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Flue gas analysis of wood combustion

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Summary:
Energetic use of biomass by combustion of wood in log-fueled fireplaces becomes more and more attractive. In-situ sensor-based flue gas analysis could help to efficiently reduce emissions. Firing experiments were carried out with simultaneously collected data about flue gas composition. This includes FTIR gas analysis, particle emissions concerning amount and size distribution (particle spectrometer), several temperature sensors and a lambda probe to determine the residual oxygen concentration beside the data from an inhouse developed sensor, that is sensitive to combustible gases. The sensor results impressively follow the FTIR data. Further investigations and data analysis should focus on correlations between sensor (incl. secondary data) and particle analysis to clarify whether gas sensor data might hint on particle emissions.

Keywords: wood-log fueled batch firing, carbon monoxide gas sensor, flue gas analysis, particle spectrometer, FTIR gas analytics

Background

Actual discussion about energy availability and transformation to renewable sources include the question of biomass use. More and more households use wood-log fueled fireplaces. However, emissions concerning toxic gases like carbon monoxide (CO) or particulate matter (PM) could be immense as both the operation and the combustible material can be highly individual. Several scientific attempts show that automated operation by sensor-based control algorithm may significantly lower the pollutant concentration [1]. Goal of the present study is to demonstrate a possible sensor for flue gas analysis and to collect simultaneously several data during batch firing. For the first time, data from a particulate spectrometer were taken to evaluate number and size distribution of particulate matter continuously during burn-off.

Experimental Setup and Devices

Combustion was done in a LEDA UNIKA fireplace with natural ventilation chimney. Reproducible experiments were done as follows: Fire was started with lighting up four pieces of pine wood (in total 300 g). After a certain time (flame nearly burned down), two other pieces (in total 800 g) were added to the combustion chamber on top of the glow. Combustion air was set to a maximum during the whole burn-off. Gas analyses were carried out by a MKS FTIR system including IAG FLS system with integrated heated filter for probe sampling. All reducing components from the FTIR data were summed up to a CO equivalent value (CO^e). Additionally, a BOSCH LSU 4.9 lambda probe measured the residual oxygen concentration (ROC). Several thermocouple signals (type K) were logged to monitor the flue gas temperature at different positions in the chimney. Beside this, a self-made gas sensor was installed in the chimney. Its measuring principle is based on generated heat by exothermic reactions of reducing gases at a catalytically activated film (details in [2]). The temperature gradient between this activated area and an inert region within the sensor tip is recorded as a thermovoltage signal U_{th}. Particle data were received utilizing a CAMBUSTION DMS 500 particulate spectrometer. Herein, a particle-loaded gas sample is diluted directly after sampling, and particles are charged by a high voltage electrode and analyzed continuously in a column by several electrometer rings.

Results

One exemplary burn-off experiment (cold start) is described in figure 1. Starting the fire causes steeply rising flue gas temperatures. In general, in terms of good combustion, the oxygen content decreases, resulting in kind of a curve that behaves inversely to the flue gas temperature (fig. 1a). Strong changes in temperature and $p(O_2)$ in the range before 1000 s indicate opening the furnace and stoke the fire with wood. Particle analysis shows higher particle concentration during the phase of lighting up with larger particles (high fluctuations). During the second phase of the experiment, particles are below 50 nm with numbers of about $1 \cdot 10^8$ (fig. 1b).

