INVESTIGATION OF CORROSION, AEROSOL- AND PARTICLE FORMATION IN A WOOD FIRED POWER PLANT

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ABSTRACT: During the combustion of wood, aerosols are released that can damage the power plant technology due to the mechanism of chlorine induced high- temperature corrosion. Thus, the aim of this investigation is to analyze the aerosols in a wood-fired cogeneration plant with regard to their corrosive properties. For these purposes two measurement methods were applied at the cogeneration plant in Schkölen. With one method particles have been extracted from the flue gas stream using a particulate sampling probe. To determine the number distribution of the particles an Electrical Low Pressure Impactor has been used to collect the particles and to sort them in terms of size. In addition, the collected particles have been examined both with respect to their morphology and with respect to their elementary composition by using a scanning electron microscope and the energy dispersive X-ray spectroscopy.

Keywords: aerosol, biomass, combustion, particle emission, plant, wood

1 INTRODUCTION

In addition to the use of wind and solar energy, biomass as energy sources is becoming increasingly important. The differences from fossil fuels such as coal, oil or gas are versatile. A problem due to the combustion of biomasses are chlorides contained in the plants as salts and chlorophyll. These chlorides lead to high-temperature chlorine corrosion of the boiler internals, which limit these types of power plants in their performance. Another disadvantage is the resulting deterioration in efficiency over comparable systems of fossil fuels. Some Biomass has a high ash and chlorine content, such as straw. During the combustion aerosols and particle are formed. The composition of these particles are the basis of the deposits at the internals of the plant. The smallest particles has a high chlorine content and are the cause for very strong corrosive deposits [2]. These are the main reason for the high rate of corrosion of the superheater tubes and quickly lead to corrosive attack. The layer formation takes place by deposition of particles and aerosols. Causes of aerosol and particle formation are mineral components in the fuel. Additionally, they can change their structure and properties during the flight through the reactor by agglomeration [1].

2 MATERIALS AND METHODE

2.1 Wood fired power plant in Schkölen

The power plant has a thermal power of about 20 MW, 5.3 MW electrical power and requires 8 t fuel per hour. The fuel is normal wood mainly from area around power plant. The fuel is burned on a moving grate. The vapor temperature is 485 °C at 68 bars. At the first location marked in **figure 1**, before the superheaters at a flue gas temperature of 750 °C online corrosion and particle measurements take place. At the second location after the superheaters at a flue gas temperature of 500 °C only particle measurements are performed.

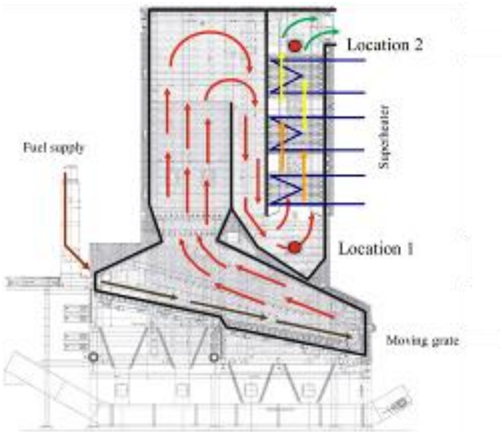

Figure 1: Schematic illustration of the wood fired power plant Schkölen with measurement locations

2.2 Online particle measurement

The test rig (e.g. **figure 2**) used for aerosol and particle measurements consists of a particle probe, in which the first dilution takes place, a cyclone to separate particles over 10 µm, an isokinetic separator, the **Fine Particle Sampler** (FPS) and the **Electrical Low Pressure Impactor** (ELPI), both from Deakti.

The **ELPI** is a system to measure aerosols and particles in real time. Thereby the particle flow passes an impactor cascade of 12 consecutive stages. To separate the particles by their diameter each stage has a different radius. At the first stages the radius is larger as in the lower ones. So the particles are separated by using centrifugal forces. In the impactor the particles are separated in 10 Stages in a size range from 0.04 µm to 6.34 µm. An overview about all stages and their D50 particle diameter is shown in **table 1**.

