Particle Emissions from Small Scale Wood Combustion Devices and their Control by Electrostatic Precipitation

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In the article the results of investigation of fine particle emissions from small scale biomass combustion devices are presented. Particle emissions were measured downstream of a wood-log stove and two pellets-boilers: one boiler was operated with wood pellets and in a multi-fuel-boiler grains; wood-, mixed- and straw-pellets were used for testing. Particle number and mass concentration in the exhaust gas strongly depends on the type of biomass and combustion conditions. The particle emission was controlled by an electrostatic precipitator (ESP) installed downstream the combustion unit. The collection efficiency of the ESP depends on corona discharge parameters, particle number concentration and gas temperature and flow rate. For steady flame combustion of wood-logs and wood-pellets, the mean mass collection efficiency of the ESP is η=88% and η=82% correspondingly. For grains η=73% and both for mixed- and straw-pellets the mass collection efficiency of η=77% is measured.

1. Introduction

Wood, straw, second-rate cereals, unsuitable for food, etc. can serve for production of heat and hot water in small-scale district-heating units. Generation of heat or energy by biomass combustion takes advantage of a renewable source of energy and can help to reduce the overall emissions of CO_2. Wood is often combusted in small units for domestic heating, in stoves and fireplaces and resulting in emissions of fine particles several tens of mg/m^3_N of gas (Nussbaumer, 2003). The utilisation of straw and agricultural crops leads to even higher emissions. The ash content of this fuel is typically ten times higher than that in wood pellets (Bäfver, 2009). As fine particles are associated with increased mortality and cardiovascular diseases, it is urgent to prevent emissions. The electrostatic precipitators (ESP) are the most common choice ensuring high removal efficiency for the complete particle size range (Bologa, 2009). In the article the results of investigation of fine particle emissions control from small scale biomass combustion devices by a novel electrostatic precipitator are presented.

2. Experimental set-up

The combustion tests were carried out in the German Biomass Research Centre. The set-up includes different biomass combustion devices. In our case these are a wood-log stove with thermal power output 9 kW and exhaust gas flow $\dot{V}$ =50 m³/h; a wood-pellets boiler with thermal power 20 kW and $\dot{V}$ =70 m³/h, and a multi-fuel-boiler with thermal power 32 kW and $\dot{V}$ =83-100 m³/h for combustion of grains, wood-, mixed- (50% wood / 50% straw) and straw-pellets. The pilot electrostatic precipitator was installed downstream the combustion units. Particle stream of the exhaust gases was extracted fro the measurements, so that the ESP could be operated with the intended flow rate of 50 m³/h. Particle mass concentration was measured upstream and downstream the ESP. Gravimetric measurements were carried out according to the Guidelines VDI-2066 and the combustion units were operated according DIN-4702. Particle number concentration was measured by Scanning Mobility Particle Sizer (SMPS). Particle mass concentration was recalculated to 13 Vol.% of O_2.

The tested pilot electrostatic precipitator is developed and patented by the ITC-TAB, Karlsruhe Institute of Technology (Bologa, 2010). The ESP ensures stable operation and it has no openings (excluding input and output) through which the exhaust gas can come out of the unit. A single-field ESP includes an ionizer and a collector. In the ionizer particles are charged in a DC, negative corona discharge. The ionizer consists of a high voltage insulator, protected by a screen system, and a robust high voltage star-shaped disk installed inside of a grounded tube electrode. The collector consists of a gas duct with a grounded brush for collection of charged particles. The brush is connected to a motor and is periodically rotated and cleaned. The ESP is supported by an automatic control system and a high voltage unit with maximum output voltage U=20 kV and corona current I=1,5 mA. The ESP casing size (L×W×H) is 440×220×800 mm.

3. Results

The gas temperature, ESP operation voltage and corona current were measured for combustion of different biomass (Table 1). The data for temperature present the arithmetic mean values across the time of measurements from which the period of the heating of gas duct and precipitator is excluded.

Table1 Temperature of gas flow and ESP operation voltage and corona current

Type of combustion device	Type of biomass fuel	Exhaust gas, °C	Clean gas, °C	Voltage, kV	Current, mA
Multi-fuel-boiler	Grains	133	107	20	0,35
Multi-fuel-boiler	Mixed-pellets	140	113	20	0,3
Multi-fuel-boiler	Straw-pellets	132	108	20	0,25
Multi-fuel-boiler	Wood-pellets	118	102	20	0,62
Pellets-boiler	Wood-pellets	176	141	19	0,55
Stove	Wood-logs	301	164	18	0,9
Atmospheric conditions, no combustion				20	0,46

The temperature of the exhaust gas from the multi-fuel-boiler was from 120°C to 140°C, and the temperature of the clean gas was about 110°C. The pellets-boiler operates with gas temperatures a little bit higher than the multi-fuel-boiler (exhaust and clean temperatures are 176° C and 141°C). During the combustion of wood-logs, the temperature of the exhaust and clean gas increased up to 300°C and 164°C, correspondingly. For wood-logs combustion, the corona current varied from I=0,3 mA for "start-up" up to I=1,4 mA for "burn-out" combustion stages. The current I=0,9 corresponds to "steady flame" combustion when the gravimetric measurements were carried out. Every gravimetric measurement lasted 30 min and it was carried out within the periods of ESP cleaning. A new log of wood of 1,3 kg was put into the stove every 30 min. The grains and pellets were moved into the combustion chamber of the boilers continuously. The results of the gravimetric measurements at flow rate $\dot{V}$ =50 m³/h are presented in the Table 2. The diagrams which characterize particle number concentration and size distribution at different gas flow rates through the multi-fuel-boiler are presented in the Fig.1.

