Emissions of harmful elements and organic pollutants from small scale wood combustion systems

Hans Ruppert[1], Torben Seidel[1], Jürgen Orasche[1,2]

[1]Geoscience Center, University of Göttingen, Goldschmidtstr. 3, D-37077 Göttingen, Germany, hrupper@gwdg.de

[2]Helmholtz Zentrum München, Institute of Ecological Chemistry, Ingolstädter Landstraße 1, 85764 Neuherberg, Germany

Abstract:

During biomass combustion not only the amount of emitted particulate matter is the relevant factor for our health but the grain size distribution and the organic and inorganic composition of the particles.

Systematic burning experiments with wood and straw in boilers reveal, that significant amounts of heavy metals such as Cd, Cr, Sn, Pb, Tl, Zn, Ni, Cu, and Sb contained in the fuel are not retained in the ashes but released in the air in form of particles smaller than 1 µm. Our balance calculations show that the real emission rates of heavy metals is yet not clear. A part of the metals may also condense and precipitate on cooler surfaces in the furnace and the chimney.

Depending on the burning conditions and the water content of the fuel the emission of critical organic compounds varies. Ovens feed by wood pellets show the best burning conditions and the lowest emissions of organic compounds. Burning wood chips and wood logs leads to higher emissions.

Our knowledge about the toxicity and carcinogenicity for the different heavy metals and organic compounds and their mixtures is very restricted. Systematic reaction test for fly ashes with living cells should be performed.