Table 1: ELPI stages with their D50 particle size

Stage	Size (µm)	Stage	Size (µm)
1	0.04	7	0.770
2	0.072	8	1.241
3	0.121	9	1.970
4	0.205	10	3.116
5	0.320	11	6.348
6	0.489	12	>10

To inhibit agglomeration and condensation in the test rig the particle flow is diluted on two positions. The first position is directly in the probe with nitrogen at a dilution rate of factor 5-10 and the second in the **FPS** with pressurized air at a dilution rate of app. Factor 83. The FPS is a high accurate dilution system with online monitoring.

With a second probe the flue gas is analyzed by an IR system from Siemens (Ultramat).

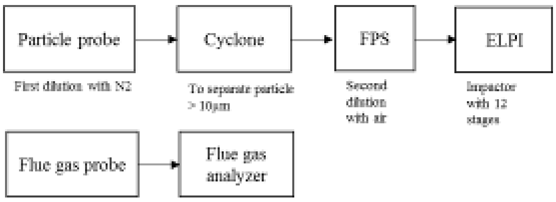

Figure 2: Test rig setup for online particle measurement and flue gas analysis

2.3 Analysis

Advanced fuel and ash analyses are performed in the labs of Energy Systems at Technical University Munich (TUM). The fuel is analyzed for elementary composition, and heating value. The ash samples are analyzed with XRF spectroscopy. In the power plant the flue gas is analyzed by IR spectroscopy with Ultramat by Siemens. The particle measurements are performed with the ELPI by Deakti. Each sample of every impactor stage is stored in a box under dry atmosphere directly after the test to avoid crystallization in the sample. The particle shape and composition is analyzed by scanning electron microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDX) at a magnification of 15000x.

3 RESULTS

3.1 Fuel and ash analysis

In **table 2** the results of the fuel and ash analysis are shown. The lower heating value (LHV) of the fuel is 17421.82 MJ kg^{-1} and the moisture content is 18.94 wt.%. The results of the ash analysis is shown in **table 3**.

Table 2: Fuel analysis of wood

Element	wt.% (dm)
C	58.48
H	5.50
N	0.33
S	0.14
O	34.12
ash	1.43

Table 3: Ash analysis

ash analysis	ma.%
CaO	28.34
K_2O	25.77
SiO_2	12.18
P_2O_5	7.63
MgO	4.40
SO_3	2.58
Al_2O_3	2.22
Fe_2O_3	1.78
MnO	1.20

3.2 Online particle measurement

The online particle measurements were performed with the ELPI. The graph (e.g **figure 3**) shows the mass percentage over particle size. Several tests between 0.5 – 1.5 hour test duration at both locations took place. Both curves are similar with a bimodal distribution with the first mode at a particle size of app. 0.3 µm. The percentage of the maximum is higher at Location 2. This effect can be explained by particle agglomeration from the smaller particles. The smallest particles agglomerate on the way through the third flue-gas pass to larger particles. This leads to an increase in the particle sizes of 0.3 µm at Location 2. On the other hand at the Location 2 there are less large particles in comparison to Location 1. This can be explained by the increase of the middle mass fraction. By using mass-% the increase of the middle fraction leads to a decrease of the other fractions. Meanwhile the fraction of larger particles is the same at both locations.

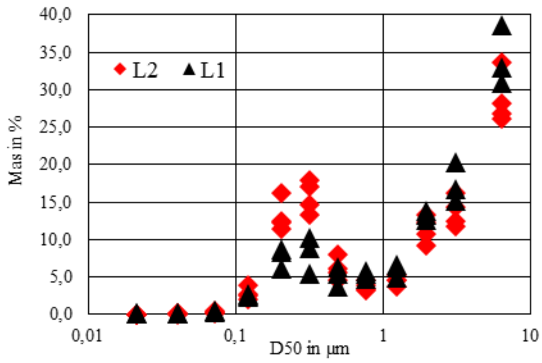

Figure 3: Particle mass distribution over the 11 ELPI stages from all measurements

3.3 Aerosol- and particle formation

In **figure 4 and 5** there are pictures illustrated from 2 different stages at both locations. The particles show a similar structure in shape and size. By the continuous deposition of particles on the individual stages the particles agglomerate on the impactor plates to equal mountain-like structures. In some cases the individual particles combine to crust-structures which makes it impossible to analyze the individual particle sizes. Stages with larger particles have similar structures as the small particles. It can be concluded, that even smaller agglomerates were deposited on these levels. However, also larger particles are found in the heaps which have a significantly higher silicon content as particles with smaller structures. All in all the particle shape is spherical and regular over the stages and at the locations.

