RELEASE OF INORGANIC ELEMENTS DURING WOOD COMBUSTION

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Abstract

The objective of this work is to quantify the release of inorganic metal species, S and Cl from wood at combustion conditions that resemble grate combustion. This was done by performing lab-scale experiments at well-controlled conditions. The obtained quantitative release data are essential for the development of models for aerosol and fly-ash formation and behavior, aiming to understand the ash-related problems occurring during combustion of wood in power plants. Experimental release data obtained in the temperature range of 500-850°C are presented for spruce and fiberboard. The results show that the release is strongly dependent on the temperature and on the inorganic composition of the fuel.

Introduction

Biomass fuels contain a certain amount of inorganic elements, of which a part may be released during combustion on the grate to form inorganic gases and particular matter (aerosols and fly-ashes), while the remaining part forms a bottom ash fraction. This formation of inorganic gases and particulate matter may lead to problems. First of all, the gases that are formed and emitted to the atmosphere include environmentally harmful gases (e.g. SO_2 and HCl). Inside combustion units, the formation of particular matter causes deposit formation on superheater tubes, which in turn leads to a reduction of the heat transfer efficiency to the water/steam system and may cause corrosion of the superheater tubes.

Although woody biomass fuels are often thought to be 'less problematic fuels' due to their relatively low ash content, ash-related problems are also observed in wood-fired boilers. Woody biomass generally has a low concentration of K, S and Cl compared to other solid fuels such as straw and coal, but the amount of Ca and heavy metals (such as Zn, Cu and Pb) is relatively high in most woody biomass fuels; especially bark contains a relatively high amount of Ca, and waste wood contains a relatively high amount of heavy metals. Combustion of wood may therefore lead to serious problems due to aerosol formation. Not only the quantity of ash, but also the composition of the ash and the volatility of the ash-forming matter are important when studying the release of inorganic elements during wood combustion.

Objectives

To be able to tackle problems involving aerosol and fly-ash formation and emissions of gaseous pollutants during the combustion of woody biomass, it is essential to understand the quantity and the mechanism of the release of the ash-forming matter from the fuel during combustion. The objective of this work is to quantify the release of inorganic metal species, S and Cl during combustion of woody biomass at well-controlled conditions.

Experimental

Equipment and Method. Combustion experiments were conducted in a lab-scale reactor, resembling the conditions in a grate-fired boiler. The experimental set-up was especially designed to study the release of inorganic elements during wood combustion, and consists of an electrically heated oven with an alumina tube inside, in which a fuel sample can be inserted and a gas can be introduced in order to provide a pyrolysis or combustion atmosphere around the fuel sample. Batch experiments with small sample sizes (30-45 g) were done at different temperatures in the range of 500-1150°C. The release of various inorganic elements during combustion was quantified by performing accurate weight measurements and chemical analysis of the biomass feedstock and the residual ash samples, and performing mass balance calculations. Focus was on the alkali metals K and Na, the alkaline earth metals Ca and Mg, and the heavy metals Cu, Zn, Pb and Cd, since they were known to form aerosols during wood combustion. Furthermore, the non-metals S and Cl were studied, since they were expected to influence the volatility of the metal elements. The influence of fuel type and chemical composition of the fuel was investigated by using various types of woody biomass fuels.

Fuel samples. The fuels used in this experimental study are spruce (wood chips), beech (wood chips), bark and fiberboard. These wood biomass fuels are samples from the same batch as the fuels that were used in the EU-project 'Bio-Aerosols'[1], in the formation and behavior of aerosols from wood combustion on a grate were investigated. In the present paper results are given for spruce and fiberboard. The fuels were dried in open air at room temperature and milled using a 4 mm-screen before they were used in the experiments, in order to obtain physically and chemically homogenous samples. The chemical characteristics of the fuels are shown in Table 1.

Table 1. Chemical Characteristics of the Fuels Investigated

Fuel type	Spruce	Beech	Bark	Fiberboard
Moisture (wt%)	6.6	4.5	10.7	6.8
Ash (wt% d.b.)	0.95	0.52	4.41	1.24
Volatiles (wt% d.b.)	82.7	84.8	72.9	80.3
Cl (wt% d.b.)	<0.01	<0.01	0.01	0.05
S (mg/g d.b.)	0.1	0.12	0.42	0.3
K (mg/g d.b.)	0.85	0.92	2.4	0.64
Na (mg/g d.b.)	0.02	0.01	0.07	0.18
Ca (mg/g d.b.)	1.9	1	16	1.5
Mg (mg/g d.b.)	0.2	0.21	0.76	0.21
Si (mg/g d.b.)	0.43	0.03	2.2	0.55
Al (mg/g d.b.)	0.08	0.01	0.45	0.35
Fe (mg/g d.b.)	0.08	0.05	0.33	0.26
Ti (mg/g d.b.)				4.5
Cu (mg/kg d.b.)	2	1.6	5	3.9
Zn (mg/kg d.b.)	14	3.7	67	27
Cd (mg/kg d.b.)	0.14	0.032	0.25	0.18
Pb (mg/kg d.b.)	0.44	0.4	1.6	16

(d.b. = dry basis)

It can be observed that the main ash forming elements are Ca, K and Si in the case of all fuels. Furthermore, all fuels contain relatively low amounts of Cl and S. Heavy metals like Cu, Zn, Pb and Cd are also present in small amounts in the fuels, of which Zn is the most dominant element. Spruce and beech both have very low ash contents (< 1 wt% d.b.), fiberboard has a slightly higher ash content (around 1

wt% d.b.) and bark has the highest ash content (around 4 wt% d.b.). Bark contains a high amount of Si and Al, probably due to the presence of sand and clay minerals attached to the fuel. Fiberboard contains a high amount of Ti, originating from the pigments in the coating.

