

## Measurements of EHD Flow Patterns in ESP with DC+Pulsed Voltage Hybrid Power Supply

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**Abstract.** Results of Particle Image Velocimetry (PIV) measurements in an electrostatic precipitator (ESP) supplied with high voltage pulses superimposed on DC voltage are presented in this paper. The ESP had a stainless-steel wire discharge electrode placed between two grounded, stainless-steel plate collecting electrodes. The DC high voltage (0-20 kV) with superimposed voltage pulses (0-30 kV), either positive or negative polarity, was applied to the wire electrode. We found no effect of the applied voltage pulses upon the flow patterns when there was no DC voltage. However, when the high voltage pulses were superimposed on DC high voltage, the flow patterns were affected significantly.

### 1. Introduction

For several decades electrostatic precipitators (ESPs) have been widely used as dust particle collectors. They are characterized by high total particle collection efficiency (up to 99.9%) with a low pressure drop. However, there has long been an interest in improving ESPs functioning and collection efficiency (especially of submicron particles which are weakly precipitated) [1-5]. One of the proposal to improve ESP functioning is to use a new kind of power supply with combined DC and pulsed voltage.

The aim of this investigation was to study the influence of the combined DC and pulsed voltage on particle flow patterns in the ESP. The Particle Image Velocimetry (PIV) method [6] was used.

### 2. Experimental apparatus

The apparatus used in this experiment (Fig. 1) consisted of an ESP, a high-voltage supply, and standard PIV equipment for the measurement of velocity fields.

The ESP had a single stainless-steel wire discharge electrode (diameter 1 mm, length 200 mm) placed in the middle of the ESP between two grounded, stainless-steel plate electrodes (200 mm wide and 600 mm long). The plate-to-plate electrode spacing was 100 mm. A flow homogenizer was placed before the ESP inlet.

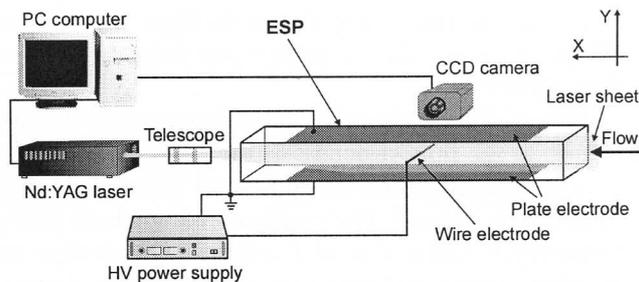


Figure 1. Schematic of experimental set-up.

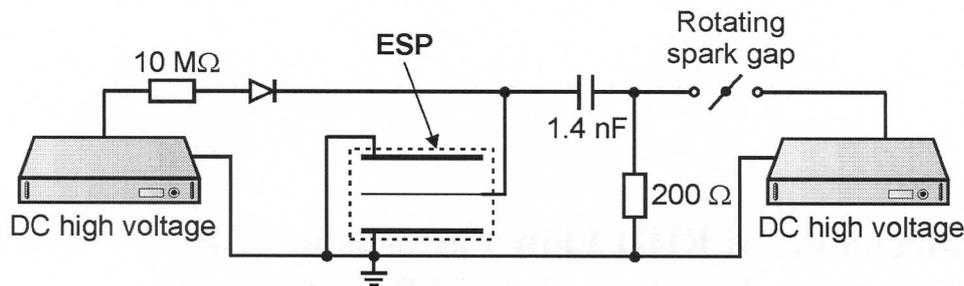


Figure 2. DC plus pulse high voltage supply system.

In the presented experiment a power supply system consisting of a DC source and a pulsed voltage supply was used (Fig. 2). The DC high voltage (0-20 kV) with superimposed voltage pulses (0–30 kV), either positive or negative polarity, was applied to the wire electrode. The DC voltage was applied through a high voltage diode. The diode separated the DC power supply from the pulsed power supply. The voltage pulses were applied through a capacitor, which separated the pulsed power supply from the DC power supply. The voltage pulses were produced using a rotating spark gap connected to another DC power supply. The pulse repetition frequency (PRF) was 48 Hz. The voltage pulse duration was 800 ns. The PRF was determined by the angular velocity of the rotating element in the spark gap.

Air flow seeded with a cigarette smoke (particles size less than 1  $\mu\text{m}$  in dry air) was blown along the reactor duct with an average velocity of 0.4 m/s.

The standard PIV equipment consisted of a twin second harmonic Nd-YAG laser system ( $\lambda = 532 \text{ nm}$ ), imaging optics (cylindrical telescope), CCD camera and PC computer. The laser sheet of thickness of 1 mm, formed from the Nd-YAG laser beam by the cylindrical telescope was introduced into the ESP to form an observation plane. The images of the particles in the laser sheet were recorded by FlowSense M2 camera. The CCD camera active element size was 1186 $\times$ 1600 pixels. The captured images were transmitted to the PC computer for digital analysis.

