Emissions From Small Scale Pellets Stoves and Boilers ⋆

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Abstract

Two automatically feeded pellets stoves, the smaller one an indoor fireplace stove (≈5 kW) the bigger one a boiler with about 40 kW of power output, were tested under various operating conditions. Contrary to the usual testing procedure, the systems were also sampled during start-up and simulated maloperation to gauge the full extent of possible gaseous and particulate emissions. Due to the current interest in the topic, a focus of the measurements were the fine dust emissions. We show that quantity and quality of inorganic and organic emissions vary greatly among different operating conditions and power classes, emphasizing the importance of process control in biomass combustion.

Key words: biomass, combustion, emission, dust, PM10

Nomenclature

Acronyms

EC elemental carbon
GC-MS gas chromatography and mass spectroscopy
HPLC high performance liquid chromatography
IC ion chromatography
ICP/AAS inductively coupled plasma/atomic absorption spectroscopy
n/a not available
OC organic carbon
OGC organic gas compounds
PM particulate matter (usually 10 µm or 2.5 µm aerodynamic diameter)
TC total carbon content
XRF X-ray fluorescence

Greek Symbols

ρ density in [kg/m^3]

Latin Symbols

c concentration [mg/m^3]
s substance
v volume fraction [-]

Superscripts

$\circ$ standard dilution, usually $\equiv 13\,\%$ volumetric
exp experimental, measured

1. Introduction

Small scale biomass combustion systems are an important part of domestic heat generation in Austria. Especially pellets systems increased in numbers during the last years because they provide a cheap yet convenient alternative to fossil fuels. Despite the rise in numbers, however, log and wood chip fired systems are still dominant due to its traditional use in domestic heating [1]. According to Kranzl [2] and Haas et al. [3] around 91 % of primary energy from domestic heating originates in log wood, 7 % in wood chips and the remaining 2 % in wood pellets.

While using renewable energy source for domestic heating is generally regarded as environmentally sound, biomass combustion was recently blamed of causing a large part of fine particulate matter immissions in Austria. According to the survey of the Austrian Environment Agency [4] 13 % of the 47 kt fine particulate matter that were emitted in Austria in 2004, originate in domestic biomass combustion.

While the direct impact of fine particulate matter on health is not yet understood entirely, the correlation of fine dust and health problems as well as premature deaths is well established in social medicine. The results of the statistical research (see [5–8] for some recent publications) prompted the European Union to take action and to establish immission limits for dust. The limit for the average yearly immission of PM10 is 40 µg/m^3 and no more than 30 days a year with concentrations of more than 50 µg/m^3.

During the course of the *BioComb* project [1] a variety of commonly used biomass combustion systems were sampled for their quantitative and qualitative emissions to provide more data about amount and composition of biomass emissions in Austria.

2. Experimental

The procedure for testing the programme facilities was modelled after the commonly used Aus-

⋆ Supported by the European Union and the provincial government of Lower Austria and by *klima:aktiv holzwärme*
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[1] Conducted by the *Austrian Bioenergy Centre* in collaboration with the *Vienna University of Technology* and the *HBLFA Francisco Josephinum - Biomass Logistics Technology Wieselburg*

trian/European normative *ÖNORM EN 303-5*.

In opposition to this well established testing procedure however, we also conducted measurements during the facilities's start-up. In addition to that, we simulated maloperation in System *A* by lowering the revolution speed of the fan of one of the systems [2]. These steps are aimed at getting emission measurements that better represent worst-case-scenarios in household operation.

Fine particulate matter and gas measurements were conducted in parallel during all experiments. Each experiment was divided into start-up, part-load and full-load periods. The gas data were logged continually whereas the collection system for fine particulate matter operated in intervals between 60 min and 120 min during each of the three measurement periods.

2.1. Test Systems

System *A* is an automatically pellet-fed room stove with a power output of about 6 kW. We conducted two experiments with this stove, the first one with factory settings, the second with deliberately low fan revolution speed.

System *B* is a biomass boiler and, with a power output of about 40 kW, considerably bigger than System *A*. As System *A* this stove was automatically fired with wood pellets. No changes were made to the control and steering equipment in this case.

