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# EHD flow in a wide electrode spacing spike–plate electrostatic precipitator under positive polarity

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**Abstract**

In this work, results of two- and three-dimensional particle image velocimetry (PIV) measurements of the flow velocity fields in a wide spacing spike–plate electrostatic precipitator (ESP) under positive polarity are presented. A DC voltage of positive polarity (up to 28 kV) was applied to the spike electrode. The average gas flow velocity was 0.6 m/s. The PIV measurements were carried out in four planes perpendicular to the plate electrodes. Three parallel planes passed along the ESP while one plane passed across the ESP duct. The results show that electrohydrodynamic (EHD) secondary flow with relatively strong vortices exist in the ESP. The EHD secondary flow pattern depends on applied voltage and measuring plane position in respect to the spike tip. The strongest vortices occur in the plane passing through the tip of the upstream-directed spike. These relatively strong EHD vortices may hinder collection of the particles in the diameter range of 0.1–1 μm in the wide electrode spacing spike–plate ESPs.

*Keywords:* Electrostatic precipitator; EHD flow; PIV measurements

## 1. Introduction

Electrostatic precipitators (ESPs) are being widely used as dust particle collectors due to their high total particle collection efficiency (99.9%) with a low-pressure drop. However, the collection efficiency of particles of submicron size is relatively low [1].

An ESP modeling and measurements performed downstream of full-scale ESPs show that the dust particle collection efficiency depends on the gas flow velocity, applied voltage, particle physical parameters, electrode geometry and on the EHD secondary flow [2–4]. The most difficult to collect are particles in diameter range of 0.1–1 μm, with a maximum for particles having a diameter of about 0.5 μm.

The influence of the EHD secondary flow on the collection efficiency has been debated for decades. The results of the modelling of particle collection efficiency [2] suggest that the particle collection could be significantly improved if the EHD secondary flow were eliminated. Consequently, improvements in the geometry and operating conditions in ESPs should be performed to reduce the EHD secondary flow in them.

One of the proposals for eliminating the EHD secondary flow in ESPs is the use of a spike discharge electrode. However, there is a lack of information on the EHD secondary flow in the ESPs with such an electrode arrangement.

Recently, the particle image velocimetry (PIV) technique has become a powerful tool for measuring the flow patterns in ESPs. In [5,6] the PIV measurements were focused on the existence of EHD secondary flow in wide electrode spacing ESPs under positive polarity, which, according to the modelling presented by Kogelschatz et al. [2], influences the collection efficiency of submicron particles. The relatively wider spacing ESP operation was chosen since such an ESP can be applied to the collection of high resistivity dust particles [1]. The ESP operation under positive polarity was used because of the relatively low ozone generations and the potential for the reduction of $NO_x$ and $SO_x$.

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In this work, results of two- and three-dimensional PIV measurements of the flow velocity fields in a positively polarized wide spacing spike–plate ESP are presented. The measurements were focused on existence of the EHD secondary flow.

The PIV measurements were carried out in four planes placed perpendicularly to the plate electrodes. Three different parallel planes passed along the ESP by the upstream- and downstream-directed spike tips, as well as in-between them. This allowed us to study the influence of the spike on the velocity field in the ESP. The fourth measuring plane passed across the ESP duct. In this case three-dimensional PIV measurements were carried out.

## 2. Experiment

The apparatus used in this experiment consisted of an ESP, high voltage supply and standard PIV equipment for the measurement of velocity fields (as presented by Mizeraczyk et al. [5,6]).

The ESP was a plane-parallel acrylic duct, 1000 mm long, 200 mm wide and 100 mm high. At the top and bottom of the duct two collecting stainless-steel plate electrodes (200 mm × 600 mm) were placed. In the middle of the ESP the spike electrode (200 mm long, 1 mm thick, and 30 mm tip-to-tip wide) was mounted in the acrylic sidewalls, parallel to the plate electrodes (Fig. 1). The spike tips were directed upstream on the one side of the electrode, and downstream on the other. The distance from the spike electrode to the plate electrodes was 50 mm.

The positive voltage applied to the spike electrode was up to 28 kV, the discharge current was up to 210 μA. The voltage was supplied to the spike electrode through a 10 MΩ resistor.

Air flow seeded with fine $TiO_2$ particles (size of less than 1 μm) was blown along the ESP duct with an average velocity of 0.6 m/s.

