IDEVELOPMENT OF ELECTROSTATIC PRECIPITATORS FOR SMALL BIOMASS-FIRED BOILERS

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ABSTRACT: Small straw and wood fired boilers may be a significant source of air pollution as the combustion generates a high amount of particle emission in the flue gas. This paper describes flue gas cleaning by electrostatic precipitators developed for small wood and straw boilers with heating capacity from 4kW up to 500kW. Fulfilling the European standard EN 303-5 for small boilers demands a cleaning system for the flue gas. Especially for straw fired boilers the challenges are high. There are no suitable filters in the market. Cleaning by means of cyclones is insufficient, fabric filters are not suitable and traditional precipitator technology does not work. Different filter sizes and types for the actual boiler size and biomass types (straw, wood chips and wood pellets) have been developed and tested. Control automation as well as effective mechanical systems for removing dust deposits from the discharge electrodes and the colleting plats has been developed and tested. Total collection efficiency of 95-99 % has been achieved.
The project is collaboration between two commercial companies and a university.
Keywords: particle emission, combustion, biomass, straw.

1 INTRODUCION

Devices for cleaning of flue gas for dust and other components may be based either on mechanical or electrical processes. The mechanical processes include cyclone separation, gas scrubbing or washing, filtration by means of fabric filters, screens, packed beds, gravidity settling and agglomeration of particle e.g. by sound. When using the electrical processes an electric force act on the particles in the gas. This method is referred to as electrostatic precipitation [1,2]. The process require electrical charging of suspended particles, collecting of the charged particles in an electric field and finally removal of the precipitated dust from the collecting electrode.

Separation of particles from a gas by electrical precipitation requires:

- Electric charging of the particles
- Collection of charged particles in an electric field
- Removal of precipitated material (deposits) from the collecting electrodes.

The combustion of biomass and especially straw generates a high amount of particle emission in the flue gas. The known mechanical methods for flue gas cleaning are not suitable for small straw boilers [3]. The objective of this work has been to develop a low-cost, efficient and reliable electrostatic precipitator designed for small biomass boilers. Today in Denmark in rural areas, there is no threshold for dust emissions from small straw-fired boilers. However, from January 2018, the common European standard EN 303-5 for smaller straw-fired boilers will be implemented in Denmark. This means that the threshold for automatically fired boilers will be 40 mg of dust per normal m^3 flue gas. With traditional techniques, this threshold can only be met by using a fabric filters. A fabric filter is relatively expensive both in procurement and in operation. The filter requires a large fan to overcome the pressure drop across the filter. The filters are vulnerable to high flue gas temperatures, which often occurs in small straw boilers. Therefore high operating cost for the replacement of filter will be necessary when using fabric filters. An ideal electrostatic precipitator for small biomass (straw, chip, wood etc.) fired boilers must be simple and inexpensive. The filter must have only few moving parts and there by the maintenance costs could be kept low. The pressure drop will be low and thus the filter will have low energy consumption. An effective and low-cost flue gas filter for small biomass-fired boilers is crucial for the use of these boilers in the future both in Denmark and in the rest of Europe [4,5]. There exists a large surplus of straw throughout Europe. If the straw could be used in these boilers, reduced CO_2 emissions will be achieved and the straw, a renewable energy source, could replace fossil fuels.

2 WORKING PRINCIPLE OF AN ELECTROSTATIC PRECIPIATATOR

2.1 Design principle of the filter

An electrostatic precipitator consists of positive and negative electrodes which are connected to a high voltage supply. The voltage level is 10-100 kV, depending on the filter size and design. The positive electrodes are traditional formed as large steel plates which are mounted with a mutual distance of 100-400 mm, thereby forming parallel channels between the plates. The smoke is passed in a horizontal flow in these channels, see Fig 1.

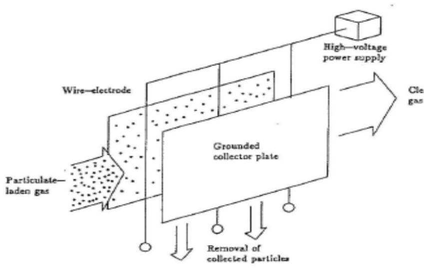


Figure 1: Schematic drawing of a wire-plate electrostatic precipitator.

The positive electrodes are named "collector plates" or "collector electrodes" as the dust particles are collected on the plats. Another very simple design consists of a tube with a corona discharge electrode installed in the center. The tube wall form in this case the grounded positive collector electrode, see Fig 2.

