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Continuous Estimation of Particle Emissions in Flue Gas of Wood Combustion using Gas Sensor Measurements

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Summary:
Single-room wood-log fueled fireplaces are widely used but contribute significantly to harmful emissions such as carbon monoxide and fine dust. Automatically controlled operation might help to reduce health risks and environmental pollution. Therefore, in-situ measurements in the flue gas are necessary to intervene by controlling the combustion air stream automatically. As the detection of particulate matter in mass, concentration or size distribution is challenging – there are no suitable sensors available -, the particle emission shall be estimated by gas sensor data. We found correlations between hydrocarbon emissions and particulate data. The hydrocarbon concentration was evaluated from measurements with two gas sensors: an exothermicity sensor for reducing gases and a novel hydrogen sensor, both installed in the flue gas.

Keywords: biomass energy technology, wood combustion, particluate matter detection, thermoelectric CO/HC-sensor, hydrogen sensing

Background

Biomass offers a great potential to reduce greenhouse gas emissions (CO_2) from fossil sources. The use of renewable bio energy covers about 9 % of the primary energy consumption in Germany, mostly by heat generation. Wood burning comes along with massive particle emissions. In that field, more than 11 million single-room fireplaces in Germany are responsible for about 15.8 t of dust emissions [1].

In the past years, research and development efforts targeted the reduction of wood-log fueled fireplace emissions. To reduce gaseous pollutants, a sensor-based algorithm to control the primary and secondary air stream automatically in combination with the use of a ceramic noble-metal loaded catalyst was investigated. For particulate matter reduction, an electrostatic precipitator was used. Together, both concepts demonstrated to lower the total emissions of wood stoves by 80 % [2]. Of course, such systems cause high costs and will only be installed when required by law.

The aim of the present contribution follows a novel approach. Controlled operation should have high reducing potential when it is well-directed by additional in-situ information about the actual particle emission. As particulate matter detection in flue gas is challenging with sensor devices, we try to find correlations of particle data with continuous gas sensor data. Therefore, we evaluated the signals of two in-house developed gas sensors, suitable for harsh conditions. Gas data are compared to continuous particle data from a particle spectrometer (DMS 500, CAMBUSTION).

Experimental

Measurements were conducted in real exhaust from a wood-log fueled fireplace (LEDA UNICA). Sensors were installed in the vertical part of the chimney (ca. 30 cm above the burning chamber).

To detect the sum of reducing gas species (carbon monoxide and hydrocarbons), a CO/HC-sensor measures the heat generated by exothermic oxidation of the target gases at a catalyst by means of a thermopile structure. Details on the measuring principle can be found in [3], experiences when using such sensors in flue gas conditions are presented in [4]. The impressive correlation of such gas sensor response with analytics data from an FTIR is shown in [5]. A novel zeolite-based potentiometric H_2-sensor was used to determine hydrogen separately. Its general setup was formerly reported in [6]. Now, a novel thick-film-based transducer with internal heater was used to fit the needs of flue gas application. Lab measurements in synthetic gas atmosphere show the applicability (Fig. 1). Even in the presence of carbon monoxide (which is the leading component in the flue gas), the sensor responds selectively towards hydrogen.

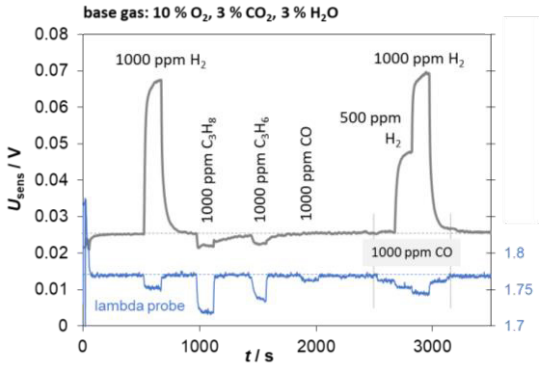

Fig. 1. Signal of a novel zeolite-based potentiometric hydrogen sensor device (H_2-sensor) in synthetic base gas with various test gases (details see text).

Results and Discussion

Several measurements with FTIR- and particle-analytics during wood combustion showed a possible correlation of hydrocarbon (HC) emissions with particle data.

