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Influence of ESP collector configuration on reduction of particulate emissions from biomass combustion facility

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Abstract. Development of compact electrostatic precipitators (ESPs) for reduction of particulate emissions from small scale biomass combustion is an actual task. Particle mass collection efficiency of an ESP depends from combustion conditions, geometry of precipitator ionizer, collector stage configuration and ESP operation parameters. The investigation of the influence of collector stage configuration on particle mass collection efficiency of a pilot space charge ESP was in the focus of the study. It was shown that the use of tube collector with integrated grounded plates enhanced particle mass collection efficiency. The loading of plates with aerosol provoked particle re-entrainment and decreased long-term ESP mass collection efficiency. The use of grounded brush electrodes ensured effective reduction of particle emissions but resulted in increase of pressure drop in the precipitator. The optimization of cleaning intervals of the ionizer and collector stages increased particle mass collection efficiency. It was shown, that the integration of automatic systems for ionizer and collector cleaning into the space charge ESP enhanced precipitator long-term operation stability and ensured effective reduction of particulate emissions form small scale biomass combustion.

1. Introduction

Electrostatic precipitators are widely used for exhaust gas cleaning [1]. In the conventional ESPs, particles are charged and precipitated in the external electric field formed between the high voltage (HV) corona discharge electrodes and grounded plates or tube-form electrodes [2]. In the space charge ESPs, particles are charged in the ionizing stage and are further precipitated under the influence of space charge phenomena in the grounded collector, installed downstream of the ionizer [3]. The ESP mass collection efficiency depends of ionizer electrode geometry, collector stage configuration, polarity and value of applied voltage, power consumption of corona discharge, exhaust gas temperature, composition and velocity, particle size, conductivity, mass and number concentrations, etc.

To ensure long-term operation stability, industrial ESPs are usually equipped with automatic systems for cleaning of ionizing and collector stages and am automatic system for evacuation of collected fly ash from the ESP. To ensure high particle mass collection efficiency, large scale industrial precipitators include several stages, installed one after another what allows effective cleaning of large volume of exhaust gases. These precipitators are equipped with powerful high voltage supply units. They usually have large size and high investment costs.

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In comparison with large-scale industrial ESPs, the electrostatic precipitators for exhaust gas cleaning from small scale biomass combustion facilities have compact design, low maintenance and operation costs [4]. The main demand to these apparatuses is that they need to ensure effective cleaning of exhaust gases and long-term operation stability for various combustion conditions and fuel quality.

The scope of the current work is the development of a compact space charge electrostatic precipitator for exhaust gas cleaning from small scale biomass combustion facilities. The task of the current study is the investigation of the influence of the collector stage configuration of a pilot ESP on the reduction of particulate emissions from wood-chips combustion boiler.

2. Experimental set-up

The study was carried out at the test facility equipped with a 100 kW wood-chips combustion boiler and an experimental set-up for investigations of electrostatic precipitators. Boiler and fuel storage were placed inside of a two-room box. The 1st room was used for fuel storage (V=18 m³) and the boiler was installed in the 2nd room. Wood-chips were delivered automatically into the boiler what ensured long-term operation of combustion facility. Exhaust gas from the boiler was delivered into the experimental set-up. The gas flow rate through the ESP was 280±20 m³/h depending on combustion conditions.

Figure 1. Compact space charge ESP

A pilot compact space charge electrostatic precipitator (Fig.1) was used for exhaust gas cleaning. The precipitator included a thermo-insulated casing with corresponding gas input and gas outputs. Gas input was opened into the corona discharge ionizer equipped with an automatic cleaning system. The ionizer included a star-form corona discharge electrode installed inside of the grounded tube (inner diameter of 250 mm). The HV electrode was installed perpendicular to the direction of gas flow in the electrode system. The width of the electrode gap was 25 mm. A DC negative polarity corona discharge was used for particle charging. A compact HV power supply unit was used for generation of corona discharge (max. voltage of 22 kV and max. current of 2.2 mA). Two tube collectors were installed inside of the casing. They connected casing bottom part with gas outputs.