Table2 Particle mass concentrations and single-field ESP mass collection efficiency (recalculated for 13 Vol.% of O_2,), gas flow rate 50 m³/h

Type of combustion device	Type of biomass fuel	Exhaust gas, mg/Sm³	Clean gas, mg/Sm³	Mass col eff., %	Mean mass col. eff., %
Multi-fuel-boiler	Grains	109	19	82	
		143	39	73	73
		107	39	64	
Multi-fuel-boiler	Mixed-pellets	133	32	76	
		135	29	78	77
		117	28	76	
Multi-fuel-boiler	Straw-pellets	367	73	80	
		437	99	77	77
		343	88	74	
Multi-fuel-boiler	Wood-pellets	10	3	72	
		11	2	82	81
		10	1	89	
Pellets-boiler	Wood-pellets	21	3	84	
		20	4	80	82
Stove	Wood-logs	35	5	85	
		32	4	87	88
		29	3	91	

4. Discussion

For combustion of wood-pellets in the multi-fuel-boiler, the single-field ESP ensures the mass collection efficiency η=81% (Table 2). The particle mass concentration in the clean gas is about 2-4 mg/m^3_N and is below the demands of the German 1.BImSchV which sets the limits for particle emissions from biomass combustion devices. For combustion of wood-pellets in the pellets-boiler, the ESP shows the same collection

efficiency (η=82%). Being operated at U=19-20 kV, in comparison with normal atmospheric conditions, the ESP is characterised by increased corona current in the ionizer.
In the case of wood-logs combustion, where the exhaust gas temperature reaches 300°C, the ESP ionizer parameters are U=18 kV and I=0,9 mA. The increase of corona current enhances mass collection efficiency up to η=88%.
In comparison with wood-pellets, the combustion of grains in the multi-fuel-boiler is characterised by increase of particle mass concentration in the exhaust gas (Table 2). It is about 5 times higher reaching 150 mg/m^3_N. During combustion of grains the mass collection efficiency of the ESP decreases about 10 % in comparison with combustion of wood-pellets and it is η=73%.

