Influence of operation type on particulate emissions from residential wood combustion

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Different recent investigations of PM_{10} revealed that biomass burning is an underestimated source of soot in the ambient air (Prévôt et al, 2006): secondary organic aerosols and condensable compounds may significantly contribute to the total organic mass found in PM_{10} in the ambient air (Robinson, 2007; Tsigaridis and Kanakidou, 2007). Furthermore, investigations on pollutant emissions from residential wood combustion (RWC) show that these emissions are strongly influenced by the type of operation and that emission factors may vary in a wide range (Nussbaumer, 2008).

The aims of the present investigation are:

- To investigate the range of pollutant emissions as a function of different types of operation. This information is used to estimate real-life emissions in comparison to emissions expected from type-tests.
- To calculate emission factors (emissions per fuel amount used) which consider all phases of a burning cycle.
- To estimate the additional contribution of condensable compounds to PM_{10} in the ambient air.
- The relevance of carbon monoxide (CO) as a tracer for unburned particulate matter and other pollutants is investigated, since CO analysis can be easily applied in practice and is currently used for emission limit values for RWC in Switzerland.

For this purpose the emissions of different wood combustion devices were measured during start-up, stationary combustion, and burnout. The filling degree, the fuel moisture, the air supply and other parameters were varied. Flue gas composition, including CO, VOC, O_2, CO_2, and NO_X was determined as well as the mass of solid particles in the chimney at 160°C according to VDI 2066. In addition, mass concentration of condensable compounds was measured at 0°C according to EPA standards. Particle number concentration and particle size distribution were analysed by electric and optical methods, i.e., SMPS and OPC.

To estimate the potential contribution to PM_{10}, solid particles and condensable organic matter are assumed as primary aerosols. However, due to re-evaporation during the dilution of flue gases in the atmosphere, the contribution of condensable compounds to PM_{10} in the ambient air can be overestimated. Results of measurements at different wood stoves are presented which lead to the following conclusions:

- The results show that a good correlation between CO and solid particles in the flue gas is observed under well defined conditions within one phase of a burning cycle. However, the correlations are not generally applicable as they vary from one combustion phase to another and as they depend on the operating conditions. Although CO is regarded as a valuable indicator for the combustion quality, it is not a generally valid indicator for particle emissions.
- Particle size ranges from 50 to 100 nm. The largest particle number is observed during start-up. In this phase up to 85 % of the total particle mass can be emitted.
- A comparison between calculated emission factors for total burning cycles with emission factors currently used in Switzerland (BAFU, 2001) reveals that the emissions from RWC might be overestimated by a factor of 2 for stoves which are operated according the manual and underestimated by a factor of 2 or more for badly operated stoves. Hence the order of magnitude of the emission factor for solid particles is reasonable but related to a high uncertainty.
- Igniting the fire from the top reduces not only the PM emissions during the start-up (Vock and Jenni, 2007) but also leads to lower emission factors over the whole burning cycle.
- Due to incomplete combustion in RWC, the organic matter available as condensable compounds may significantly contribute to the total mass of PM_{10} found at 0°C in the flue gas. The mass concentration of condensables can exceed the mass concentration of solid particles in the flue gas by a factor of 1.3 under ideal operating conditions up to more than a factor of 12 under unfavourable conditions.
- Hence considering only solid particles can significantly underestimate the contribution to PM_{10} in the ambient air. On the other hand, considering solid particles and condensables may overestimate the contribution due to re-evaporation in the ambient (Lipsky and Robinson, 2006).

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Acknowledgements

The project was supported by the Swiss Federal Office for Energy (BFE) and the Swiss Federal Office for the Environment (BAFU). We thank Holzenergie Schweiz, Liebi LNC AG, Schmid AG Holzfeuerungen, Sigmatic AG, Tonwerk Lausen AG and Tiba AG for the cooperation.

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Introduction

Investigations of PM_{10} in the ambient air reveal that biomass burning is an underestimated source of soot in the ambient air[1] and that secondary organic aerosols significantly contribute to the total organic mass found in PM_{10}[2]. Further, investigations on pollutant emissions from residential wood combustion (RWC) show that the emissions are strongly influenced by the type of operation and that emission factors may vary in a wide range.

Method

The emissions of wood stoves were determined under different operating conditions by varying load, fuel moisture, air supply, type of ignition and other parameters.
The mass concentration of solid particles (SP) was measured in the chimney at 160°C according to VDI 2066. Condensable compounds (CC) were trapped at 0°C according to EPA method 5H. The particle number concentration and particle size distribution were determined by SMPS and OPC. In addition, O_2, CO_2, CO and VOC were analysed continuously. From these data, emission factors were determined which consider all phases of a burning cycle.

