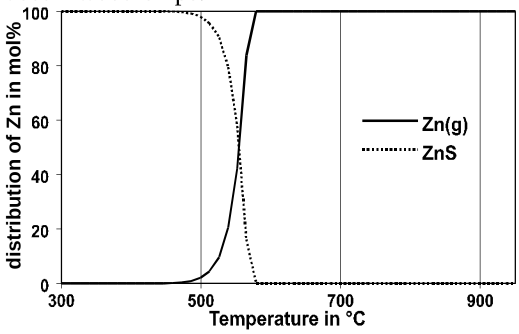


Figure 11: Cd concentrations in the bottom ash versus combustion air ratio in the primary combustion zone

Explanations: regression function: $y=(0.13+1.01 \cdot x^3)^2$, $r^2=0.68$, F_{stat}-value=10.7.

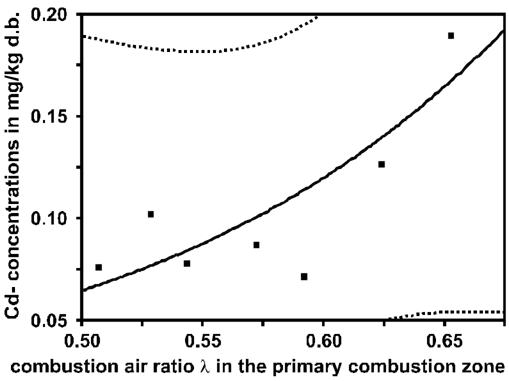
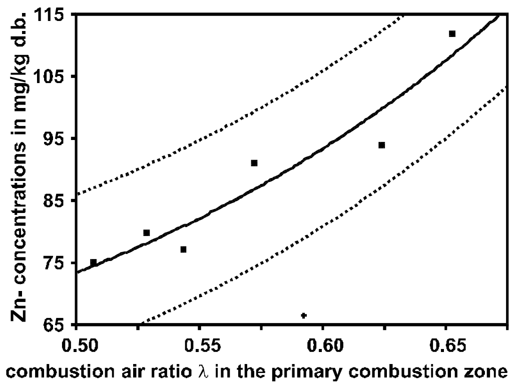


Figure 12: Zn concentrations in the bottom ash versus combustion air ratio in the primary combustion zone

Explanations: regression function: $y=(6.97+13.12 \cdot x^3)^2$, $r^2=0.92$, F_{stat}-value=43.6.



Influence of particle size on the heavy metal concentrations in fly-ash fractions

The average concentrations of Cd in the sieve fractions of fly ashes increase with decreasing particle size (see Table 1). In the smallest sieve fraction (< 5 µm) the concentrations are three to five times higher than in the > 60 µm fraction. The results show that the particle size (particle surface) is the most important influencing variable for the precipitation of Cd on fly-ash particles at temperatures below 600 to 700 °C.

Table 1: Average Cd and Zn concentrations in the size-classified subfractions of fly-ashes

Explanations: A boiler fly-ash and a cyclone fly-ash were examined.

particle size	µm	60-100	40-60	20-40	5-20	<5
Cd	mg/kg d.b.	28	26	35	75	137
Zn	mg/kg d.b.	217	248	327	897	1,659

Moreover, the formation of aerosols (submicron particles) by condensation of gaseous heavy metal species is important. This was proven by taking aerosol samples from bark- and wood chip-fired combustion plants by means of low-pressure Berner impactors and analyzing the submicron particle fractions for their heavy metal concentrations (see Table 2).

Table 2: Average Cd and Zn concentrations in submicron particle fractions of fly-ashes

Explanations: The tests were carried out in the state-of-the-art combustion plant (Lofer), fuel used – bark, impactor measurement took place in the flue gas channel behind boiler outlet

mean particle size	μm	0.375	0.188	0.095
Cd	mg/kg d.b.	80	112	140
Zn	mg/kg d.b.	34,300	45,500	47,600

Amount of ash fractions produced

Table 3 shows that state-of-the-art technology and the technology with integrated fractionated heavy metal separation produce similar amounts of bottom ash. Compared to state-of-the-art technology the amounts of fly-ashes produced in the new plant are lower and the amounts of condensation sludge considerably higher (approx. 3 times, see Table 3). This is mainly due to the lower precipitation efficiency of the high-temperature cyclone for smaller particles as compared to multi-cyclones operating at temperatures of about 200 °C. Therefore, larger amounts of condensation sludge (filter fly-ash) have to be disposed of or industrially utilized, which increases the operating costs of the plant and results in a disadvantage of the new technology. In comparison to state-of-the-art technology, the amounts of flue dust produced by the new technology are lower due to the high dust precipitation efficiency of the aerosol electrostatic filter.

