Effect of the Discretization of the Active Electrode of Wire to Cylinder ESP on the Collection Efficiency of Submicron Particles for Different Particle Sizes

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***Abstract*— The main purpose of this paper is to analyze the effect of longitudinal distribution of DC corona discharges of both polarities on the collection efficiency of submicron particles in electrostatic precipitators (ESPs). Two models of wire-to-cylinder ESP have been used to collect particles within the range of 0.1 µm to 1 µm. The "continuous-ESP" model has a conventional wire-to-cylinder electrode configuration. The "discrete-ESP" is similar to the continuous-ESP, but the corona wire is partly covered with PVC sheaths.**

Electrical measurements show that the current-voltage characteristics are similar for the two ESP models, whatever the polarity of the applied voltage. As expected, the current magnitude is higher in the case of the continuous-ESP, for given conditions. Results obtained with the aerosol spectrometer show that the particle collection efficiency increases with the size of the particles in the size range 0.2-0.5 µm and is higher at high applied voltage in both models. However, we notice that the total collection efficiency is higher with the negative voltage in the case of the continuous-ESP and that the performances of discrete-ESP seem to be less influenced by the polarity, especially at high flow rates.

***Index Terms*—aerosol spectrometer, collection efficiency, electrostatic precipitator**

I. Introduction

For several decades electrostatic precipitators (ESPs) have been widely used as dust-particle collectors [1-2]. They are characterized by high total particle collection efficiency (up to 99.9%) [3]. However, there is still a problem with collection efficiency of submicron particles [4-5]. Collecting of fine particles is of crucial importance, because many of them, in the size range 0.1–1 µm have a detrimental effect on both human and animal health [6]. The fine particles may contain hazardous trace elements such as lead, mercury, arsenic, zinc, biological agents and others. Therefore, there has long been an interest in improving the ESP collection of submicron particles. The motion and precipitation of particles in the duct of an electrostatic precipitator (ESP) depend on the dust-particle properties, electric field, space charge and gas-flow.

In the case of wire-to-cylinder ESP, the negative dc corona generates discrete active spots called "tufts" along the corona wire, while the positive dc corona gives a uniform bright sheath around the wire [7-8]. This is assumed to indicate a difference in the relative spatial distribution of positive or negative dc coronas [9]. Thus, the interaction between the primary flow and the secondary flow (ionic wind) is quite strong in negative corona, because of the small local vortices along the wire [10].

The aim of this study is the investigation of the effect of the longitudinal distribution of DC corona discharge on the ability to reduce the quantity of submicron particles within the range of 0.1 µm to 1 µm. Two different ESPs are used. A wire-to-cylinder ESP (C-ESP, or continuous-ESP) is compared with wire-sheath-cylinder ESP (D-ESP, or discrete-ESP). The configuration D-ESP models well the effect of electrode contamination due to the deposition of insulating particles on the surface of the corona wire.

The submicron particles, with a mean size of about 0.3 µm, are generated by incense burning and introduced into the ESP in order to examine their collection efficiency. The concentration of particles at the ESP output is measured with an aerosol spectrometer at various operating conditions and the collection efficiency is calculated. In the first part of the paper, the experimental setup is described. Then, the effect of flow rate and particle presence on the current-voltage characteristic is outlined. The influence of applied voltage and flow rate on the collection efficiency of D-ESP and C-ESP is then documented and discussed. Finally, the collection efficiency of the two ESP models is assessed for different particle sizes.

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II. EXPERIMENTAL SETUP

The experimental setup, illustrated schematically in Figure 1, consists of a particle supply section, an ESP section, a particle detection section, and a high-voltage power supply. Dry clean air (relative humidity < 5%) is introduced into a custom-designed smoke generator, where the burning of incense sticks generates submicron particles. Then, the particles are entrained by the airflow through the ESP. A small amount of the exhaust is connected to a diluter with a controlled additional clean air. The particle concentration in the diluted sample is measured using an aerosol spectrometer (Pallas Aerosol Technology, Model Wellas-1000, sensor range of 0.18-40 µm, concentration up to 10^5 particles / cm^3).

The cross-sections of the two ESPs are shown on figure 2. They are made of stainless steel wire of 0.45 mm in diameter and a copper tube of 200 mm length and 38 mm inner diameter. The wire electrode of the discrete-ESP is covered with 10 PVC sheaths, each one 20 mm in length and 1 mm in diameter. The distance between two successive sheaths is 2 mm.