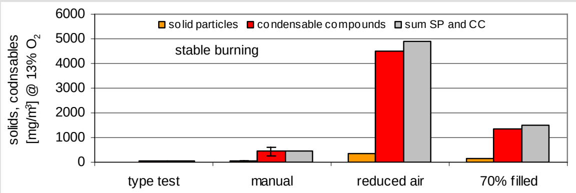
Results

- Condensables can exceed the mass of solid particles in the flue gas by a factor of 1.3 under ideal operating conditions up to more than a factor of 12 under unfavourable conditions. Condensables are most relevant for RWC and its contribution to PM_{10}.
- Overfilling the fuel chamber and igniting the fire from the bottom can cause very high PM emissions, while igniting the fire from the top reduces the PM emissions[3].
- The highest particle emissions (i.e. mass and number concentration) are observed during start-up. At the same time size distribution indicates an increase of coarse particles.

Conclusions

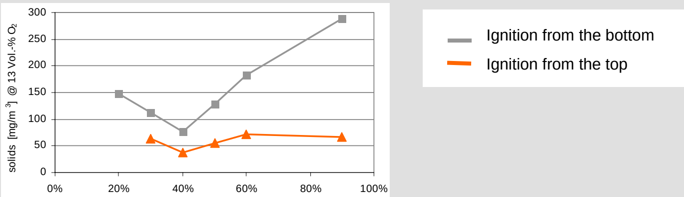
- Considering only solid particles can significantly underestimate the contribution of RWC to PM_{10} due to relevant contributions of condensables and secondary organic aerosols. The fraction of condensable compounds depends on the operating conditions.
- The start phase strongly contributes to the total emissions of a burning cycle.

Solid and condensable emissions at different operating conditions

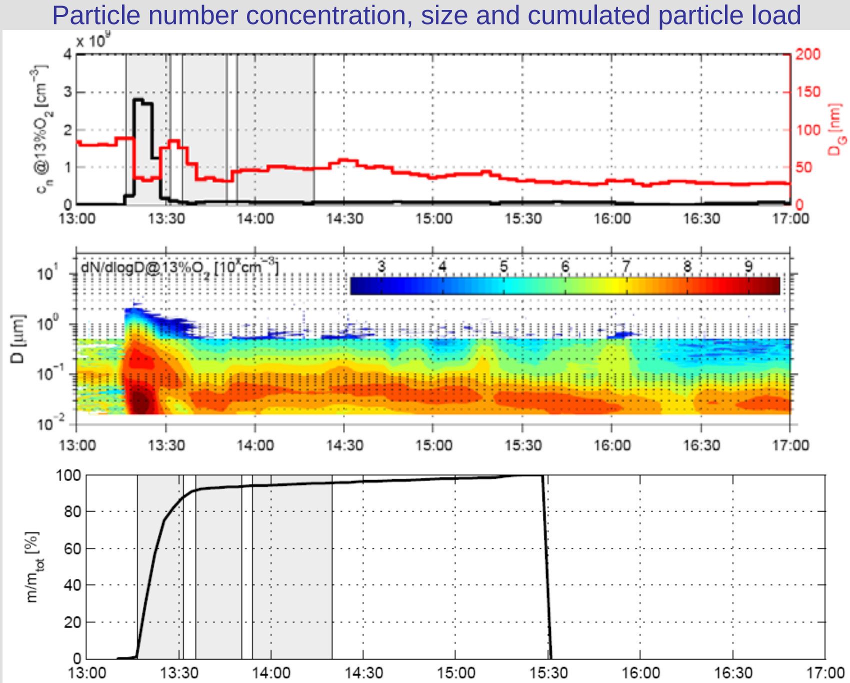


ratio CC:SP	type test	ignition from the top	reduced airinlet	70% filled
start-up		6		9
stable burning	1.3	8	12	10
burnout		5	24	9

Emission factors as function of load and ignition type



Particle number concentration, size and cumulated particle load



c_n: number concentration SMPS D: diameter SMPS+OPC m/m_{tot}: cumulated particle load SMPS+OPC

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Acknowledgements
Swiss Federal Office of Energy
Swiss Federal Office for the Environment
Adrian Lauber, HSLU
Schmid AG, Sigmatic AG, Tonwerk Lausen AG