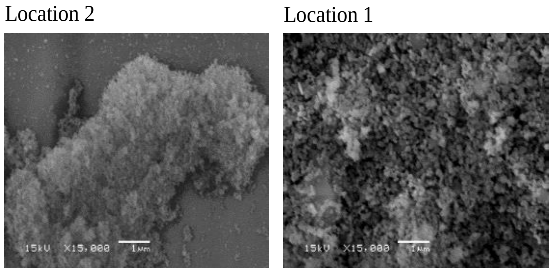

Figure 4: SEM pictures form the first stage (0.004 µm); magnification x15000

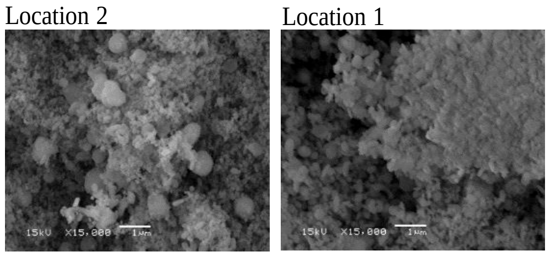

Figure 5: SEM pictures form the sixed stage (0.489 µm); magnification x15000

3.4 Aerosol- and Particle composition

At both locations the particle composition is very similar (e.g. **figure 6**). Potassium, Sulfur and Oxygen are the Elements with the highest atom-%. Potassium, Sulfur and Chlorine content decrease with rising particle size while Calcium, Oxygen, Silicon, Carbon and Phosphor content rise with increasing particle size.

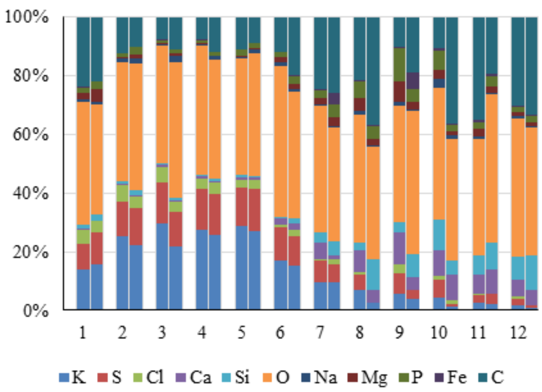

Figure 6: Particle composition of Location 1 (left) and 2 (right); the x-axis show the several stages

In summary, we have K_2SO_4 and KCl mainly in particle sizes up to 0.489 µm. Above this particle size mostly CaO, SiO_2 and K_2O dominate. These compounds were found in the ash analysis as well. These compositions suggest a low corrosion potential. This is also confirmed by the power plant operator and our online corrosion monitoring.

5. SUMMARY

In this paper, the aerosol and particle formation, particle morphology and particle composition and their corrosive potential in a wood fired power plant is investigated. The two measurements locations were before and after the superheater tubes. The online particle measurement was performed with an electrical low pressure impactor. The morphology and the particle composition was carried out with an SEM/EDX. The results show that particles to a size of 0.489 µm consist mostly of KCl and K_2SO_4. Larger particles (≥ 0.770 µm) contain a smaller amount of K, Cl and S. However the amount of SiO_2, CaO, P and K_2O increases. The particle morphology hardly changes from spherical particle agglomeration in the smaller distribution to particle agglomeration with some bigger particles at bigger size. The particle size distribution is very similar between the two measurement locations. At Location 2 share of the middle fraction is higher than at Location 1. This can be explained by agglomeration of the smallest particles on the way through the third flue-gas pass to larger particles. All in all the results show low corrosive potential which is consistent with the experience of the power plant operator.

4 REFERENCES

[1] Deuerling, Christian Frank, Untersuchungen zum Einfluss von Rauchgas-Aerosolen in Müll- und Biomasse-Verbrennungsanlagen auf die Hochtemperatur-Korrosion der Überhitzer, (2009)

[2] Nielsen, et al., The implications of chlorine-associated corrosion on the operation of biomass-fired boilers, (2000), *Progress in Energy and Combustion Science* 26 (3), 283–298

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5 LOGO SPACE

Bundesministerium für Wirtschaft und Technologie

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