2.2. Dust Collection System

The dust (PM10 respectively PM2.5) collection system was developed at the Institute of Chemical Technologies and Analytics at the Vienna University of Technology. Figure 1 shows the scheme of the sample acquisition: dilution, cooling/condensation, separation, and collection. Dilution of the exhaust gas takes place immediately after separating a part of the exhaust gas from the chimney. The particle-free and dry dilution air cools the exhaust gas and at the same time prevents condensation of water. By changing the amount of dilution air it is moreover possible to vary the duration of a collection period even when there are large changes in particle concentrations. The desired particle fraction is separated by means of a impactor system. The particle fraction is then collected simultaneously onto eight filters (six quartz filters and two cellulose filters).

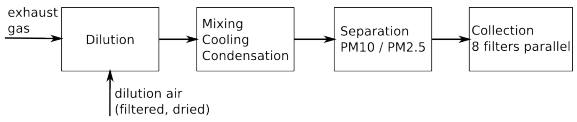

Figure 1. Scheme for collection of particulate matter samples from exhaust gases.

3. Results and Discussion

3.1. Gaseous Emissions

Unless specified otherwise all following emission values are corrected to a volumetric oxygen content of $v^{\circ}_{O_2} \equiv 13\,\%$ in the exhaust gas; all gas related figures are calculated for normal temperature, pressure. This is necessary to be able to account for varying dilution factors due to differences in process control of the systems. The conversion was calculated using Equation 1.

$$c_s = \rho_s \cdot v_s \frac{21 - v^{\circ}_{O_2}}{21 - v^{exp}_{O_2}} \quad (1)$$

Where s is one of CO, NO_x or OGC and their respective densities ρ_s are 1.25 kg/m^3, 2.05 kg/m^3 and 1.64 kg/m^3. [3] If not specified otherwise all following values were calculated in this way and are given as concentrations in mg/m^3.

3.1.1. System A

System *A* was operated in two different modes, once using its factory defaults, once using reduced fan revolution speed to simulate maloperation. During maloperation conditions, part-load values could not be recorded anymore. The difference of the two experiments is evident looking at the carbon monoxide values (see Figure 2).

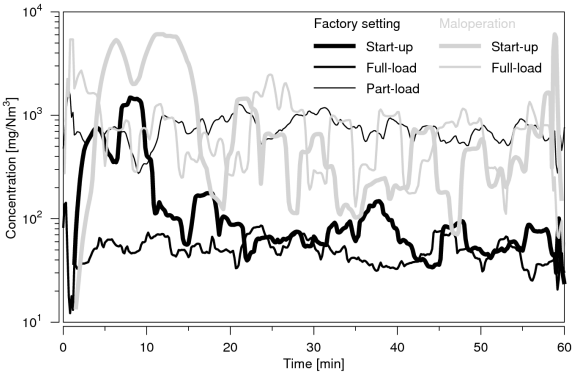

Figure 2. CO values for System *A* - maloperation shows high influence.

Table 1 shows mean values for all experiments. All values except the carbon monoxide value under maloperation meet the current legal limits which currently are about 770 mg/m^3 for carbon monoxide and 230 mg/m^3 for NO_x.

in [mg/m^3]		Start-up	Full-load	Part-load
Factory setting	CO	177.62	50.56	751.19
	NO_x	125.01	128.35	120.62
Malop-eration	CO	1170.07	803.97	n/a
	NO_x	89.57	94.49	n/a

Table 1. Average emission values for System A.

[2] There is currently no information about the actual commonness of such a setting.

[3] definition in norm ÖNORM EN 303-5

3.1.2. System B

Figure 3 shows the emissions for System B. As before, the difference between the experiments is evident in the carbon monoxide values. Table 2 shows the average values.

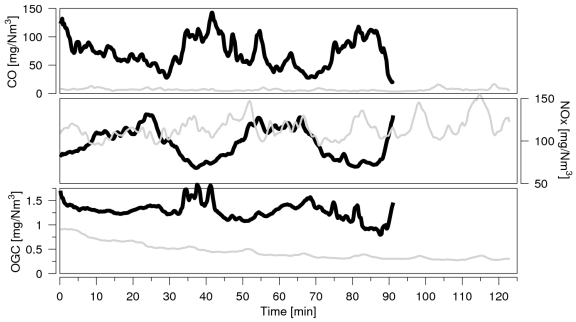

Figure 3. Emission values for System *B*. Black: part-load, grey: full-load operation.

in [mg/m^3]		Start-up	Full-load	Part-load
Factory setting	CO	490.78	6.74	72.16
	NO_x	118.04	114.85	97.01

Table 2. Average emission values for System B.

3.2. Particulate Emissions

The cellulose filters from the sampling system were analysed with XRF and after acid-decomposition with ICP/AAS. The quartz filters were used for analysing organic and ionic compounds. The method repertoire for this comprises: HPLC, GC-MS, IC, Thermo-Optical Carbon Analysis, and more.

