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The correlation between corona current distribution and collection of fine particles in a laboratory-scale electrostatic precipitator

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A B S T R A C T

An analysis of the electrostatic gas cleaning fundamental phenomenon shows an essential influence of discharge electrode construction on the gas cleaning process efficiency.

In the physical model tests there were used rigid discharge electrodes with corona emitting elements of various geometries. Different constructions of discharge electrode were tested in the aspect of discharge current uniform distribution on collecting electrode surfaces. Measurements of discharge current distribution has been carried out for discharge electrodes with different spike shapes and in different electric field geometry. The research aim was to determine the optimal discharge electrode construction ensuring high collection efficiency of fine particles. Collection efficiency measurements of selected fly ash samples (from coal fired boilers) were carried out on a laboratory testing bench in a horizontal electrostatic precipitator model.

1. Introduction

In ESP dusty gas flows between discharge electrodes (of negative polarity) and collecting electrodes (of positive polarity) and the dust particles are charged by collision and diffusion of ions and electrons originating from corona discharge. Fly ash particles hovered with flue gas accumulate on their surface an electric charge originating from gas ions. The process of charging lasts until a particle reaches its so called saturation charge q_s [1]. Hence, the motion of charged dust particles in the direction of collecting electrodes is a result of an electric field effect, gas flow velocity and ionic wind [2].

The complexity of phenomena occurring in the inter-electrode space rules out any analytical modeling. Therefore, there exist many experimental studies carried out in laboratory as well as in industrial conditions [3–8]. Hitherto, most of the studies pointed out [9–11] that electric field parameters in the inter-electrode region have an influence on the charging and collecting processes, but it was also shown that the discharge electrode construction plays an essential role in these processes. The analysis of collected dust patterns on collecting electrode surface has shown that the layer morphology depends on the EHD field shape [12]. Experimental studies of Miller et al. allowed gathering information of locally collected dust layer porosity as well as size of the particles in this layer. The results proved a rule that high density layer develops in front of the discharge points. At the same time the measurements of dust particles size distribution at different regions of collecting electrodes does not given unambiguous results. Studies presented in [12] have shown that fine particles have been mainly collected in the regions of high density compactness. However, Blanchard et al. have found these regions larger number of the collected 'big' particles when compared to other regions [13]. So that matter needs further studies. However, it seems that there exists a possibility to improve the collection efficiency of submicron particles by ESP via designing discharge electrode geometry, for a given electrode spacing, and taking into account the physical and chemical properties of fly ash.

2. Laboratory scale ESP

In order to study the influence of discharge current distribution on fly ash collection efficiency, an ESP model tests had been carried out. The research bench consisted of a one stage ESP chamber, comprising discharge and collecting electrode systems, inlet and outlet air channels, fly ash feeder, an exhaust gas fan and high voltage supply unit. Technical parameters of the model channel are as follows: length of electric field $L = 2 \times 1000$ mm; height of the field $H = 450$ mm; distance between the same polarity electrodes $2h = 400$ mm; and the distance between discharge electrodes $s = 170$ mm.

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For a comparative purpose, two constructions of discharge electrode were tested with properties characterized by the voltage–current (*V–I*) characteristics as well as with discharge current distribution on the collecting electrode surface.

2.1. Discharge electrodes configurations

For the research were used two types of discharge electrodes: a pipe with tinplates (so called RDE-1) and a pipe with spikes (so called RDE-2 with spikes) as shown on Fig. 1. The voltage–current characteristics of the tested electrodes are shown in Fig. 2.

2.2. Current distribution in a collecting electrode

The results of discharge current distribution on the surface of collecting electrode measured with moving probe are shown in Fig. 3. The construction of RDE-2 electrode has provided high covering of the collecting electrode surface with discharge current, with low relative standard deviation RSD = 60.7% of its value, and the highest average magnitude of the discharge current $i_d = 97.3$ nA. For comparison these values for RDE-1 electrode were: RSD = 94.7%, and $i_d = 36.6$ nA, respectively.

2.3. Fly ash properties

Physical and chemical analyses of the fly ash used in the tests are given in Table 1. In Fig. 4 are given the results of fly ash particle size distribution. The chemical composition of fly ashes show differences in the content of: SiO_2, CaO, SO_3 and K_2O. From the size distribution characteristics it can be seen that fly ash A-2 contains more fine particles than fly ash A-1.