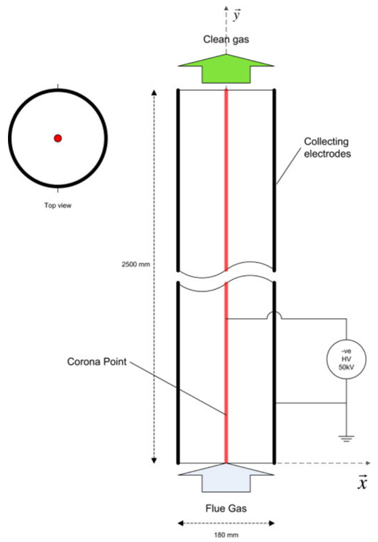


Figure 2: Schematic drawing of a tube electrostatic precipitator [7].

2.2 Electric field

The operation of electrostatic precipitators depends on the applied voltage. The voltage must produce enough electrical stress for ionizing and electrical charging of the dust particles. When the difference in voltage between the positive collector plates and negative discharge electrode is sufficiently high, the electric field near to the negative discharge electrode will be very high and it will excite electrons/ions. The electrons will immediately move toward the positive collector platelets. A corona charging occurs.

The fast moving electrons will ionize the gas, and electrons and ions will collide with other flue gas molecules and produce further ions. The ions will then be connected to the neutral dust particles and thereby the dust particle becomes negative charged and attracted to the collector plates. See Fig. 3 [7].

Little by little, the dust particles will settle as an isolating layer on the collection plates. Therefore to maintain the cleaning effect, the plates must be kept free of dust. In a conventional filter typically periodic rapping is used for cleaning the plates. How often it is necessary to clean collection plats dependents on the amount of dust, dust particle size and the type of dust particles. Particularly the resistivity of the dust is very important. Dust of high resistivity, over about 10^9 Ωm, will form a tight barrier on the collection plats, causing accumulation of electric charge leading to back-corona discharge [1,2,8].

The flue gas from straw fired boilers has both a very high amount of dust and the particles produced are of the type leading to dust with a high resistivity. Therefore, in an electrostatic precipitator for straw boilers the most important problem is the back corona. The layer thickness of the dust on the collecting plates must be reduced to a minimum if the filter should have a good cleaning effect.

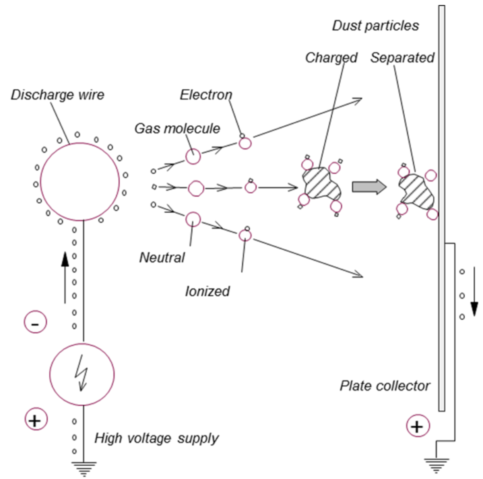


Figure 3: Corona discharge and the precipitation process in a wire-plate filter.

This work has focused on developing a new set-up with rotating collection plates with a mechanical system for removing the dust layer on the colleting plates.

3 APPROACH AND TEST SET-UP

The project is collaboration between two companies and a university. The company Reka A/S produces biomass boilers and company Magnussen & Speiermann projects and produces components for large electrostatic precipitators used in e.g. coal-fired plants. Aarhus University, Department of Engineering has a laboratory for development and testing of biomass boilers where the focus is on the efficiency and emissions.

The first part of the project was a screening of the literature. Based on literature and existing knowledge within project partners experimental models were constructed, tested and optimized in the laboratory. Prototypes have been made and tested in laboratory.

Installations and test in practice for documentation of operational reliability and collection efficiency will be made.

3.1 Laboratory test facilities

A great deal of the work has taken place in the biomass combustion laboratory at Aarhus University, Department of Engineering. The laboratory has facilities for devolving and test of biomass boilers. The primary object of the laboratory is to improve the efficiency of smaller biofuel plants, reduce emission of environmentally damaging substances including carrying out incineration experiments with new types and different combinations of biomass.

The capacity of the laboratory is dimension for boilers up to 1MW and can be connected to one to three boilers at the time depending on the size of the boiler/plant. In connection with the lab, there is also an instrument room and an office. The standard measurement possibilities includes: Inlet temperature (Pt-100), outlet temperature (Pt-100), water flow (Inductive flow meter), flue gas temperature (Thermo element, available draught (Micromanometer), O in flue gas (Paramagnetic detector), CO-content in flue gas, 0-1000 ppm (infrared detector), CO_2 detector, NO_x detector, hydrocarbon detector, SO_2 detector, flue gas dust content (Ströhlein equipment) and flue gas conditioning (heating coil + refrigerant type dryer).