The determination and identification of the total carbon content (TC) and its composition (EC and OC) is an important step in the characterisation of combustion aerosols; samples are heated (to 1000 °C for TC, temperature programme for EC and OC) with oxygen and the formation of CO_2 is monitored.

Another important analytical tool is IC; soluble cations (ammonium, sodium, calcium, etc.) and the anions (chloride, nitrite, sulfate) are measured this way. The values indicate the parts of the fuel that cannot be burned to gaseous products. Their relative amount is usually higher in automatically fired stoves than in hand fired.

in [mg/m^3]		Start-up	Full-load	Part-load
A	factory default	13.0	12.1	4.6
	maloperation	52.6	76.7	n/a
B	factory default	49.8	16.9	32.0

Table 3. Average PM10 emissions for System *A* and *B*.

3.2.1. System A

The carbon distribution of the particulate emissions of System *A* can be seen in the thermograms in Figures 4 to 6. The experiments with maloperation show high values in start-up and full-load operation.

Figure 7 shows the composition of the collected particles. The absolute values as well as the relative quantities of emissions of System *A* vary to a high extent between maloperation and factory default operation.

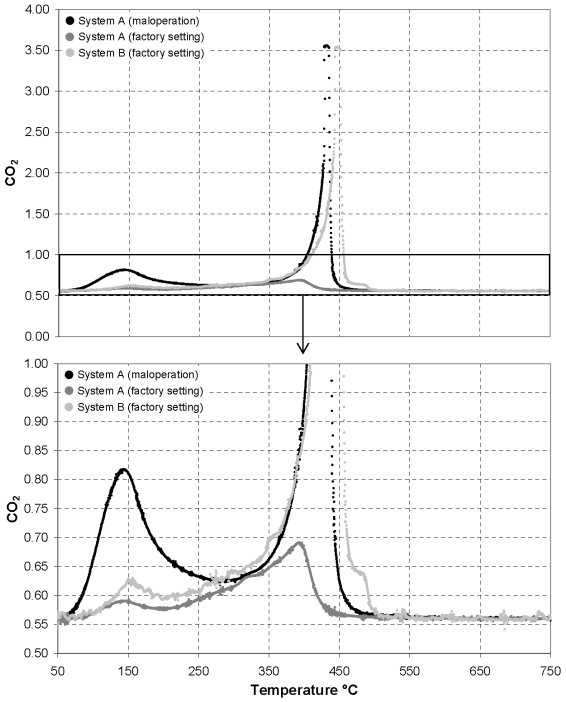

Figure 4. Thermogram start-up operation. The upper panel shows the entire analysis, the lower a close-up of the indicated region. Peaks around 400–500 °C correspond to black carbon, low temperature peaks to OC. Qualitative similar, the systems show big absolute differences. Start-up shows high values for all three cases.

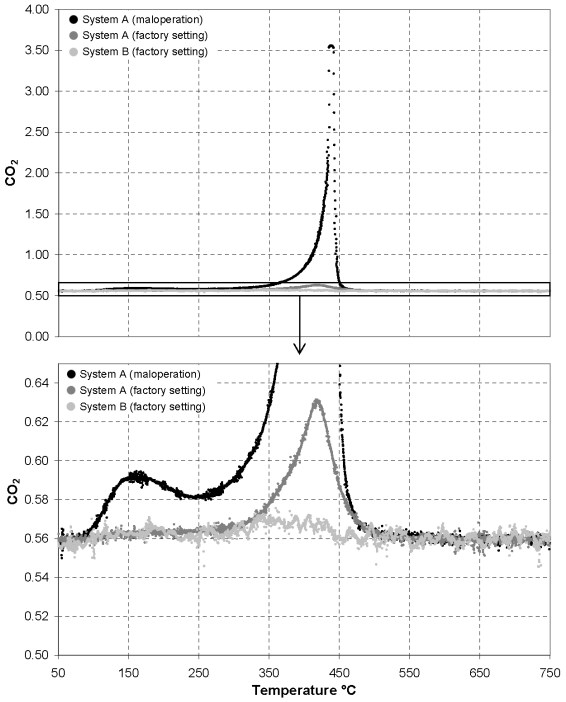

Figure 5. Thermogram full-load operation. OC is significantly higher for maloperation in System *A*, System *B* emits comparatively little OC.

