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Effect of relative humidity on current–voltage characteristics of an electrostatic precipitator

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A B S T R A C T

This paper aims at characterizing the behavior of dc corona discharge in wire-to-plane electrostatic precipitators (ESPs) as influenced by the relative humidity (RH) of the inlet air. The current–voltage characteristics and time evolution of the current are analyzed. Experimental results show that discharge current is strongly affected by the RH level of the inlet air. For instance, the time-averaged current is lower at higher RH for a given voltage, except when RH = 99%. Time evolution of the discharge current is affected by the humidity especially in the case of negative corona.

1. Introduction

Corona discharge, as applied to Electrostatic Precipitators (ESPs), is a gas discharge phenomenon associated with the ionization of gas molecules by high-energy electrons in a region of high intensity electric field. The process of corona generation in the air at atmospheric conditions requires a non uniform electrical field, which can be obtained by the use of a small diameter wire electrode, energized from a high-voltage supply, and a metallic plate or cylinder, connected to the ground, which is designated as collecting electrode. Industrial ESPs are used with success to reduce the emissions of smoke, fumes and dust, playing an important role to maintain a clean environment and to improve the air quality [1–4]. In terms of mass/volume, the penetration of particles through an industrial ESP can be lower that 1% [2]. In practice, in all these systems particles are charged by means of the ions produced by a DC corona discharge. The electrically charged particles are then driven by the electric field forces towards the collecting electrodes. Their migration is also influenced by the viscous forces associated to the fluid flow and the ionic wind [5–8]. The wet ESP operates on the same principles as the dry ESP; the major difference is that the charged particles are removed from the collecting electrodes by a flushing liquid (usually water), instead of mechanical rapping [9]. Wet ESPs are the solution of choice in the case of humid gases, submicron particles, as well as for controlling the emission of sticky or low electrical resistivity particles [10].

In such systems, the knowledge of the inlet air relative humidity (RH) effect on DC corona discharge behavior is of crucial importance. Some aspects of this effect require further investigations in order to validate a realistic mathematical model of the physical phenomena, as an essential step towards the accurate numerical simulation of the electrostatic precipitation process. The main objective of this investigation is to analyze the effect of the inlet air RH, which can vary from 10% up to saturated conditions, on both positive and negative DC corona discharges employed in wire-to-plane ESPs. In particular, the current–voltage characteristics and time evolution of current are analyzed and discussed.

2. Experimental setup

The schematic representations of the wire-to-plane ESPs used in this investigation are shown in Fig. 1. The collecting electrodes of these ESPs consist of two parallel stainless steel plates, 200 mm-length and 100 mm-width in *x*-direction and *z*-direction, respectively. These two-grounded electrodes are distanced at 100 mm from each other. The high voltage electrodes consist of stainless steel wires (0.2 mm-diameter) parallel to *z*-axis midway between the grounded electrodes. In the first ESP (called 1W-ESP, Fig. 1a), only one wire is connected to the high voltage. The second configuration (called 3W-ESP, Fig. 1b) uses 3 similar wires to create

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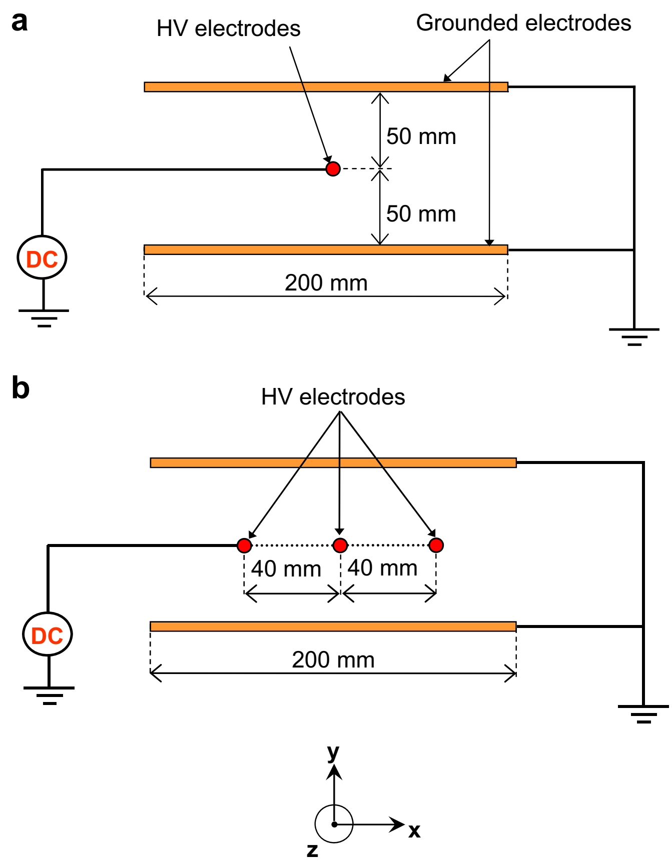

Fig. 1. Laboratory ESP configurations: (a) 1W-ESP, and (b) 3W-ESP.

the corona discharges. The distance between two successive wires is set at 40 mm.