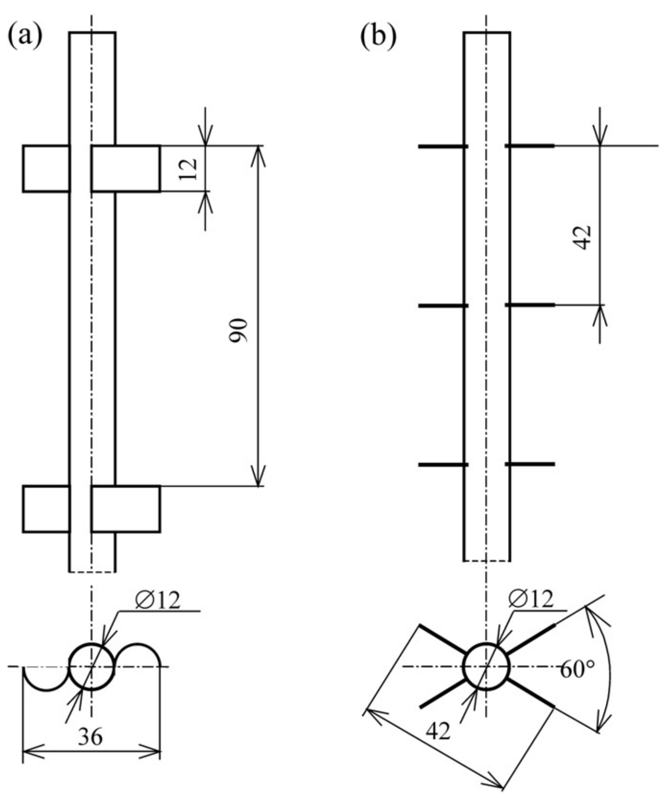

Fig. 1. Design of the discharge electrodes: (a) RDE-1, (b) RDE-2, dimension in mm.

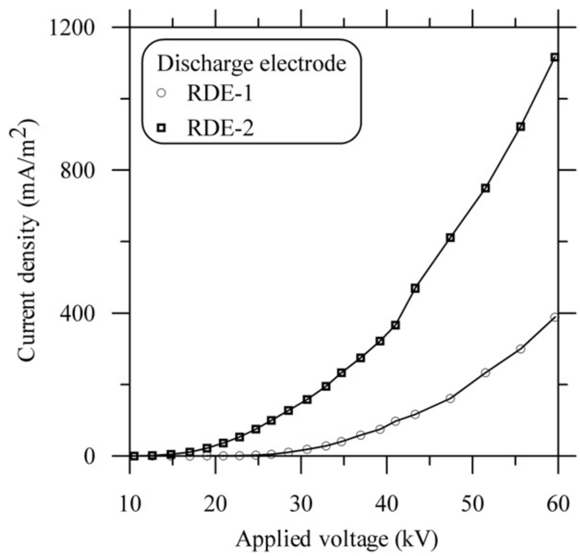

Fig. 2. Current–voltage curves of discharge electrodes tested under air conditions.

3. Results and discussion

3.1. Measurements of total collecting efficiency

The collection efficiency tests were carried on for selected fly ash samples of properties shown in Table 1 and having fractional size distribution presented in a Fig. 4.