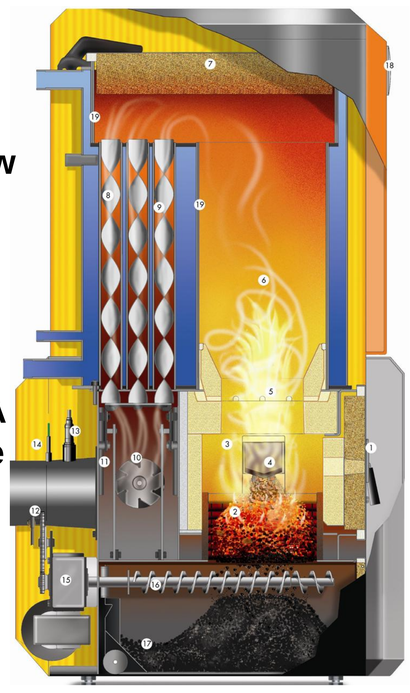

Fig. 1: Furnace Guntamatic Powerchip 20/30

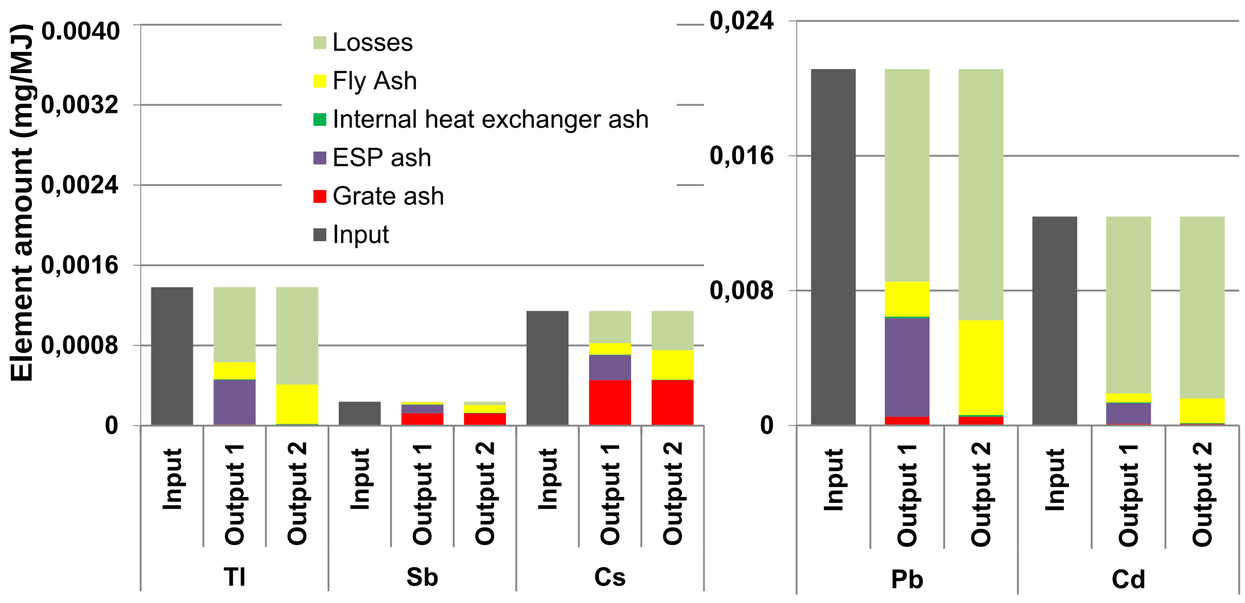

Fig. 4: Amount of heavy metals in wood (source), different ash fractions (sinks) and calculated losses during the production of 1 megajoule (MJ) net energy from burning spruce wood chips; *Boiler: Guntamatic Powerchip 20/30, 30 kW, with and without an electrostatic precipitator (ESP)*

Situation

The application of wood as a heat supplier may reduce the greenhouse gas effect, the shortage of fossil energy sources and the dependency from fossil fuels. Wood combustion in Europe is widely applied e.g. for residential heating in stoves and boilers. About 14 Million out of 40 Million households in Germany own small-scale wood-burning furnaces (example in Fig. 1). We investigate how the air quality is influenced by wood combustion due to the emissions of fine particles loaded by harmful elements and organic pollutants.

Assuming that the elements are not retained in the lining material of the stove and the chimney about 99 % of Tl and Cd, 97 % of Pb, 60 % of Cs, and 46 % of Sb contained in the fuel are emitted. By application of an ESP, the emissions decrease slightly to 89 % of Cd, 69 % of Pb, 67 % of Tl, 38 % of Cs, and 11 % of Sb (compare Output 1 with ESP and Output 2 without ESP).

Systematic measurements, if the elements are released into the atmosphere or if they are retained in the stove or the chimney, must be performed.

Emission of particulate matter, CO and organic substances

In Fig. 5 the emitted amount of selected compounds during the production of 1 megajoule (MJ) net energy by wood log burning are plotted. There is no clear trend for all the compounds, but during the inflaming phase of wood burning (first load) and smouldering phases (third reload) notable emissions of harmful substances such as particulate matter, CO, benzo[a]pyrene etc. are measured.

Methods

Systematic burning experiments with wood pellets, chips and logs were performed by using state-of-the-art small-scale combustion systems connected with a dilution tunnel (Fig. 2). The wood-burning furnaces tested hold optimized emission characteristics. To collect the hazardous fly ash, an innovative filter holder consisting of PTFE with a diameter of 150 mm is used in our study (Fig. 3) assuring sufficient material for the analysis and a low background contamination.

Fig 2: Furnace connected to the dilution tunnel at the TFZ, Straubing, Bavaria

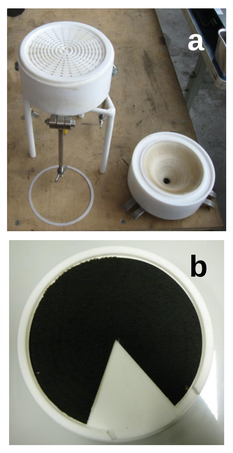

Fig 3: a) new filter holder; **b)** loaded quartz filter; the lacking piece is used for organic analysis.

For the *inorganic analysis* the fuel and the ash fractions were digested with a mixture of concentrated $HF/HClO_4/HNO_3$ in closed PTFE vessels. The fly ash was dissolved only by $HClO_4/HNO_3$ to prevent dissolution of the quartz filters. The elements were determined by ICP-MS and ICP-OES. For the direct analysis of particle-bound non-polar and polar *organic species* the filter loads were treated by MSTFA (N-Methyl-N-(trimethylsilyl)-tri-fluoracetamide) for in-situ derivatization during the thermal desorption step and quantified by GC-TOFMS [1].