The power supply system consists of a DC high voltage (SPELLMAN SSL 150, ± 40 kV; ± 3,75 mA) with a resolution of 0.1 kV. The generator is protected by a resistance of 10 kΩ. The current is measured using a digital multimeter (METERMAN 37 XR, resolution: 1 µA).

All the experiments are carried out at atmospheric pressure and room temperature with controlled air flow rate.

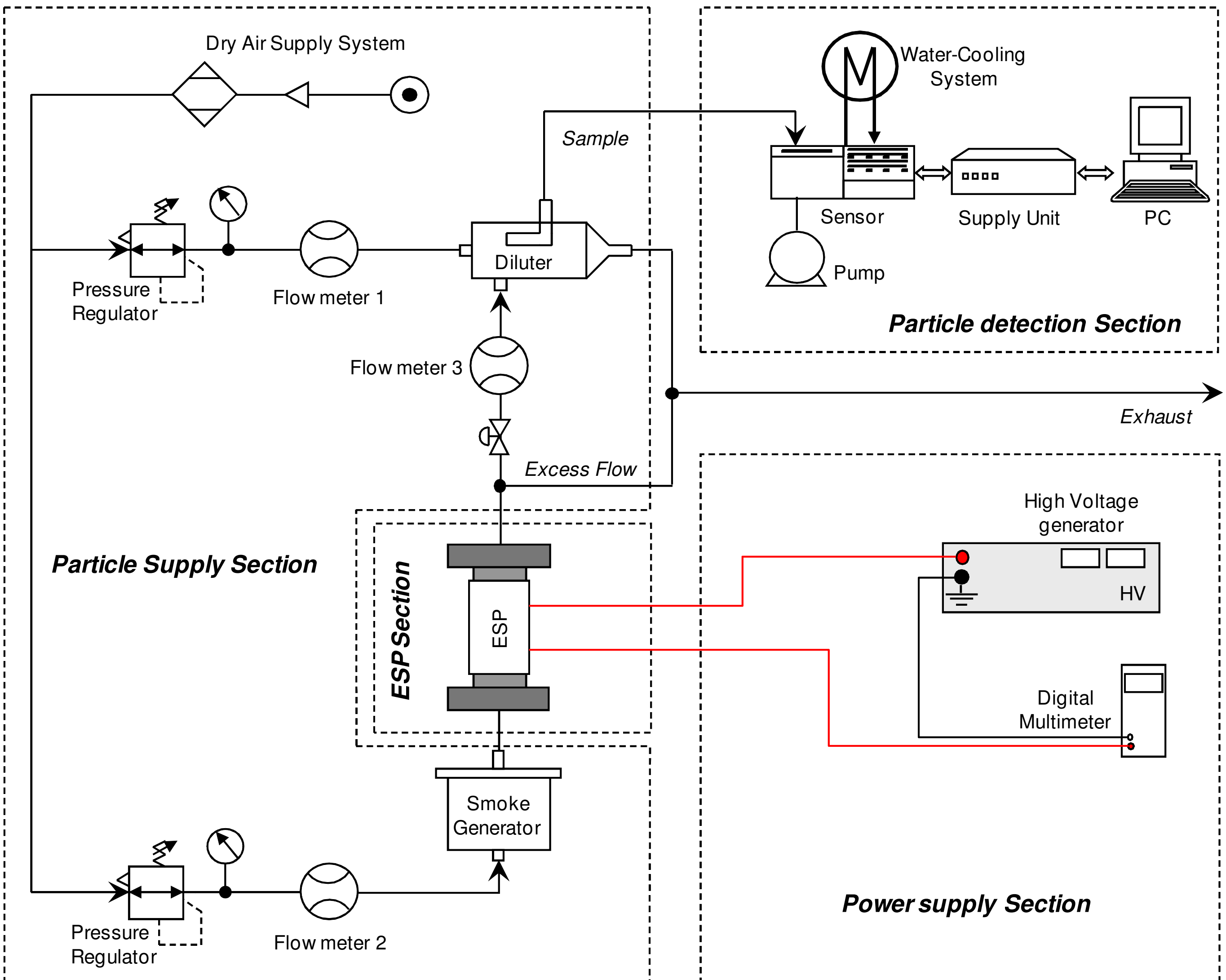


Figure 1. Schematic illustration of the experimental setup.