The PIV measurements were carried out in a plane placed along the ESP, perpendicularly to the wire electrode at its half-length. The observation area (the area of the laser sheet “seen” by the CCD camera) covered a region between the plate electrodes from 15 mm before the wire electrode (in respect to the main flow direction) to 205 mm behind the wire electrode.

All the velocity fields presented in this paper resulted from the averaging of 150 measurements, which means that each velocity map was time-averaged.

### 3. Results

The 2D PIV measurements were carried out for the DC high voltage (0 kV, 10 kV and 20 kV) with superimposed voltage pulses (0 kV, 10 kV, 20 kV and 30 kV), for both positive and negative voltage polarity. Due to the limited size of this paper only selected results are presented.

Instantaneous images of the flow structures and flow velocity fields measured under different discharge conditions are shown in Figs. 3 and 4, respectively. The lack of influence of the pulsed discharge on the flow structure and velocity field when no DC voltage was applied can be seen in Figs. 3a and 4a.

When DC voltage of 10 kV without pulses was applied, for negative (Fig. 3b) and positive voltage polarities, the flow structure was the fine dark line originated from the wire electrode. For the negative polarity the influence of additional pulse discharge is clearly visible (Fig. 3c). The characteristic eddies were formed. Each eddy corresponds to a single high voltage pulse. The distance between the consecutive eddies results from the high voltage pulse frequency and main flow velocity. For the positive voltage polarity (not shown in this paper) the influence of high voltage pulses was also visible, however flow structure was more chaotic and the influence of pulse frequency is not so clear.

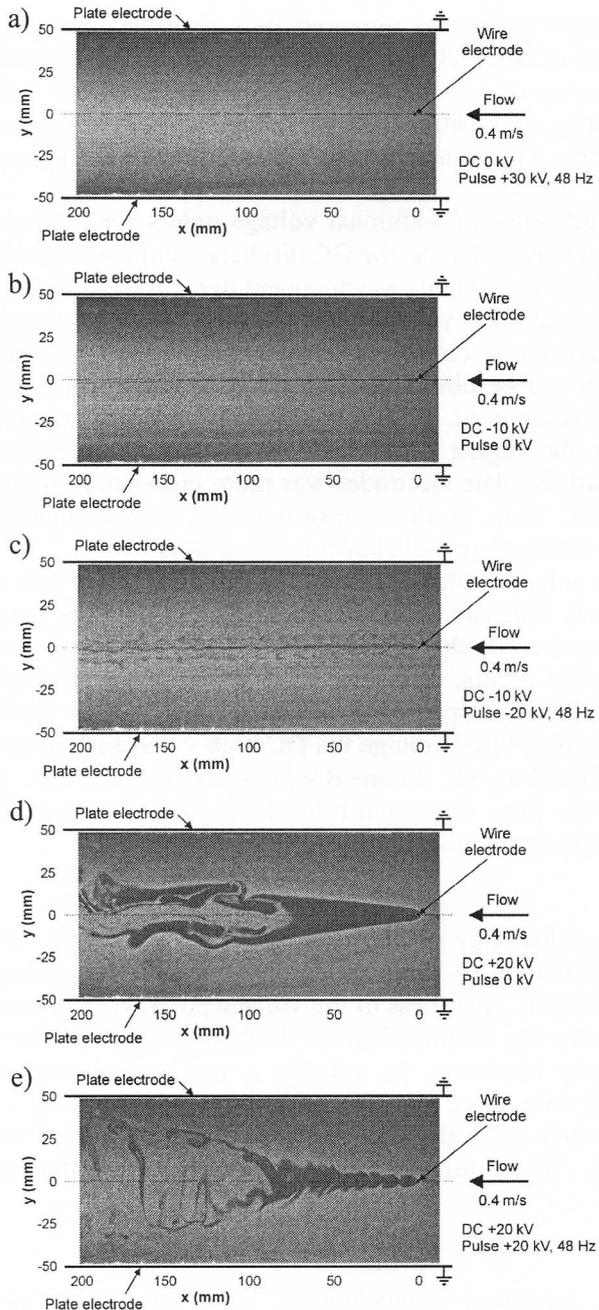


Figure 3. Instantaneous images of the flow in the ESP.