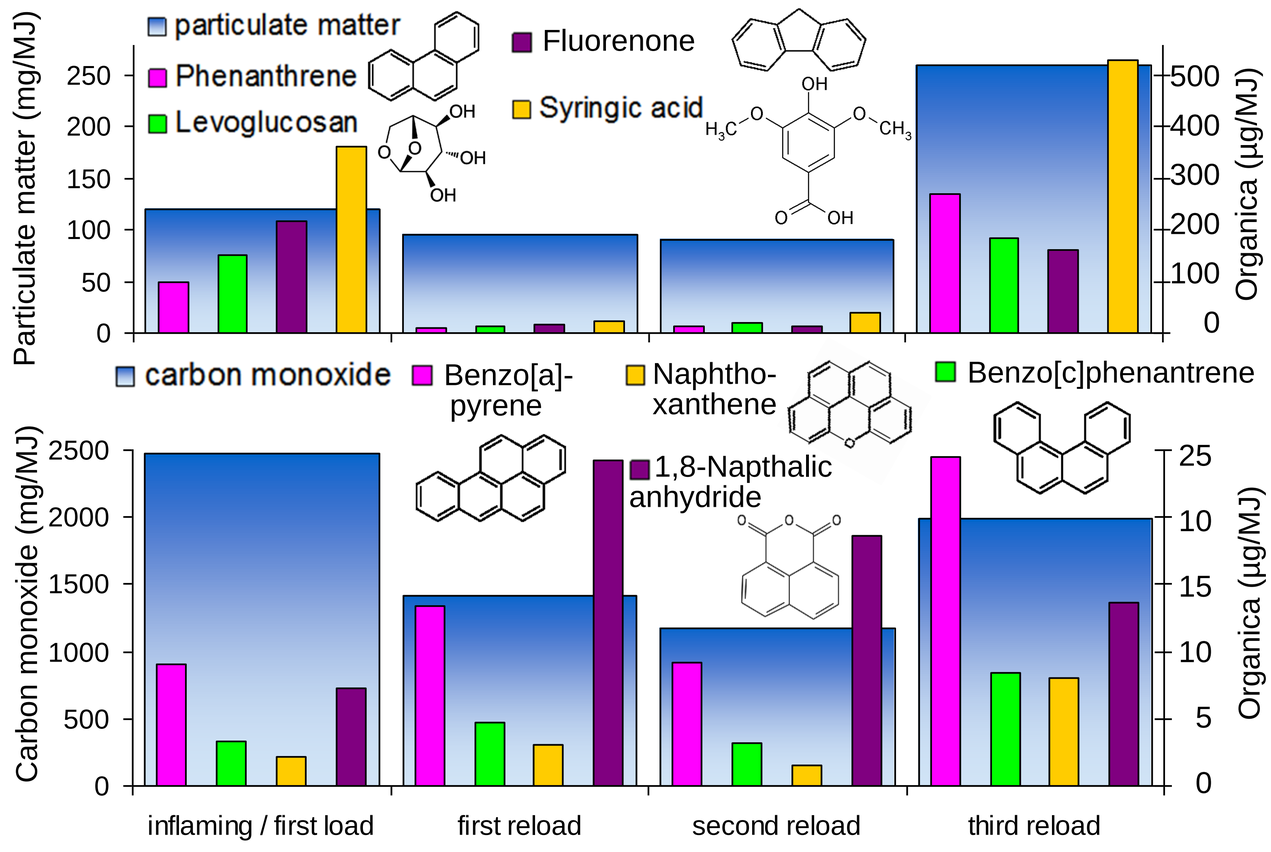

Fig. 5: Emission profile of a wood log stove during different stages of burning. The third reload comprises a 10 minutes smouldering phase. *Stove: Buderus Blueline, 8 kW*; *Fuel: beech wood log. Combustion time for each load : 45 min. Left axis: Particulate Matter and CO, respectively. Right axis: different organic compounds (Levoglucosan: multiply axis by 100).*

Grain size of particles emitted by combustion of wood

More than 90 % of the particle are in the grain size range between 0.09 and 0.6 µm with a fairly constant maximum at 0.15 µm (Fig. 4). These very fine particles may easily enter the alveoli of the lung and trespass into the blood. Because these particles are highly enriched by harmful substances, also these compounds are transferred in our body.