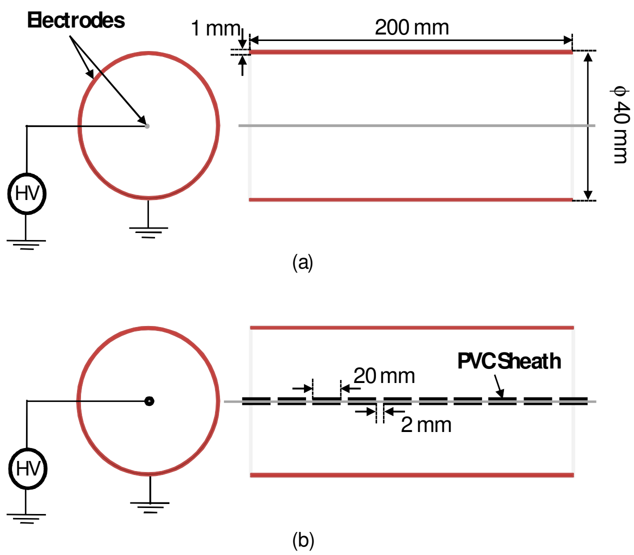


Figure 2. Cross view of the continuous (a) and discrete (b) ESPs.

III. ELECTRICAL CHARACTERIZATION

A. Effect of flow rate on the current-voltage characteristics

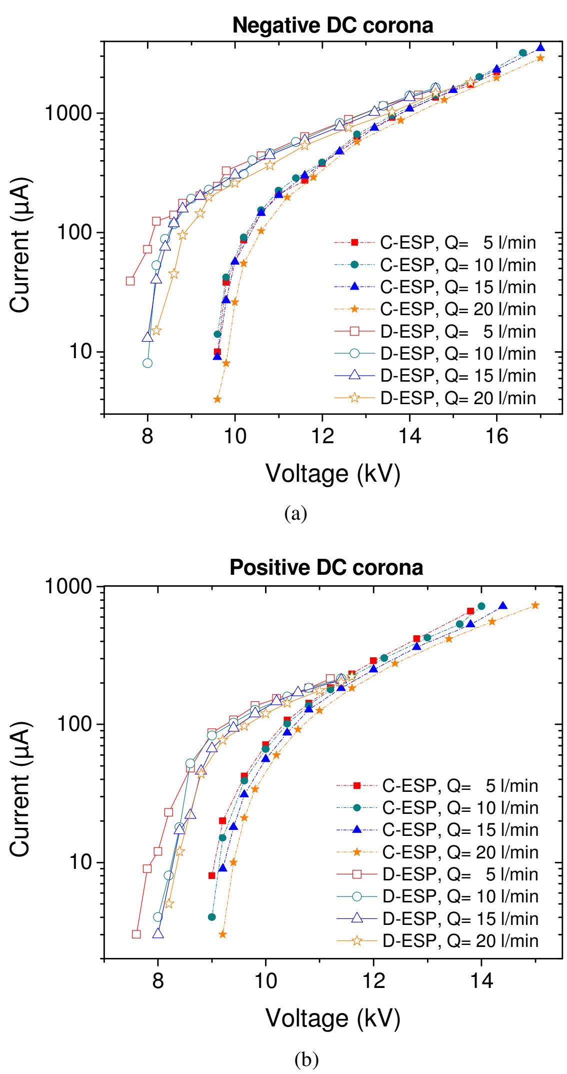


Figure 3. Influence of air flow rate on the current-voltage characteristics for negative (a) and positive (b) DC corona for both ESPs.

Figure 3 shows the effect of the flow rate on the current-voltage characteristics in negative and positive DC corona. The higher the flow rate, the lower is the current magnitude for both ESPs. However, this tendency is more significant with the D-ESP than with the C-ESP, and at the positive polarity than at the negative one. During the discharge, it seems that some charge carriers are transported outside the active section because of the flow rate [10-12]. Also, in the D-ESP, the ability to inject charges in the gap is reduced because of the PVC sheaths which act as a dielectric barrier.