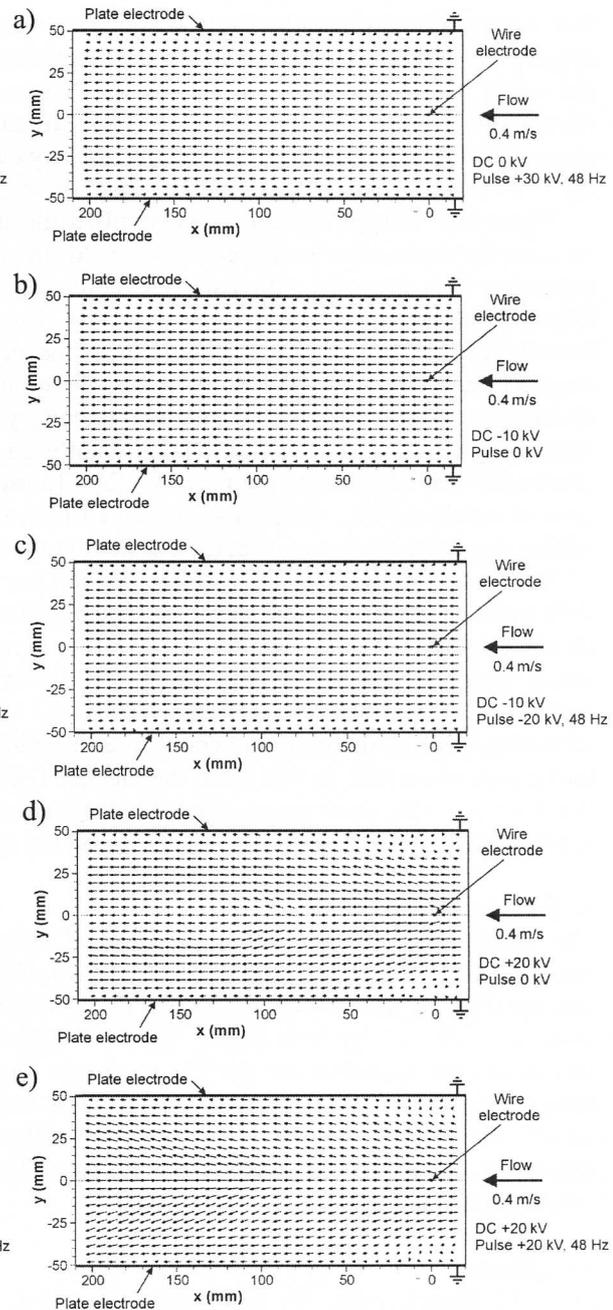


Figure 4. Flow velocity fields in the ESP.

Flow velocity fields for the negative polarity of the DC voltage of 10 kV and pulses of 0 kV and 20 kV are presented in Figs. 4b and c. The velocity behind the wire electrode slightly decreased and the disturbance of the flow slightly increased when amplitude of the pulse voltage increased. For the positive voltage polarity (not shown in this paper) the similar behavior as for the negative polarity was observed.

Increasing the DC high voltage (to 20 kV) results in building of stronger flow structures. For the negative voltage polarity the flow structure was rather turbulent and unstable. The additional high voltage pulses dispersed the flow structure, spreading toward the collecting electrodes (not shown in

this paper). For the positive voltage polarity without pulses the observed flow structure was quite regular dark region (cleared from the dust particles) of width 20 mm from  $x = 80$  mm. At  $x = 200$  mm the width of the structure was still about 20 mm, however some dust particles penetrated the dark region due to the mixing (Fig. 3d). The influence of additional high voltage pulses was more pronounced than in the negative voltage polarity case. The regular structure was torn apart and spread up to whole channel width at  $x = 200$  mm (Fig. 3e).

When DC voltage of 20 kV was applied the influence of additional voltage pulses for the flow velocity field was even more pronounced. At the positive polarity, the DC discharge alone resulted in forming a flow structure with a significant decrease of the velocity x-component in the region 50 mm-200 mm behind the wire electrode (Fig. 4d). The additional voltage pulses dispersed this structure. Simultaneously, the significant increase in the velocity x-component from 80 mm behind the wire electrode and further in the downstream direction can be observed. The effect of additional pulse discharge is also clearly visible for the velocity y-component. With the increasing pulse voltage the velocity y-component increased significantly in the region of 80 mm-200 mm behind the wire electrode. This means that the particles flow toward the plate electrodes was more pronounced in the case of combined DC with pulse discharge than DC alone. In the case of negative voltage polarity, adding the pulse discharge affected the flow in the similar way (not shown in this paper).

We found that with no DC voltage applied the pulsed discharge having PRF in a Hz range with a duty cycle of about 1/26000 hardly affects the flow. This can be explained by the fact that the short discharge pulses can produce the ions and, in consequence, charge the dust particles, but the electric force, which is generated only when the discharge occurs, lasts too short to cause an effective secondary electrohydrodynamic (EHD) flow, which is capable of affecting the primary flow. However, a different situation occurs when besides the pulsed voltage the DC high voltage is applied to the wire electrode. In this case, the electric field and the DC corona discharge exist all the time in the ESP. An additional space charge and the electric force originated from the pulsed discharge can enhance the influence of the DC discharge on the flow in the ESP significantly.

#### 4. Conclusions

The influence of the superimposed DC and pulse discharge on the flow patterns in the ESP was investigated. It was found that at relatively low DC voltage (0-10 kV) additional pulse discharge does not significantly affect the flow velocity field in the ESP, regardless of the voltage polarity. However, when the DC voltage was higher (20 kV), applying the additional pulse discharge results in more turbulent flow than that for the DC discharge alone. Moreover, the velocity x- and y-component(s) increase in a region 80 mm-200 mm behind the wire electrode. The increase in the velocity y-component can improve the dust collection efficiency since the dust particle movement toward the collecting electrodes becomes more pronounced. To confirm better collection efficiency further investigations are needed.

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