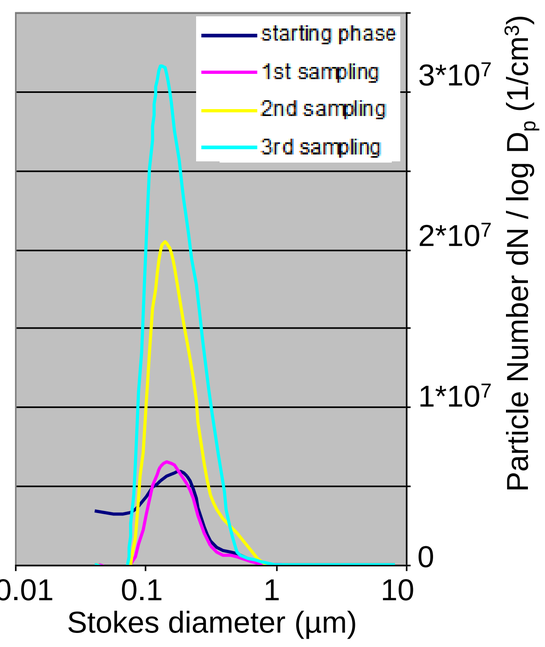

Fig. 4: Particle number distribution N in dependency of the logarithmic particle diameter D_p during burning experiments in a wood log stove (Fig. 5); measurement by an electrical low pressure impactor.

The fate of heavy metals during wood burning

Based on the amount of elements contained in the fuel wood and the amounts in different ash fractions, it is possible to calculate element fluxes. In Fig. 5 the fluxes are normalized to the production of 1 megajoule (MJ) net energy. The uncritical elements K, Ca, and Mg tend to be enriched in the grate ash, whereas the heavy metals Pb, Cd, Tl, Sb, and Cs are enriched in fly ash, electrostatic precipitator (ESP) ash and internal heat exchanger ash.

Particulate Matter: particle emission during burning of biomass, consisting of inorganic and organic compounds. The ash content of the fuel and the completeness of burning (oxidation) determine the amount and composition of the particulate matter.

Carbon monoxide CO: A very toxic gas; indicates incomplete oxidation during combustion.

Levoglucosan ($C_6H_{10}O_5$): formed from the pyrolysis of carbohydrates; it is a chemical tracer for biomass burning.

Benzo[a]pyrene $C_{20}H_{12}$: a polycyclic aromatic hydrocarbon whose metabolites are mutagenic and highly carcinogenic; product of incomplete combustion at 300 to 600 °C.

Phenantrene $C_{14}H_{10}$: a polycyclic aromatic hydrocarbon; irritant, photosensitizing skin to light.

Fluorenone $C_{13}H_8O$ & Naphthalic anhydride $C_{12}H_6O_3$: presumably precursor substances for oxidative stress in lung (respiratory tract irritation); not direct health effect.

Benzo[c]phenanthrene $C_{18}H_{12}$ & Syringic acid $C_9H_{10}O_5$, Naphthoxanthene $C_{18}H_{10}O$: no data about their carcinogenicity; no reliable toxicity data.

References:

[1] Orasche, J.et al. (2011). Atmospheric Chemistry and Physics, Discussion Paper, 11, 15255-15295

More information: www.bioenergie.uni-goettingen.de

Acknowledgement

The study was supported by the Federal Ministry of Science and Culture, Lower Saxony, Germany

Niedersächsisches Ministerium für Wissenschaft und Kultur

Geology & Medicine for a safer Environment

GEOMED 2011

4TH INTERNATIONAL CONFERENCE ON MEDICAL GEOLOGY

Hans Ruppert