B. Effect of particles on current-voltage characteristics

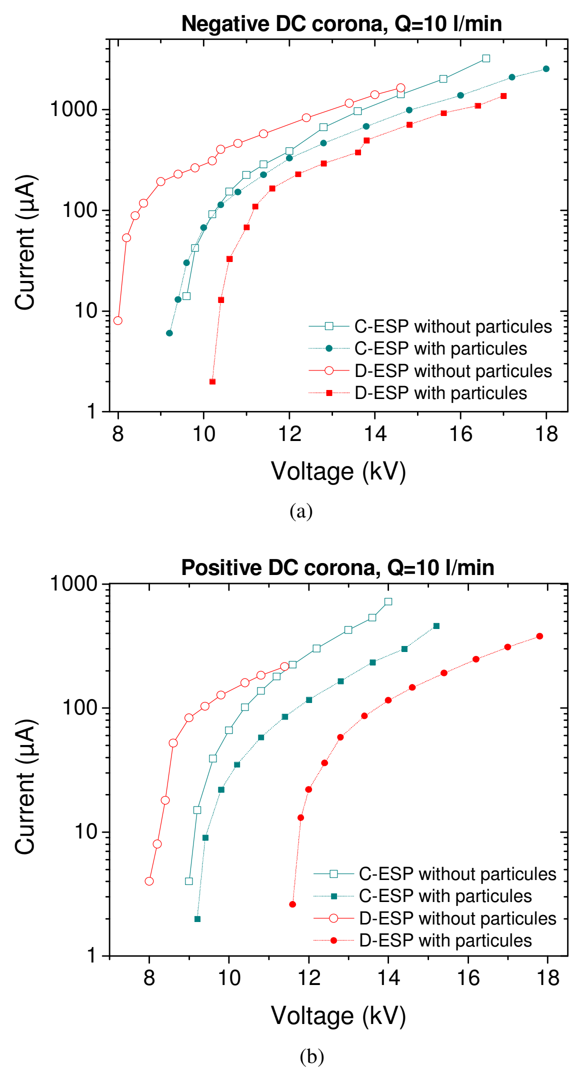


Figure 4. Influence of particle presence on the current-voltage characteristics for negative (a) and positive (b) DC corona for both ESPs.

Figure 4 shows the influence of particle presence on the current-voltage characteristics. Under a fixed applied voltage, the time-averaged current magnitude decreases with the presence of particles for both ESPs. This is due to the much smaller mobility of the submicron particles than those of ions, but also to the complex process of charge transfer to particles [13-14].

IV. COLLECTION EFFICIENCY

A. Particle size distribution

Figure 5 shows an example of particle size distribution in the outlet gas without corona discharge. The median particle diameter is about 0.3 µm. Since the conventional particle mass/volume collection efficiency is not relevant to submicron particles due to the existence of heavier particles, collection efficiency in terms of number/volume is considered in this investigation. The total-number collection efficiency (η) is defined as follows [15]:

$$\eta = 1 - \frac{N_{ON}}{N_{OFF}} \qquad (1)$$

Where N_{ON} and N_{OFF} are the number of particles per cm^3 with and without plasma, respectively.

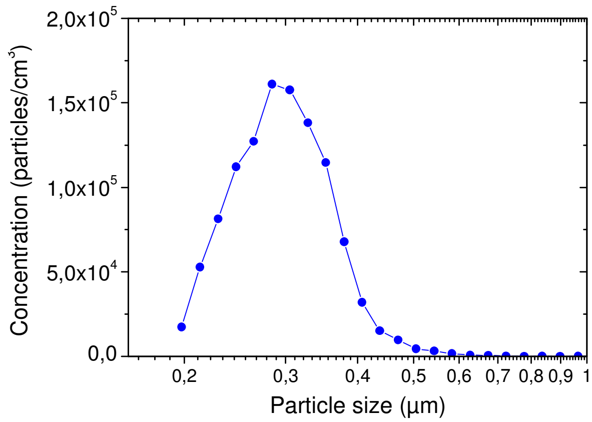


Figure 5. Particle size distribution in the ESP without corona discharge.

B. Global Collection efficiency

The collection efficiency is influenced by several parameters such as applied voltage magnitude, air flow rate, geometric configuration, particle concentration, temperature. Figure 6 illustrates the evolution of the collection efficiency as a function of the applied voltage for two flow rates (5 and 20 l/min). The collection efficiency is higher at high applied voltage in both ESPs. However, the collection efficiency reaches the maximum (up to 99%) at lower voltages in the case of C-ESP.

As expected, when the flow rate increases the resident time of the particles inside the ESP reduces, and then the collection efficiency decreases. Also, the results obtained with the aerosol spectrometer show that in the case of the C-ESP, the collection efficiency is higher with the negative voltage. However, the D-ESP seems to be less influenced by the polarity especially at high flow rates; this points out the influence of the spatial distribution of the discharges on the collection efficiency of an electrostatic precipitator.