Table 3: Average mass distribution among the different ash fractions

Explanations: all data in wt% (d.b.), comparison of state-of-the-art technology (Lofer) and the technology with integrated fractionated heavy metal separation (Straßwalchen), fly ash means a mixture of combustion zone fly-ash and hot cyclone fly-ash for the technology with integrated fractionated heavy metal separation and a mixture of secondary, tertiary and cyclone fly-ash for the state-of-the-art technology (see Fig. 1 and Fig. 2).

ash fraction/ plant	bottom ash	fly ash	condensation sludge	flue dust
Lofer	67.1	25.3	4.6	3.1
Straßwalchen	68.6	17.3	12.0	2.1

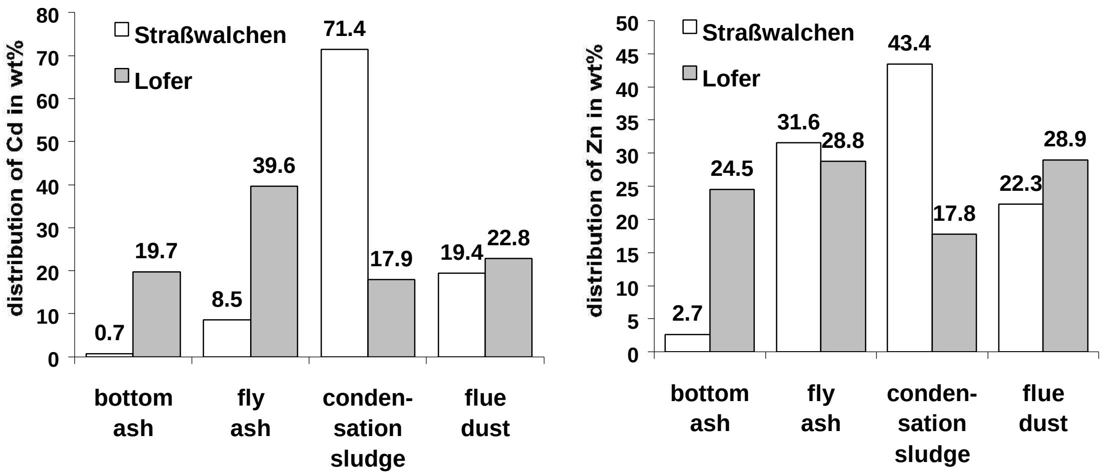
Distribution of Cd and Zn among the different ash fractions produced

In the bottom ash, which represents the largest ash fraction (see Table 3), only small amounts of Cd and Zn are bound (see Fig. 13). Less than 1 % of Cd and only about 3 % of Zn were found in the bottom ash of the plant equipped with the new technology. These results are considerably lower than those achieved by state-of-the-art technology, which demonstrates the high Cd and Zn fractionation efficiency of the new technology (especially the effect of a reducing atmosphere).

Furthermore, the fly ashes produced in the new plant contained less Cd than the respective ash fraction from the plant equipped with state-of-the-art technology, whereas the amounts of Zn were slightly higher.

Figure 13: Average distribution of Cd and Zn among the different ash fractions produced

<u>*Explanations:*</u> see Table 3.



The condensation sludge (filter fly-ash) precipitated in the new plant contains on an average 4 times as much Cd and about 2.5 times as much Zn as the condensation sludges from state-of-the-art combustion plants. Consequently, an upgrading effect of heavy metals in the filter fly-ash fraction was achieved by using the combustion technology with integrated fractionated heavy metal separation. The heavy metal emissions with the flue dust are lower for the new combustion technology due to efficient dust precipitation effected by an aerosol electrostatic filter installed subsequent to the condensation unit.