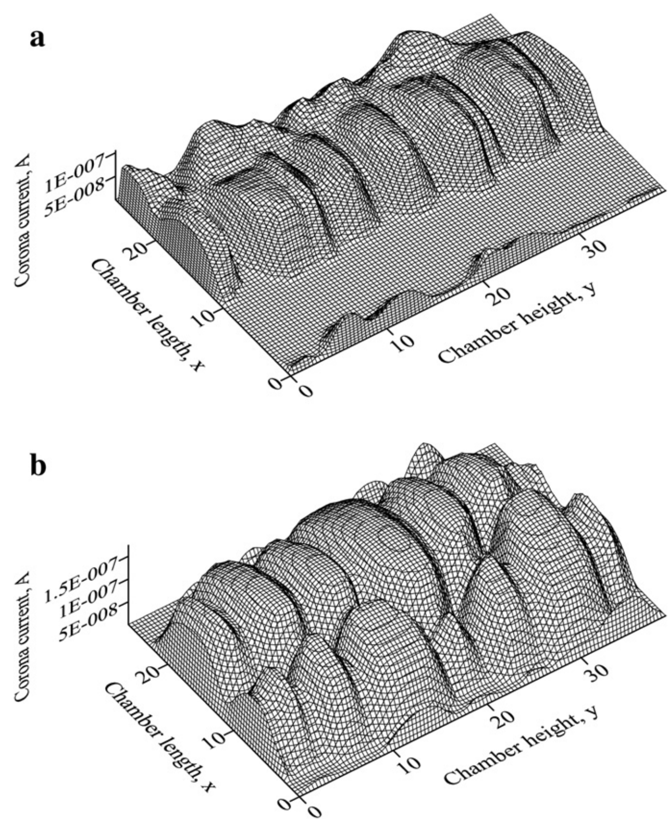

Fig. 3. Discharge current distribution on surface of collecting electrode measured for: (a) RDE-1 electrode and (b) RDE-2 electrode, at 50 kV supply voltage (gas velocity 0 m/s).

Table 1
Properties of the ash used in the experiments.

Parameter	Units	Fly ash type	
		A-1	A-2
Chemical composition of ash:	%	–	–
SiO_2	–	51.20	45.67
Fe_2O_3	–	7.91	8.94
Al_2O_3	–	25.27	21.65
TiO_2	–	1.06	1.09
CaO	–	3.41	8.23
MgO	–	1.94	2.60
SO_3	–	0.51	1.57
K_2O	–	3.02	4.83
P_2O_5	–	0.01	–
Na_2O	–	1.00	1.32
Unburned carbon in ash:	%	4.19	3.50
Density	kg/m^3	2080	2210
Resistivity	Ω cm	2.0×10^8	3.2×10^7

The total collection efficiency was estimated by measuring the fly ash mass flow rate at the inlet and at the outlet and calculated according to the following formula:

$$\eta_C = 1 - \frac{\dot{m}_{out}}{\dot{m}_{in}}. \quad (1)$$

where: $\dot{m}_{in}$ – fly ash mass flow rate at the inlet of ESP, (g/s),

$\dot{m}_{out}$ – fly ash mass flow rate at the outlet of ESP, (g/s)

Fig. 5a and b present collection efficiency changes as a function of supply voltage for RDE-1 and RDE-2, respectively.

Total collection efficiency for RDE-2 electrode has been higher than that for RDE-1 electrode, for both tested fly ashes. This difference is probably caused by more "current-aggressive" *V–I* characteristic as well as more uniform discharge current distribution. In turn, lower collection efficiency for A-2 fly ash, for both discharge electrodes, may result from larger percentage of fine particles in this ash (median diameters for these ashes were: $d_{50} = 50$ μm for A-2, and $d_{50} = 80$ μm for A-1), and also from low resistivity of this fly ash (10^7 Ω cm).

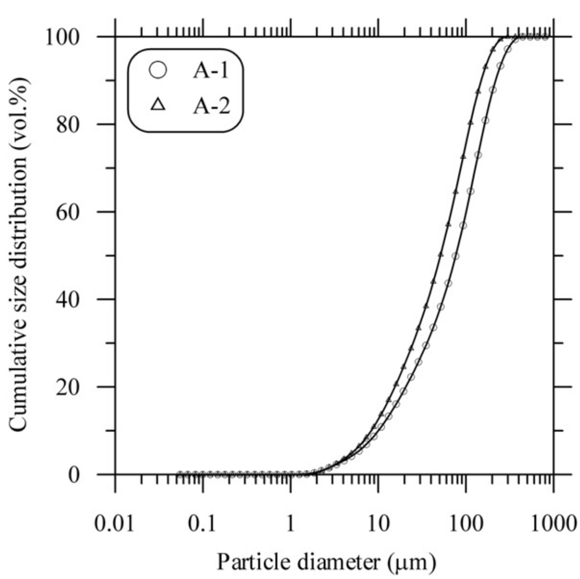

Fig. 4. Particle size distribution of tested fly ashes.

