# Condensing Heat Exchanger for Fine Particle Precipitation and Efficient Heat Recovery in Small Scale Wood Combustion

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The wood pellet is an alternative energy source suitable for use at various large scale as well as domestic pellet stoves. The main negative side in this type of biomass usage during combustion process is the fine particle (PM1 defined as a particles with median aerodynamic diameter $d_a \leq 1$ µm) and gaseous emissions. Therefore it is important to develop low emission biomass combustion devices. The aim of this work was to study the potential of condensing heat exchanger (CHX) for simultaneous fine particle precipitation and efficient heat recovery.

Experiments with a condensing heat exchanger were performed for optimal fine particle precipitation. The heat exchanger was operated in two different modes: floor heating and high temperature heating with incoming and outcoming water temperatures of 24,1 – 25,7 ˚C and 54,3 – 57,5 ˚C, respectively. Reference measurements were carried out with a conventional tube heat exchanger.

The condensing heat exchanger was installed in the combustion reactor which consists of a 40 kW solid fuel burner and a ceramic insulated combustion chamber. The CHX was equipped with water scrubbing system to keep the heat exchanger walls clean. The temperatures of a flue gas and water upstream and downstream the CHX were monitored continuously as well as pressure drop over the CHX. The flue gas composition was analyzed with FTIR (Gasmet) and single gas analyzers (ABB) which continuously were measured CO2, CO, O2 and NOx. The condensate which was collected in the bottom of CHX was weighed and later on analyzed for the content of inorganic compounds.

Before particle measurement the sample air flow was diluted by a porous tube – ejector dilution system (dilution ratio 23 - 32). After dilution sample was divided by the different instruments. PM1 fraction particles were collected by the pre cut – off impactors. The filters were weighed and analyzed for OC, EC and inorganic compounds. Particle number size and mass size distributions were determined by ELPI (Dekati), DLPI (Dekati) and SMPS (TSI).

During the experiments the air to fuel ratio ranged from 1,9 to 2,3 at floor heating mode and 1,7 to 2,0 at high temperature heating mode. The CO, organic carbon (OC) and elemental carbon (EC) in all measured cases were very low, showing nearly complete combustion conditions. The PM1 were mainly composed of K, Na, $SO_4^{2-}$, $Cl^-$ and Zn. The condensate analysis showed a similar chemical composition as shown for the particle emissions.

The average of PM1 emissions is presented in Figure 1. Summarizing, the experimental set up with CHX generated 32 % lower PM1 emissions in the high temperature heating case and 36 % of PM1 lower emissions in floor heating case compared to the reference boiler case. The results showed that the thermal efficiency in floor heating mode reached over 100 %, due to released heat by water condensation. The usage of the scrubber increased the PM1 emissions in comparison to the CHX operated without scrubber. The heat exchanger thermodynamics and fine particle desposition was also simulated with a computational model. Theoretically CHX was predicted to have PM1 precipitation of 56 and 50 % in floor and high temperature heating modes, respectively, based on thermophoretic and diffusiophoretic forces. The reference boiler was simulated to have a PM1 precipitation of 19 %. Thus, the experimental findings between the conventional reference boiler and the CHX were in good agreement with the simulations.

The results indicate that a condensing heat exchanger in small scale biomass-fired boilers can be designed for fine particle reduction with simultaneous high thermal efficiency. The tested system is especially suitable for floor heating operation and for moist fuels, for example wood chips.

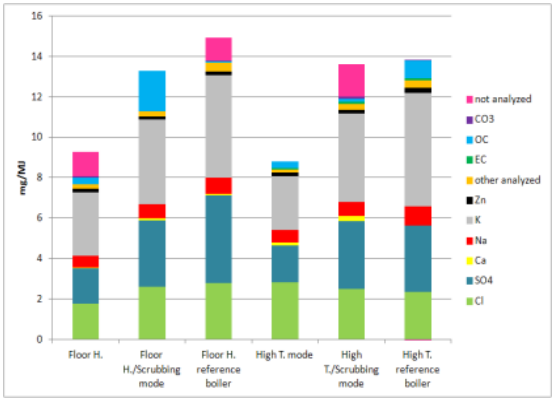


Figure 1. PM1 emissions and their chemical composition downstream the CHX and conventional reference boiler.

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