The pilot ESP operated in the following way. Exhaust gas flowed through the gas input into the corona discharge ionizer. Particles were charged in the corona discharge field and the gas transported charged particles into the casing bottom part. A part of the particles was precipitated in the ionizer. The ionizer was periodically cleaned and the collected material fell down into the casing bottom part. The rest of charged particles was precipitated under the influence of space charge phenomena inside of the pilot ESP in the casing bottom part and in the tube collectors. The cleaned gas flowed further into the ESP gas outputs.

During the tests the following parameters were measured: gas temperature upstream and downstream the ESP, gas velocity in the gas duct, pressure drop P in the ESP, corona discharge voltage U and corona current I. Gravimetric measurements of particle mass concentrations in the gas flow upstream $C_{m\text{-}Raw}$ and downstream $C_{m\text{-}Clean}$ of the ESP were carried out simultaneously using the analysers SM 500 (Fa. Wöhler). Particle mass collection efficiency was calculated as $\eta = \frac{C_{m-Raw} - C_{m-Clean}}{Cm-_{Raw}} 100\%$.

For investigation of particle re-entrainment phenomena, a special sedimentation box was installed downstream the ESP. After the measurements, fly ash was taken out from the ESP and sedimentation box. The fly ash was weighted and these data were used for recalculation of particle re-entrainment from the pilot precipitator. The results of the tests were used for analysis of the ESP long-term operation stability and efficiency of exhaust gas cleaning.

3. Results of experimental study

Tests were carried out for various collector configurations. In the Test-1 and Test-2 the collectors of 6 and 4 grounded plates were installed in the ESP casing bottom (Table 1). The data for the long-term test with 6-plate collector were measured during the time of t=171 h of ESP operation (Test-1.2). The intermediate data were also joined for t=55 h (Test-1.1). The results of the tests have shown, that the pilot ESP ensured effective reduction of particle emissions during the long-term operation (Fig.2). For the same combustion conditions and operation time (Test-1.1 and Test-2), the pressure drop in the precipitator and the ESP particle mass collection efficiency were the same. To simplify the cleaning of the ESP from collected fly ash, an ash box was installed into the casing bottom part and the 4-plates collector was maintained inside of the ash-box what was similar to the 6-plates configuration.

Table 1. ESP parameters.

	t, h	P, Pa	U, kV	I, mA	*$C_{m\text{-}Raw}$, mg/Nm³	*$C_{m\text{-}Clean,}$ mg/Nm³	η, %
Test-1.1	55	17±1	20.6±1	2.0±0.1	97±9	22±5	77±4
Test-1.2	171	17±1	20±1	2.1±0.1	98±10	24±5	75±5
Test-2	52	17±1	21.5±0.3	2.2±0.15	91±6	22±4	75±5
Test-3	53	19±1	21.8±0.3	2.2±0.2	113±10	31±3	73±3
Test-4	50	29±1	21.7±0.3	2.2±0.1	91±10	19±4	78±4
Test-5	32	28±1	20±0.1	2.1±0.1	65±5	13±4	79±5
*Data without 40% reduction due to measurement equipment tolerance							

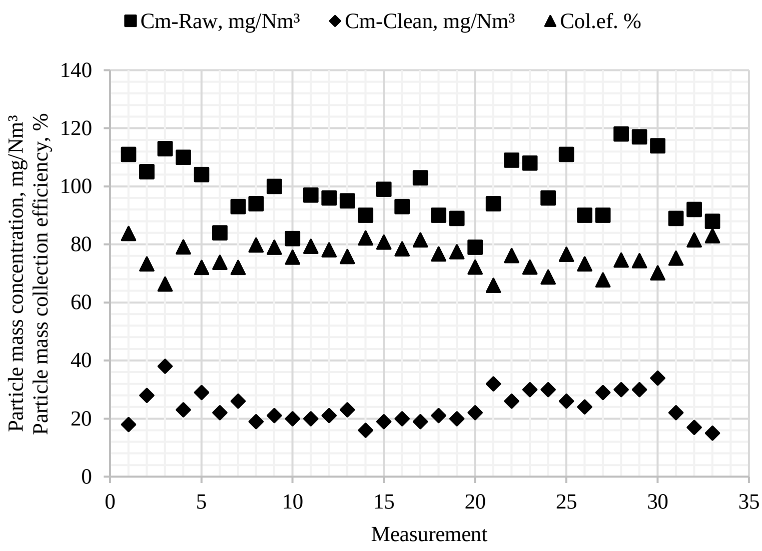

Figure 2. Particle mass concentration $C_{m\text{-}Raw}$ and $C_{m\text{-}Clean}$ and precipitator particle mass collection efficiency η