In this study both positive and negative DC high voltage polarities are used. The DC high voltage is provided with an accuracy of 0.1 kV by a reversible power supply (SPELLMAN SL 150, ±40 kV; ±3.75 mA), which is protected by a ballast resistor of 10 kΩ. The time-averaged current is measured through a digital multimeter (METERMAN 37 XR, accuracy ≈1 μA). The time evolution of the discharge current is monitored using a shunt resistor of 100 Ω and a digital oscilloscope (Lecroy 424, 200 MHz, 2 GS/s).

As shown in Fig. 2, the experiments are carried out inside a closed cylindrical vessel (glass, 500 mm-high, and 250 mm-diameter) filled with clean air. Since the effect of temperature and pressure on the electrical behavior of a corona discharge has been examined extensively in the literature, the effect of the relative humidity of the inlet air (0 < RH < 100%) is the only parameter taking into account in this work. During each experiment, the temperature (T) and the pressure (P) inside the test chamber are controlled ($T = 22 \pm 1$ °C, $P = 1 \times 10^5 \pm 7 \times 10^2$ Pa).

The relative humidity of the ambient air varies between 45 and 70%. It was reduced by introducing a dry clean air (RH < 5%) coming from a compressed air network system, or increased by adding water vapor resulting from heated water after a period of relaxation in a container (during 15 min). The RH of the air inside the test chamber is monitored with a dedicated sensor (Hygrometer SR-1364, accuracy ≈ 3%).

Each current–voltage characteristic represents the average of five series of measurements. Between any two measurements, the gas is entirely renewed and the electrode surfaces are cleaned.

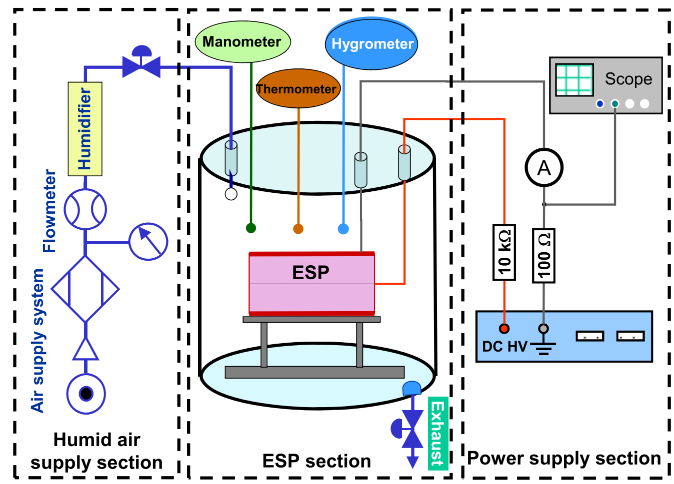

Fig. 2. Experimental setup.

3. Results and discussion

In the following sections, the effect of air RH on the current–voltage characteristics of the two electrode configurations is discussed.

3.1. Current–voltage characteristics

Fig. 3 shows the current–voltage characteristics in the case of 1W-ESP and 3W-ESP for both high voltage polarities. The right side scale indicates to the current density at the collecting electrodes.

The discharge behavior is similar in both ESPs. The discharge current increases with the applied voltage when it exceeds the corona onset voltage until gas breakdown. At a given voltage, the discharge current is higher with the negative polarity, which is explained by the difference between the apparent mobility of negative charge carriers compared to positive ones [11] and [12].

Whatever the polarity, the discharge current increases with the number of HV electrodes for a given voltage. However, the corona current generated by three wires is lower than three times the value measured with one wire ($I_{1\ wire} < I_{3\ wires} < 3 \times I_{1\ wire}$). This is due to the electric field interaction between two successive high voltage wires. In fact, the distance between the wires is lower than the interelectrode gap.

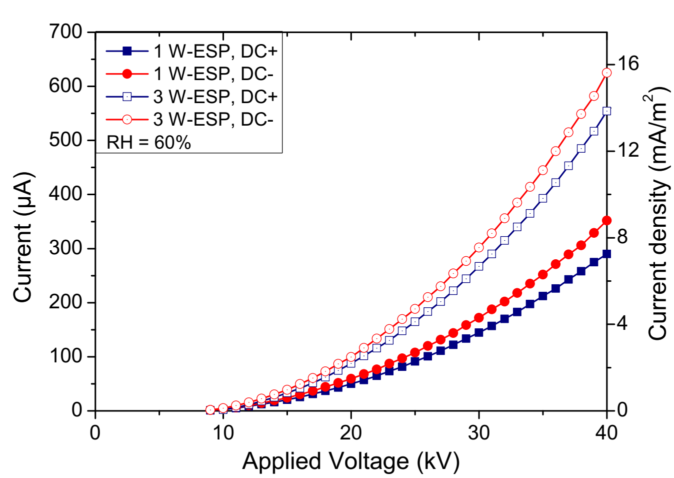

Fig. 3. Current-voltage characteristics of 1W-ESP and 3W-ESP for RH = 60%.