Results and Discussion

Quantitative release data were obtained for spruce and fiberboard in the temperature range of 500-1150°C. The experimental results show that the release of the studied elements is strongly dependent on the temperature and the inorganic composition of the fuel. In general, a high release of Cl, S, Zn, Pb, and Cd was observed, up to 100% at high temperature (above 850°C). The elements K, Na, and Mg were found to be released at lower levels, whereas no release was observed for the elements Ca, Si, Al and Fe.

Figure 1 shows the release of Cl, S and K during combustion of spruce and fiberboard as a function of temperature in the range of 500-850°C. In this temperature range, a very high release of Cl (~100%) and S (~75%) and a low release of K (up to ~30%) were observed for spruce. Cl was found to be (almost) completely released already at 500°C. Preliminary thermodynamic equilibrium studies of spruce indicated that Cl may start to be released around 500°C, in the form of $HCl_{(g)}$ or $KCl_{(g)}$. Since the concentration of Cl in the fuel is very low, a complete release of Cl around 500°C seems likely. The equilibrium calculations also showed that the release of K starts around 850-900°C, by the formation of $K_2SO_{4(g)}$. This may explain the steeper increase in the release observed between 800 and 850°C. The high release of S is not well understood yet. S is expected to be released mainly in the form of $SO_{2(g)}$ and $K_2SO_{4(g)}$, but the release of $SO_{2(g)}$ is also not expected to occur at temperatures below 900°C in the case of spruce.

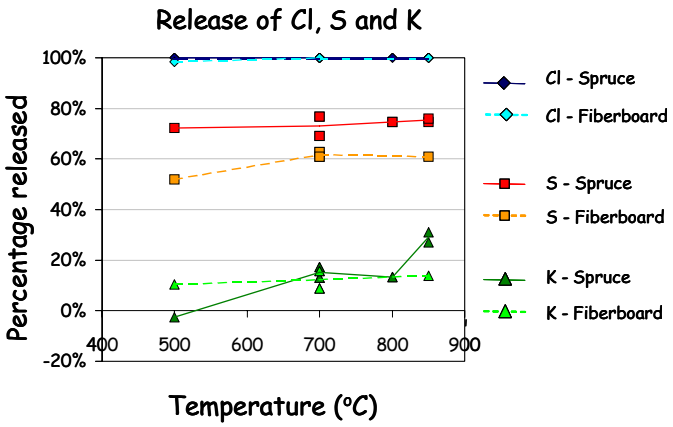

Figure 1. Release of Cl, S and K during combustion of spruce and fiberboard as a function of temperature in the range of 500-850°C.

Similar release trends were observed for fiberboard, although the release of S and K was lower in this case (see Figure 1). This may be due to a difference in speciation of these elements in the ash. The presence of certain inorganic elements may have an influence on the volatility of other elements. For example, in the case of fiberboard, the high content of Ti in the ash may play a role in decreasing the volatility of certain elements.

Figure 2 shows the release of Zn, Pb and Cd during combustion of spruce and fiberboard as a function of temperature in the range of 500-850°C. For spruce, it was found that the release of Zn and Pb increased form ~0 at 500°C to ~100% at 850°C, whereas Cd was released almost completely at 500°C. Completely different release trends were found for fiberboard, where the lower amounts of Zn, Pb and Cd released may again be due to the presence of other inorganic elements in the ash.

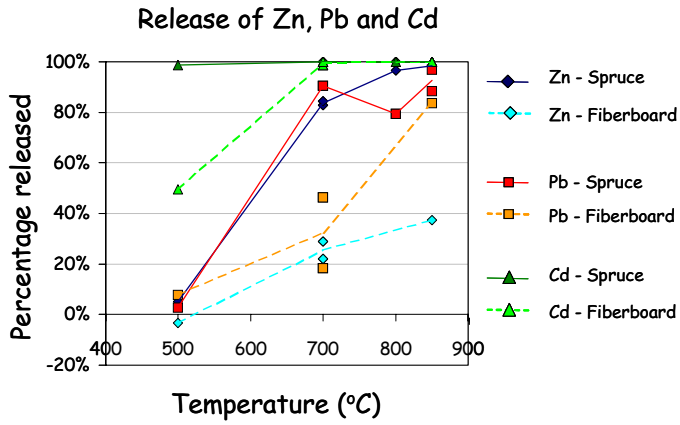

Figure 2. Release of Zn, Pb and Cd during combustion of spruce and fiberboard as a function of temperature in the range of 500-850°C.

Detailed thermodynamic equilibrium studies, as well as investigations of the structures and chemistry of the fuels and ashes will be performed in order to obtain a better understanding of the release data and the possible release mechanisms.

Conclusions

The release of inorganic elements during wood combustion was investigated by performing lab-scale experiments at well-controlled conditions and was found to be strongly dependent on the temperature and the inorganic composition of the fuel. In general, a high release of Cl, S, Zn, Pb, and Cd was observed, up to 100% at high temperature (above 850°C). The elements K, Na, and Mg were released at lower levels. This paper shows the results of the experimental release data for spruce and fiberboard in the temperature range of 500-850°C.

The obtained quantitative experimental data on the release of inorganic elements during wood combustion can be used as input data for aerosol and fly-ash formation and behavior models aiming to find solutions for ash-related problems during wood combustion.

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References

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