The Test-3 was carried out when the ESP was equipped with an ash-box with 4-plates and the 5-plate collectors were installed inside of the both ESP tube collectors. The maintenance of the plates increased the grounded collection surface. The results of the tests have shown, that the use of the plates slightly increased the pressure drop in the pilot ESP. But there was no any enhancement of ESP mass collection efficiency. It was also observed, that the thickness of the ash layer on the walls of collector tubes (Test-1 and Test-2) was larger, that the thickness of ash layer on the surface of the plates (Test-3). The reason could be the change of gas velocity profile inside of the collector tubes with 5-plate. Another reason could be the change of the fuel quality. Particle mass concentration in the exhaust gas in the Test-3 was larger than in the tests Test-1 and Test-2.

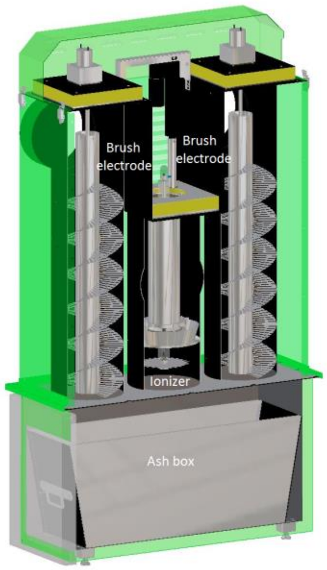

Figure 3. Compact ESP with brush electrodes

For enhancement of ESP particle mass collection efficiency and long-term operation stability, the pilot space charge ESP was equipped with an automatic cleaning system for collector stage. Grounded brushes were installed inside of the collector tubes. Brushes were equipped with motors, which ensured their periodical rotation (Fig.3). The brush collectors operated in the following way. Exhaust gas, loaded with charged particles, flowed through the spiral brushes. Charged particles were precipitated both on the surface of collector tubes and brushes. The special elements were installed in the collector tubes for cleaning of brushes during their rotation. Itself the rotation of brushes ensured the cleaning of collector tubes walls. The precipitated fly ash fell down and was collected in the ash box.

Test-4 was carried out with brush electrodes and ash-box equipped with 4-plates collector. The results of the tests have shown, that at the same values of applied voltage U and corona current I (Test-3 and Test-4), in comparison with 5-plates electrodes, the use of grounded brushes enhanced particle mass collection efficiency. The use of brushes was characterized with an increase of pressure drop inside of the precipitator.

The study was carried out for optimization of ESP collector configuration. It was optimized the height and position of brushes inside of collector tubes. It was optimized the density of brushes and the wire thickness. This improved the brushes operation stability and cleaning efficiency and reduced the pressure drop in the electrostatic precipitator. It was shown, that the direction of brush rotation played an important role for effective transport of collected fly ash into the ash box during the collector cleaning. The direction of brush rotation was important for reduction of particle re-entrainment from the precipitator, especially at high exhaust gas flow rates. The use of optimized brushes simplified the configuration of ESP collector stages.

In the Test-5 the pilot ESP was equipped with optimized brush electrodes and with a plates collector free ash box. The use of optimized brush collectors ensured high particle mass collection efficiency. The tests have shown, that the simultaneous automatic cleaning of the ionizer and collector, equipped with brushes, could provoke particle re-entrainment. The cleaning intervals of the ESP ionizer and collector stages were optimized and particle re-entrainment from the ESP was reduced.

4. Conclusions

The design of the compact space charge electrostatic precipitator with brush electrodes installed inside of the collector stages ensured ESP long-term operation stability at various combustion conditions, fuel quality and particle mass and number concentrations in the exhaust gas. Grounded brushes ensured large surface for particle precipitation under the influence of space charge phenomena.

The use of plates collector free ash box decreased ESP weight and maintenance costs. The refuse from collector plates simplified the cleaning of the ESP from collected fly ash.

The use of automatic cleaning systems for ionizer and collector stages enhanced ESP particle mass collection efficiency and long-term operation stability. The optimization of the ESP cleaning interval allowed the reduction of particle re-entrainment from the electrostatic precipitator.

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