3.2 Basis filter concept

The dust in the flue gas from straw fired boilers consists mainly of alkaline salts. The dust has a high resistivity as mentioned previously. This means, that typically only a very thin layer, thickness of about 0.1mm, can be deposed on the colleting plates before the electrical resistance through the dust layer becomes so high, that the filter cleaning efficiency is drastically reduced. The mass of the dust in this thin layer is low compared to the sticking force between dust and collecting plate, meaning that the dust cannot be removed from the collecting plates by means of a traditional rapping technique. Thus, a conventional electrostatic precipitator is unsuitable for straw flue gas.

In a previously conducted research project Arhus University, Department of Engineering and Reka A/S developed a test set-up and a first prototype of an electrostatic precipitator with circular rotating colletion plates. Instead of a rapping system, the dust was removed by means of thin scrapers [3]. See fig 4.

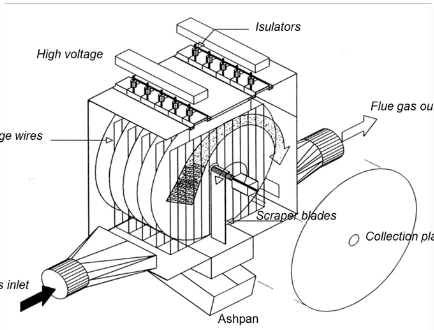


Figure 4: Principle drawing showing the working principle of the developed filters [3].

Two final prototypes for boiler sizes, respectively 10-50kW and 200-500kW, was designed, constructed and tested. The results described in the following sections are based on these prototypes

4 RESULTS

4.1 Characteristics of the prototype filters

The current–voltage characteristics for the two different filter sizes were measured with clean filter and atmospheric air. During the measurements each filter was connected to a Remo high voltage power supply unit with adjustable output voltage in the range between 0 and 40 kV. For the small filter (boiler size 10-50 kW) a 400 kW unit was used, and for the filter for boiler size 200-500 kW a 750 kW unit was used.

The results are shown in the figures 5 and 6.

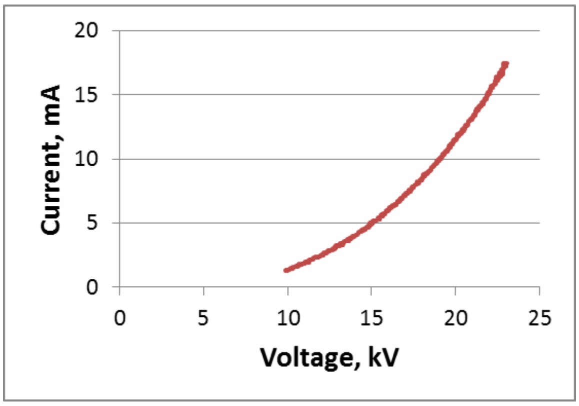


Figure 5: Current - voltage characteristic of the electrostatic precipitator for a 200-500kW biomass boiler. Distance between collection plates was 134mm and distance between discharge wires/electrodes was 40mm.

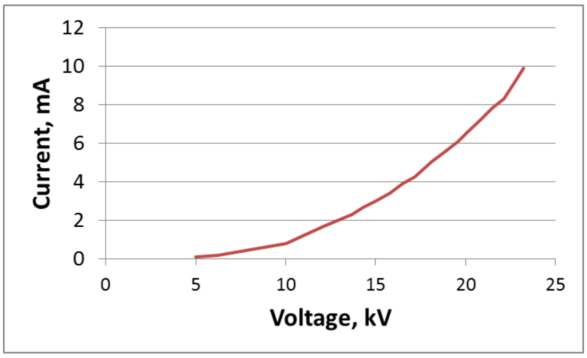
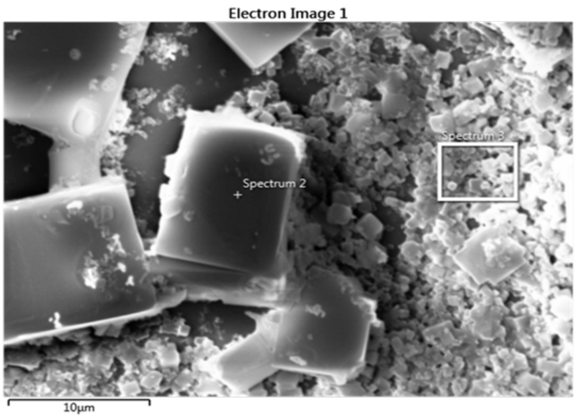


Figure 6: Current - voltage characteristic of the electrostatic precipitator for a 10-50kW biomass boiler. Distance between collection plates was 94mm and distance between discharge wires/electrodes was 30mm.