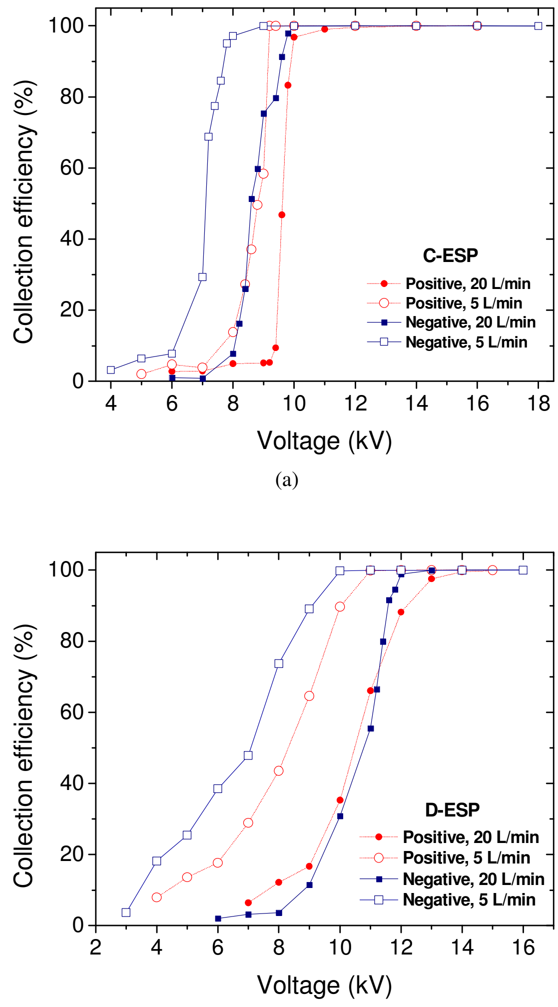
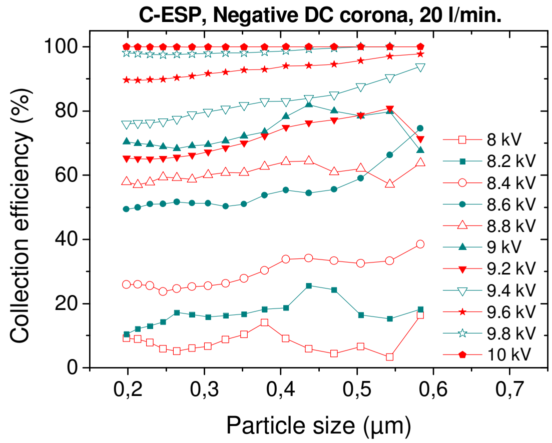


Figure 6. Voltage and flow rate effect on the collection efficiency for continuous (a) and discrete (b) ESPs.

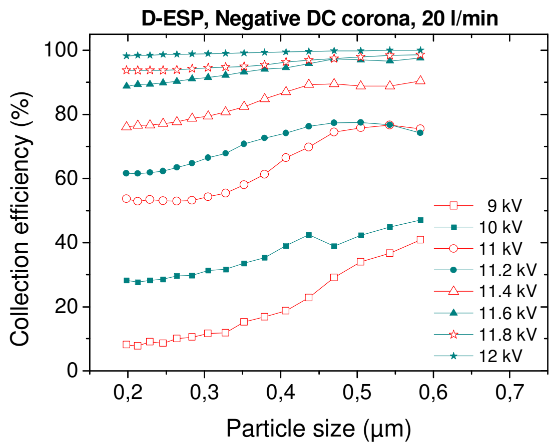
C. The Collection efficiency for different size of particles

The distribution of the particles by diameter of the incense, reveals that more than 95% of the particle's diameter is between 0.2 - 0.5 µm. This allowed us to consider only this range of particles in the study of the collection efficiency of both ESP.

Figure 7 shows the evolution of the collection efficiency according to the diameter of the particles for various values of applied voltage (negative corona, air flow 20 l/min) for the two configurations. As expected, the collection efficiency of the two ESPs increases with the size of the particles from 0.2 to 0.5 µm. This behavior is explained by the fact that the net charge by particle increases with their diameter due to the establishment of the field charging mechanism. The fluctuations which appear on the operating characteristics are primarily of stochastic nature. The same behavior is noted for the two types of polarity and for lower flow rates.



(a)



(b)

Figure 7. Effect of the voltage on the collection efficiency for different particles size in the case of continuous (a) and discrete (b) ESPs.

V.CONCLUSION

The main results show that the two models (C- ESP and D-ESP) have similar current-voltage characteristics in negative and positive coronas. On the other hand, the experiments confirmed that the particle collection efficiency of the system is higher at high applied-voltage and at low flow rate in both ESPs. In the case of the C-ESP, the collection efficiency is higher with the negative voltage. However, the D-ESP seems to be less influenced by the polarity especially at high flow rates; this points out the influence of the spatial distribution of the discharges on the collection efficiency of an electrostatic precipitator. The collection efficiency increases with particle diameter in the range 0.2-0.5 µm for the both ESP models.

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