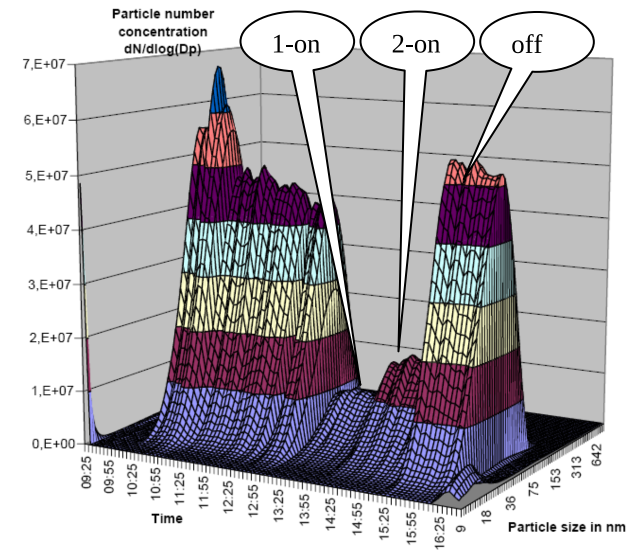

Fig.1,a

1-on: $\dot{V}$ *=50 m³/h*

2-on: $\dot{V}$ *=83 m³/h*

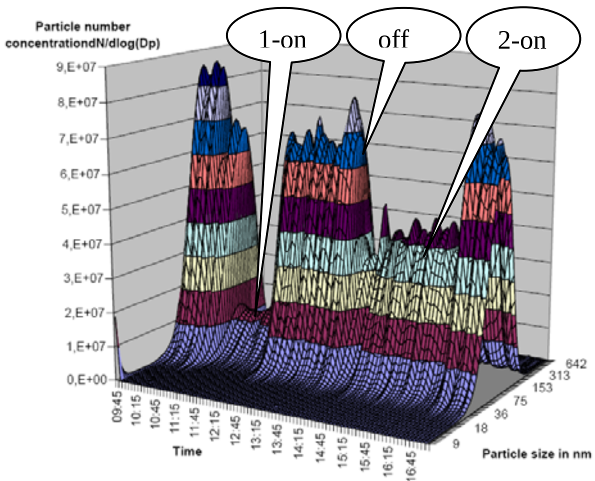

Fig.1,b

1-on: $\dot{V}$ *=50 m³/h*

2-on: $\dot{V}$ *=90 m³/h*

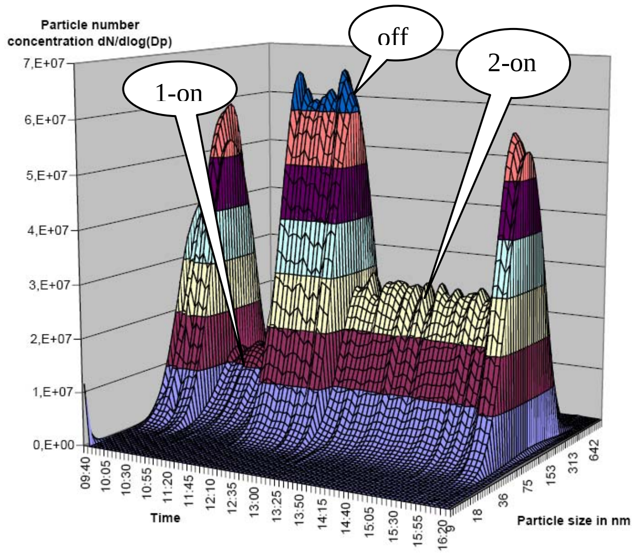

Fig.1,c:

1-on: $\dot{V}$ *=50 m³/h*

2-on: $\dot{V}$ *=100 m³/h*

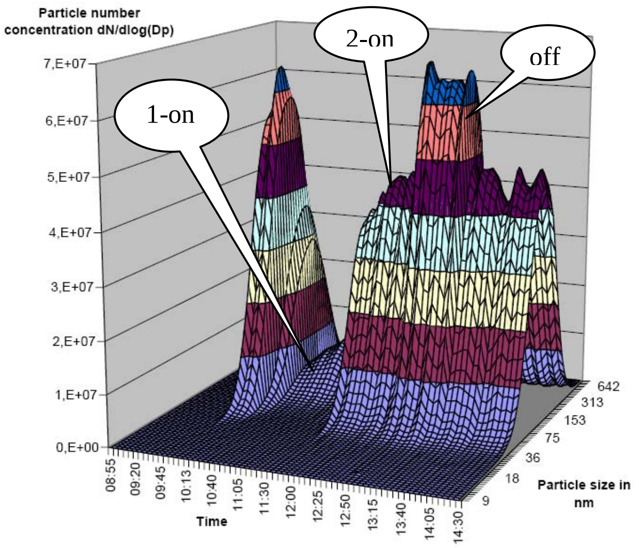

Fig.1,d

1-on: $\dot{V}$ *=50 m³/h*

2-on: $\dot{V}$ *=100 m³/h*

Fig.1 Particle number concentration and size distribution in the gas flow for multi-fuel-boiler: a) wood-pellets, b) grains, c) mixed-pellets, d) straw-pellets;
1-on and 2-on: single-field ESP is "switched-on";
off : single-field ESP is "switched-off"

For mixed- and straw-pellets combustion, the mass collection efficiency of the ESP is η=77%, but the mass concentration of the aerosol in the clean gas is higher than 20 mg/m^3_N. This is due to high particle mass concentration of aerosol upstream the ESP which reaches the values over 400 mg/m^3_N. To ensure particle mass concentration downstream the ESP less than 20 mg/m^3_N, the application of two-field ESP is useful.

The particle size distribution and number concentration were measured downstream the ESP at different operation conditions. The data marked “off” and “1-on” correspond to the switched-off and switched-on electrostatic precipitator at gas flow rate $\dot{V}$ =50 m³/h. The data for increased flow rates through the switched-on ESP are marked by “2-on”.

The measurements show that for grains combustion particle number concentration in the gas flow (Fig.1,b) is higher than for wood-pellets (Fig.1,a). At constant applied voltage this results in corona discharge suppression in the ionizer and in decrease of corona current. For mixed- (Fig.1,c) and straw-pellets (Fig.1,d), the particle number concentration in the exhaust gas is slightly higher than for the wood-pellets combustion, but mean particle diameter is larger. But during the straw-pellets combustion, the aerosol contains salt particles, which are less conductive and being loaded on the grounded electrode in the corona discharge zone provoke back corona discharge which negatively influences on the ESP collection efficiency. As the result, the ESP operation is characterised by decrease of corona current due to both corona discharge suppression and back-corona discharge in the ionizer.

With increase of flow rates through the ESP, the size distribution downstream the ESP remains unchangeable but the number concentration of particles which penetrate the ESP increases. This means that at the same applied voltage and corona current the increase of gas flow rate through the electrostatic precipitator slightly decreases the ESP collection efficiency. For effective particle collection, the velocity in the ESP collector needs to be v~1 m/s.

The collector is automatically cleaned by rotation of the grounded brush. In case of combustion of wood-logs and wood-pellets (relative low particle mass concentration), the cleaning cycle of the collector is about 1 min per 1h. For grains, mixed- or straw-pellets (high particle mass concentration), the cleaning cycles is 1 min per 30 min. To avoid the damage of high voltage insulator by spark discharges, the ESP is switched on when the gas temperature in the insulator room of the ionizer is above 100°C.

Acknowledgement

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