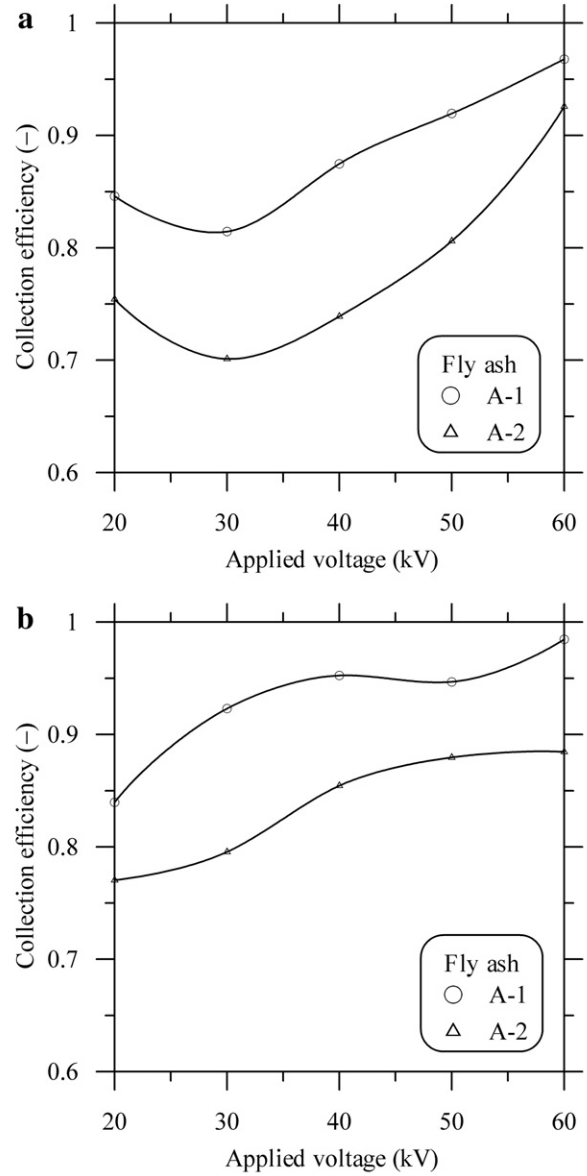

Fig. 5. Collection efficiency as a function of supply voltage of: (a) RDE-1 electrode, (b) RDE-2 electrode; at gas velocity 0.8 m/s.

3.2. Studies on fractional collection efficiency

In order to estimate the influence of discharge current density on fine particle precipitation it was necessary to determine the fractional collection efficiency. For this purpose, fly ash samples were collected from the inlet and outlet of an ESP, and the particle size distribution was measured with Malvern analyzer. From these measurements, the fractional collection efficiency was calculated using the following equation:

$$\eta_f = \frac{q_{3inlet} - (1 - \eta_C) \cdot q_{3outlet}}{q_3} \quad (2)$$

where: q_{3inlet} – number of particles in a given size interval at the ESP inlet, (–)

$q_{3outlet}$ – number of particles in a given size interval at the ESP outlet, (–).

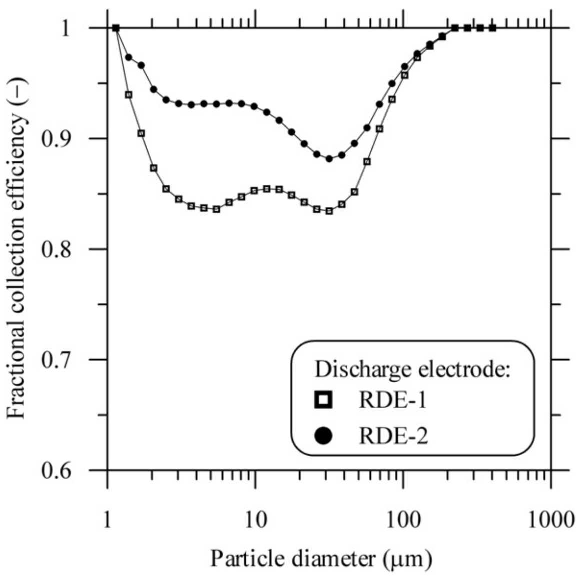

Fig. 6. Fractional collection efficiency of A-1 fly-ash sample at 50 kV supply voltage.

Selected results of these measurements are presented on Fig. 6.

There has been observed a minimal collecting efficiency of particles of diameter in a range of 3–30 μm. Usually, the minimum collection efficiency, described in technical literature, is in a range from 0.2 to 0.5 μm [14] that is explained by more difficult charging process of particles in this size range. In that case of polydisperse fly ash, the collection efficiency may be influenced by many other fly ash properties, such as the particle shape, its chemical composition and others. The size distribution of particle at ESP outlet has been clearly shifted toward finer sizes ($d_{50} = 80$ μm at the inlet and $d_{50} = 30–35$ μm at the outlet).

In order to compare operational parameters of tested discharge electrode constructions on Fig. 7 have been shown the ratio of percentage of particles at the outlet of ESP to the percentage at the inlet, in given size ranges. The obtained results indicate that the RDE-2 electrode is more effective also in the collecting of fine particles.