CONCENTRATIONS OF CD AND ZN IN THE USABLE ASH MIXTURE

Table 4 shows the calculation results for the concentrations of Cd and Zn in the usable ash (mixture of bottom ash and fly ashes except the filter fly-ash and the flue dust) for different combustion technologies.

The results show that application of the new technology with integrated fractionated heavy metal separation considerably reduces the concentrations of Cd in the usable ash. The average concentrations approach the respective guiding values for soils valid in Austria. The Zn concentrations in the usable ash, however, are almost similar for both technologies. This is mainly due to the high Zn concentrations in the fly-ash precipitated in the high-temperature cyclone. The Zn levels in the bottom ash are considerably reduced using the new technology (see Fig. 4).

Table 4: Concentrations of Cd in the usable ash of biomass combustion plants equipped with state-of-the-art technology (Lofer) and with technology with integrated fractionated heavy metal separation (Straßwalchen) compared to guiding and limiting values

Explanations: all data in mg/kg (d.b.), data source: limiting values Forest – [Bundesministerium für Land- und Forstwirtschaft, 1997], limiting values agriculture – [Salzburger Landesregierung, 1997], guiding values for soils – according to ÖNORM L1075, usable ash – mixture of all ash fractions in a plant specific ratio excluding filter fly-ash and flue dust.

		bark	wood chips		limiting values forest	limiting values agriculture (quality class I)	limiting values agriculture (quality class II)	guiding values for soils
Cd	Lofer	6.3	7.4	Cd	8.0	5.0	10.0	1.0
	Straßwalchen	0.8	1.3					
Zn	Lofer	943	1,037	Zn	1,500	1,000	2,000	300
	Straßwalchen	562	1,008					

CONCLUSIONS

The test runs and investigations carried out revealed a high potential of fractionated heavy metal separation in biomass combustion plants by means of primary measures. Depending on where the ash precipitation takes place the following three influencing variables are considered to be of significance (see Table 5): the gaseous atmosphere around ash particles, the temperature of ash precipitation and the size of the fly-ash particles.

Table 5: Important influencing variables for efficient fractionated heavy metal separation in dependence on the zone of ash precipitation

influencing variables	precipitation zone: grate and primary-combustion zone	secondary-combustion zone	boiler and downstream units
reducing atmosphere	x		
temperature of precipitation	x	x	
size of the fly ash particles		x	x
temperature range [°C]	400 - 900	800 - 1,100	< 800

The concentrations of Cd and Zn in the ash at high temperatures depend on the reduction potential of the gaseous atmosphere around the ash particles (important for the bottom ash) and on the temperature of precipitation (important for fly ashes precipitated at high temperatures and in an oxidizing atmosphere) [I.Obernberger et.al., 1997a]. Consequently, the temperature in the primary combustion zone should be as high as possible and the primary air ratio under-stoichiometric. In an oxidizing atmosphere (in the secondary combustion chamber) the temperature of ash precipitation is an important influencing variable at temperatures above 900 °C (according to the experimental results achieved). As soon as condensation or surface reactions take place (at temperatures below 700 – 900 °C) fractionated heavy metal separation can only be achieved by particle size-selective ash precipitation.

At present the development of a combustion technology with integrated fractionated heavy metal separation is at a high level as regards the reduction of Cd and Zn in bottom ashes. Furthermore, the Cd concentrations in hot-precipitated fly-ashes are considerably lower than in fly-ashes generated by multi-cyclones, whereas the potential of hot fly-ash precipitation as regards the fractionation of Zn is rather low. Moreover, the amounts of filter fly-ash increase due to the lower precipitation efficiency of hot cyclones as compared to the respective performance of multi-cyclones. Therefore, hot cyclones are considered not efficient enough for fractionated heavy metal separation.

The further development of a combustion technology with integrated fractionated heavy metal separation will place special emphasis on modifications of the grate and the primary combustion zone. The amounts of bottom ash should be increased with the aim of precipitating the total amount of usable ash on the grate. This could be achieved by recycling the fly-ashes collected in the multi-cyclone into the primary combustion zone. Appropriate laboratory-scale glowing experiments with fly ashes have already shown the high volatilization potential of heavy metals in contaminated fly-ashes under reducing conditions and at high temperatures [J.Neuhold, 1995, J.Dahl et.al., 1997b]

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