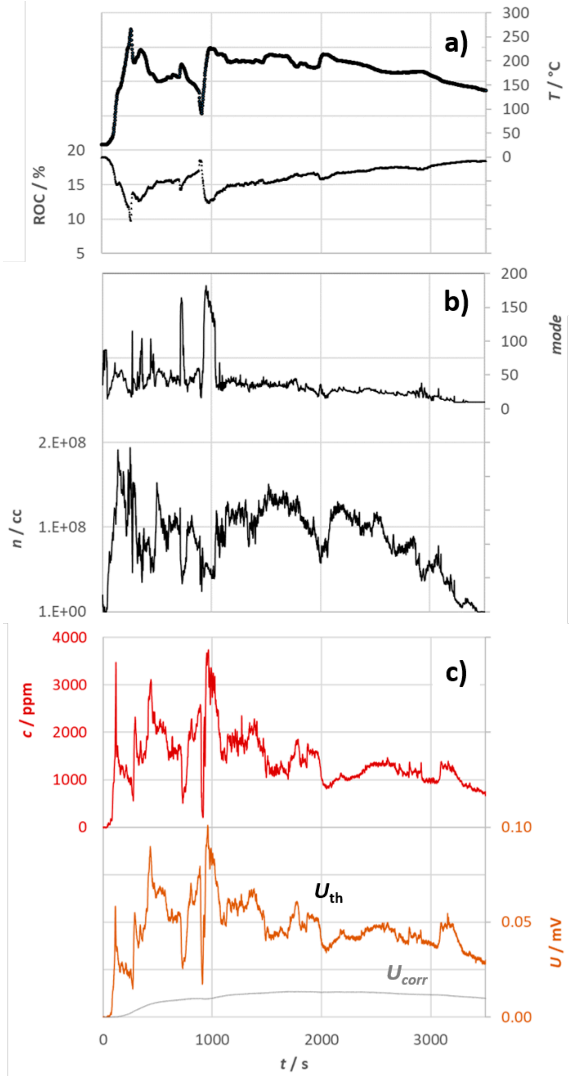

Fig. 1. Several measures during burn-off: a) flue gas temperature at sensors position (T/°C) and residual oxygen concentration $p(O_2)$/%); b) particulate size mode (maximum of monomodal size distribution in nm) and particulate number value (n/cm^3); c) sum of reducing gases (as CO^e equivalent value in ppm) from FTIR analysis, sensor raw signal U_{th} and changing offset voltage U_{corr} from temperature-based coupling effects with respect to the sensor housing to be subtracted.

The gas analysis (FTIR data) shows also higher values during the first phase of the experiment (fig. 1c). Here also, good combustion should result in lower pollutants concentrations. However, the wood-log fueled combustion is highly individual. Fig. 1c also shows the sensor raw data U_{th} (set to zero at $t = 0$) with its fast response behavior. The signal is slightly cross-sensitive to changing temperatures in the sensor housing, resulting in a variable offset-voltage. This drawback is overcome as follows: An offset-correction value (U_{corr}) was derived from simultaneously taken temperature data ($T_{housing}$ is the temperature at the flange outside the chimney, where the sensor is installed) after equation (1), in which c denotes a constant coupling factor (here: 0.00023 mV/°C).

$$U_{corr} = T_{housing} \cdot c \quad (1)$$

The now corrected sensor signal ($U_{th} - U_{corr}$) was processed with the sensor's sensitivity (slope of the linear characteristic curve with 25 µV / 1000 ppm CO, which is a typical value achieved in lab measurement with synthetic gas) to a ppm value. Both data are plotted against each other to show their impressive correlation (fig. 2).

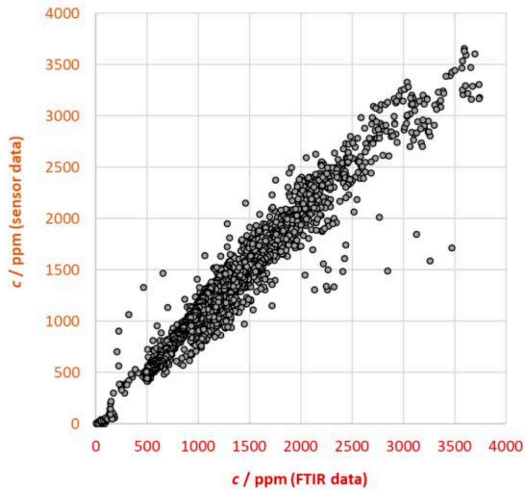

Fig. 2. Sensor data vs. FTIR gas analysis of real exhaust flue gas analysis. Details see text.

Outlook

Highly individual flue gas composition during wood burning in a single room fireplace was analyzed by different devices and methods. Results from a developed thermoelectric gas sensor correlate well with FTIR analytics. Together with several secondary data, correlations might also be found to deduce from gas sensor results to particle formation.

References

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