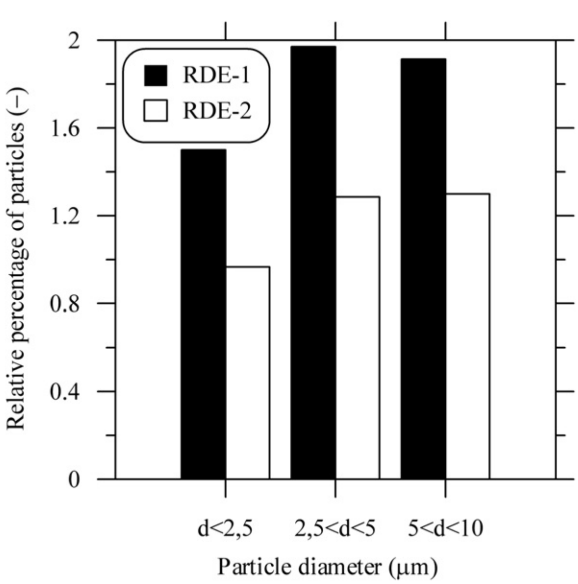

Fig. 7. Comparison of A-1 fly-ash sample relative percentage in selected ranges of particle diameter at ESP outlet, at 50 kV supply voltage.

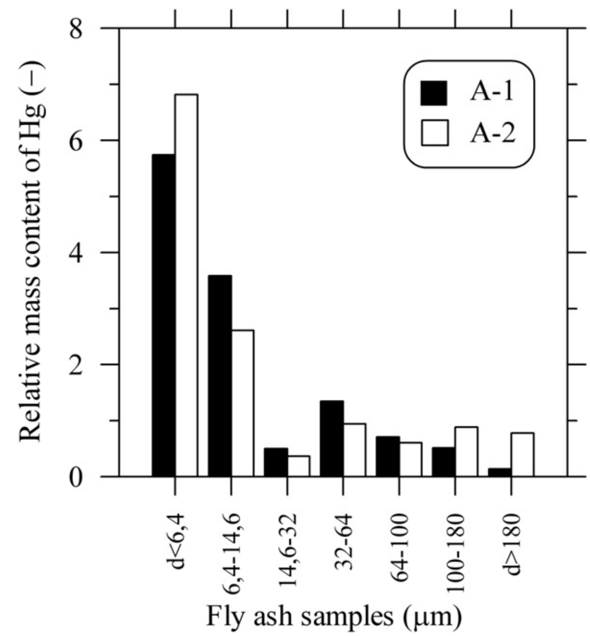

Fig. 8. Results of mercury content measurements in fly ash samples A-1 and A-2; percentage content related to sample content (non separated).

3.3. The studies of mercury contents

It is generally known that coal combustion increases emission of mercury into the atmosphere. A technical literature indicates [15,16] that submicron particles contain a relatively large percentage of mercury. In order to determine the mercury content in respective particle size fractions of fly ashes A-1 and A-2, there were carried out measurements of mercury contents using selective ASA method with enrichment by amalgamation. The results are presented on Fig. 8.

On the base of parameters presented in Fig. 8 it can be noticed that the relative mass content of mercury increases in the fine fractions range (below 14.6 μm), and below 6.4 μm it is the highest. It may be expected that an increase of the collection efficiency in this size fractions will result in decreasing the emission of mercury into the atmosphere.

4. Summary

In this work we have presented the results of studies aimed at confirming that properly chosen discharge electrode construction for a specific fly ash may increase the collection efficiency of fine particles. The results of these studies obtained for industrial fly ashes are promising and show that an increase in the uniformity of the discharge current distribution may positively influence also the fine particle collection efficiency of ESP. The fractional collection efficiencies may sometime differ from those described in technical literature but this may be a result of polydispersity of industrial fly ashes used in the experiments.

Laboratory measurements also indicate that in order to obtain a high collection efficiency of fine particles it is important that the current–voltage characteristics are steep and the discharge current is uniformly distributed over the collection electrode. It may be assumed that fine particles are mainly collected in regions of high and uniformly distributed discharge current.

Taking into account that high efficient collection of fine particles in ESP is an important issue, further work will be directed toward optimization of electrode geometry: discharge electrodes as well as collecting electrodes for fly ash with different chemical and physical parameters. Although the mass percentage of fine particles in fly ash is very small, its negative influence on human health is very serious, especially because of increased mercury content in the fine particle range.

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