4.2 Dust particles analyses

The dust deposed on the collection plates was analyzed by means of scanning in an electron microscope. Results from these physical and chemical analyses are presented in figure 7.



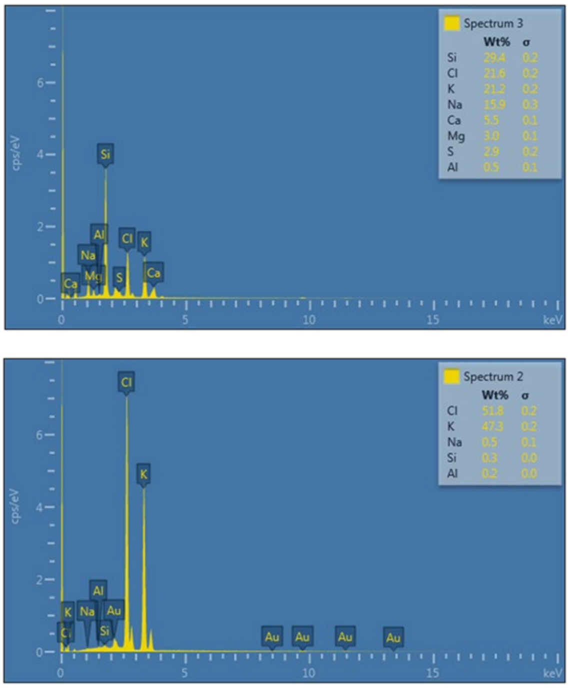


Figure 7: Electron microscope scanning of the dust particles in the flue gas from a boiler fired with straw.

The scanning showing the chemical composition of the dust displayed large amount of Cl, K, Na and Si. The particles were small and all the detected particles and crystals were below 10 µm.

4.2 Collection efficiency of the proto type filters

The measurements of particle mass concentration in the flue gas flow before and after passing through the filters were carried out during steady combustion conditions. Different types of biomass were used as fuel. Wheat straw, rye straw, wood pellets and wood chips have been combusted in the biomass boiler.

The electrostatic precipitators were operated at voltage at 20-26 kV and current up to 10 mA for the small filter and up to 18 mA for the large filter.

Results of the measurements for the large filter and a 200 kW Reka biomass boiler is presented in table 1.

Table 1: Mass collection efficiency for prototype filer designed for a 200 – 500kW biomass boiler

Fuel	Straw, wheat	Straw, wheat	Wood chips
Boiler effect, kW	213	222	215
Flue gas temperature, °C	210	210	190
O_2, %	10.5	10.5	9.0
Raw gas, mg/nm^3	720	1150	160
Cleaned gas, mg/nm^3	13	21	1.3
Mass colletion effency,%	98	98	99

For the combustion of different types and qualities of wheat straw the particle mass concentration in the cleaned gas (exhaust gas) were 13-21 mg/nm^3 corresponding to a mass collection efficiency of 98 %. When the fuel was wood chip the particle emission - as expected - was much lower. The particle mass concentration in the cleaned gas was for wood chips 1.3 mg/nm^3 corresponding to a mass collection efficiency of 99 %.

Results of the measurements for the small filter and a 40 kW Reka biomass boiler is presented in table 2.

Table 2: Mass collection efficiency for prototype filer designed for a 10 – 50kW biomass boiler

Fuel		Straw, pellets	Wood pellets
Boiler effect, kW		36	39
Flue gas temperature, °C		135	125
O_2, %		7.4	6.3
Raw gas, mg/nm^3		670	49
Cleaned gas, mg/nm^3		16	0.3
Mass colletion effency,%		98	99

For the combustion of straw pellets the particle mass concentration in the cleaned gas was 16 mg/nm^3 corresponding to a mass collection efficiency of 98 %. When the fuel was wood pellets the particle emission in the raw gas was only 49 mg/nm^3. The particle mass concentration in the cleaned gas was for wood pellets 0.3 mg/nm^3 corresponding to a mass collection efficiency of 99 %.

5 CONCLUSIONS

Different filter sizes and types for biomass boilers with 10kW - 500kW effect have been developed and tested. The filter efficiency for straw, straw pellets, wood chips and wood pellets has been documented. Control automation for the power supply at the filters as well as effective mechanical systems for removing dust deposits from the electrodes has been made.

Total mass collection efficiency of 95-99 % has been achieved for straw, wood chips and wood pellets. This new design and set-up for electrostatic precipitators effectively reduces the particle mass in the flue gas from small scale biomass boilers below the norms for particle emission stated in the European standard EN 303-5.

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