3.2.2. System B

The themograms for System *B* (see Figures 4 to 6) show considerably higher black carbon concentrations compared to full-load operation, where hardly

any can be found. Comparing the chemical profiles (Fig. 7) shows high carbon fractions ($>$ 60 % TC) for start-up and part-load; full-load operation shows almost exclusively incombustible ash components.

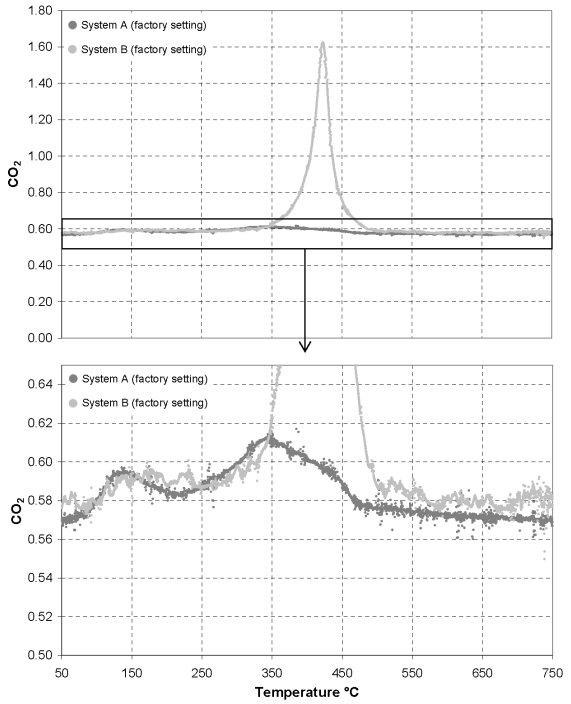

Figure 6. Thermogram part-load operation. While *B* performs better than *A* in full-load, the situation is reversed for part-load operation.

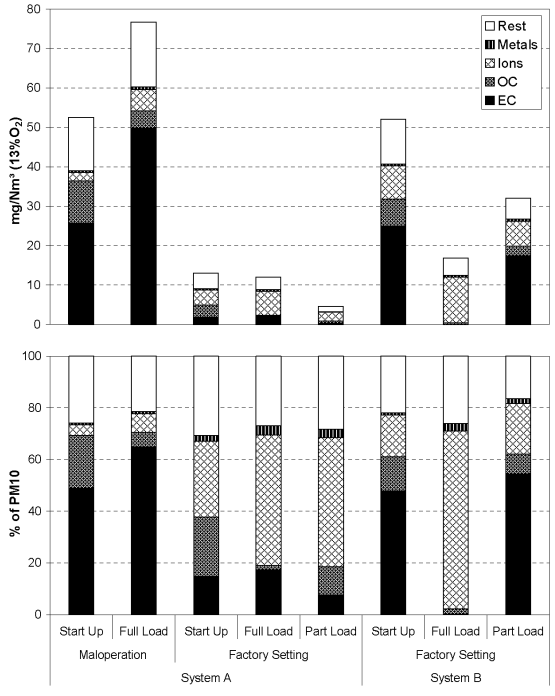

Figure 7. Chemical composition of particulate emissions. The upper panel shows absolute values in mg/m^3, the lower mass fractions. The *rest* fraction comprises hetero-atoms in organic compounds respectively moisture. High absolute values correlate with high carbon content, high mineral content with low values. System *A* shows big absolute and relative differences; System *B* smaller absolute mineral emissions and higher carbonaceous emissions in start-up and part-load operation.

4. Conclusion

Two automatically fired biomass system were monitored under various operating conditions. While both systems fulfil legal emission standards, the influence of start-up and part-load operation as well as faulty settings of the control equipment is evident.

Detailed analysis shows high variability in fine particulate matter emissions. Absolute PM10 emissions are 2 to 6 times higher during part load operation and maloperation compared to normal conditions. In addition, the composition of PM10 changes dramatically, with important implications for judging the biological impact of emissions. There is clearly a need for better assessment of the biological activity of different types of PM10 dust in addition to absolute amounts emitted, before it is reasonable to establish effective emission limits.

Our results show that process measurement and control systems play a major role in particulate matter emission since even fully automated systems show a considerable change in quantity and quality of emissions. Improvements in this field – especially targeting systems with manual fuel feeding, as we will show in upcoming publications – have a big potential to establish the role of biomass as energy source without side effects.

Acknowledgements

We would like to thank the European Union, klima:aktiv holzwärme and the government of Lower Austria for the support of our work.

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