To derive the HC concentration from sensor data and as the CO/HC-sensor measures a sum of CO and HC gas concentrations, we follow the consideration that the H_2- concentration in the flue gas is double the value of the CO-concentration (at least in the burn-out phase during CH_4 combustion [7]). So, the concentration values measured by the H_2-sensor divided by "2" were subtracted from the sum concentration values measured by the CO/HC-sensor (eq. 1).

$$c(HC) = c(CO/HC) - c(H_2)/2 \qquad (1)$$

Fig. 2 shows time continuous data during wood combustion exemplarily.

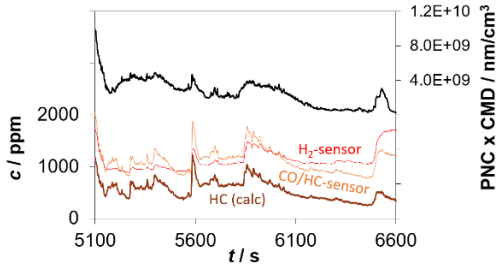

Fig. 2. Sensor measurements and particle analysis while one burning phase (stoking with "wood 3" until burn-out) as part of a combustion experiment. HC-concentration values are calculated from the sensor signals according to eq. (1).

Now, resulting continuous HC-concentration values are plotted against simultaneously collected particle data (here we used the product of the particle number concentration, PNC and the count media diameter, CMD). All data in Fig. 3 represent a more than 2-hour lasting experiment with different phases of wood burning (igniting the fire and stoking with different wood four times) with values every second.

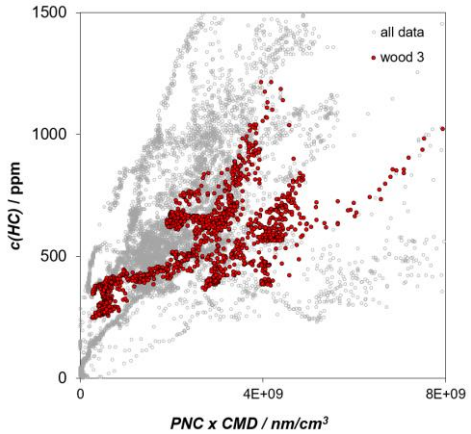

Fig. 3. Correlation of HC-concentration evaluated from two sensor measurements after eq. (1) with simultaneously collected data from a particle spectrometer (DMS 500). Highlighted points refer to data shown in fig. 2, background data to the whole experiment (more than 2 h, 9000 data points including ignition, cold start and four times stoking with wood.

Regarding the contiguous data for one burning phase ("wood 3" was the 3rd time of stoking with softwood of suggested humidity), significant correlation of the data gets visible although some assumptions might not be valid for the highly individual exhaust gas compositions during wood-log combustion. Furthermore, in comparison to the single sensor results (CO/HC or H_2), scattering of data in such display is significantly reduced. Future investigation should also take in account other secondary data such like residual oxygen concentration or temperatures to refine the results and elucidate more the interrelations of particle generation with operation parameters.

References

[1] Basisdaten Bioenergie Deutschland 2022, available online: Basisdaten.fnr.de

[2] X. Zhang, B. Ojha, H. Bichlmaier, I. Hartmann, H. Kohler, Extensive Gaseous Emissions Reduction of Firewood-Fueled Low Power Fireplaces by a Gas Sensor Based Advanced Combustion Airflow Control System and Catalytic Post-Oxidation, *Sensors* 23, 4679 (2023); doi: 10.3390/s23104679

[3] S. Wiegärtner, G. Hagen, J. Kita, W. Reitmeier, M. Hien, P. Grass, R. Moos, Thermoelectric hydrocarbon sensor in thick-film technology for on-board-diagnostics of a diesel oxidation catalyst, *Sensors and Actuators B* 214, 234–240 (2015); doi: 10.1016/j.snb.2015.02.083

[4] G. Hagen, J. Herrmann, X. Zhang, H. Kohler, I. Hartmann, R. Moos, Application of a Robust Thermoelectric Gas Sensor in Firewood Combustion Exhausts, *Sensors* 23, 2930 (2023); doi: 10.3390/s23062930

[5] G. Hagen, J. Herrmann, R. Moos, A. Müller, T. Wöhrl, Flue gas analysis of wood combustion, SMSI 2023, Nuremberg Germany, doi: 10.5162/SMSI2023/D3.4

[6] G. Hagen, R. Moos, Planar Zeolite-Based Potentiometric Gas Sensors, *Sensor Letters* 9, 1-4 (2011); doi:10.1166/sl.2011.1430

[7] T. Nussbaumer, Schadstoffbildung bei der Verbrennung von Holz, Ph.D. thesis (1989), ETH Zürich, Switzerland