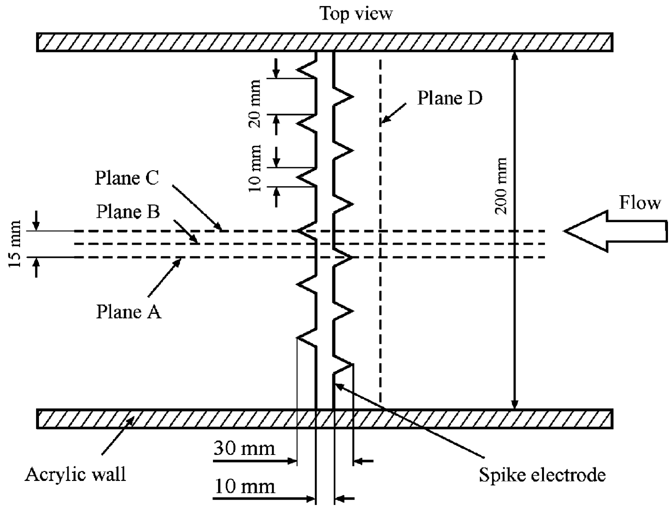

Fig. 1. Top-view schematic drawing of the spike–plate ESP.

The PIV measurements were carried out in four planes—A, B, C and D, all placed perpendicularly to the plate electrodes (Fig. 1). Three planes were fixed along the ESP duct. The first of them (plane A) passed through the tip of the upstream-directed central spike electrode, the second plane (plane B) passed in-between the upstream and downstream spikes, while the third plane (plane C) passed through the tip of the neighbouring downstream-directed spike electrode. The fourth plane (plane D) was placed across the ESP duct, 15 mm before the upstream-directed spike tips.

The flow velocity field maps [area of 260 mm × 100 mm] obtained in planes A, B and C were composed of three adjacent overlapping velocity fields [area of each 100 mm × 100 mm]. All the velocity fields resulted from the averaging of 100 measurements, which means that each velocity map was time-averaged. Based on the measured velocity fields, the apparent flow streamlines of a hypothetical two-dimensional flow were calculated and presented in this paper.

## 3. Results

Figs. 2–5 show the flow streamlines in the spike–plate ESP at a primary flow average velocity of 0.6 m/s. At this velocity the Reynolds number was $Re = V \times L/\nu = 4000$ (the parameters used to calculate $Re$ were: the primary flow velocity $V = 0.6\,\mathrm{m/s}$, characteristic length (plate–plate distance) $L = 0.1\,\mathrm{m}$, and air dynamic viscosity $\nu = 15 \times 10^{-6}\,\mathrm{m^2/s}$).

The flow streamlines in the plane A (without voltage) are shown in Fig. 2. As can be seen, the flow is uniform in the whole measured area with a slight disturbance near the spike electrode. Very similar results were obtained in planes B and C.

When the applied voltage exceeded corona onset (about 11 kV) the flow pattern changed significantly, depending on applied voltage. Figs. 3–5 show the flow streamlines in the planes A, B and C, respectively, for three selected voltages: 15.6, 23.8 and 27.9 kV. The total discharge current was 40, 120 and 210 μA, respectively. Thus the electrohydrodynamic numbers [$\mathrm{Ehd} = I \times L^3/(\nu^2 \times \rho \times \mu_i \times A)$] [7], based on the flow channel data, were $1.26 \times 10^7$, $3.78 \times 10^7$ and $6.61 \times 10^7$, respectively. Hence, the ratios of the Ehd number to the Reynolds number squared ($\mathrm{Ehd}/Re^2$) were: 0.8 (for 15.6 kV—Figs. 3a, 4a and 5a), 2.4 (for 23.8 kV—Figs. 3b, 4b and 5b) and 4.2 (for 27.9 kV—Figs. 3c, 4c and 5c). The parameters used to calculate Ehd were: the total discharge current $I$, characteristic length (plate–plate distance) $L = 0.1\,\mathrm{m}$, air dynamic viscosity $\nu = 15 \times 10^{-6}\,\mathrm{m^2/s}$, air density $\rho = 1.205\,\mathrm{kg/m^3}$, ion mobility ($N_2^+$ in air) $\mu_i = 2.93 \times 10^{-4}\,\mathrm{m^2/Vs}$, and discharge area (100 mm long and 200 mm wide discharge area on the two plate electrodes) $A = 2 \times 100\,\mathrm{mm} \times 200\,\mathrm{mm} = 0.04\,\mathrm{m^2}$. The uniform current distribution on the plate electrodes was assumed. This assumption was justified by the optical emission intensity measurements of the discharge from the