Experimental study of high resistivity particles collection using an electrostatic precipitator in wire-to-cylinder configuration

F. Kherbouche[1, 4], Y. Benmimoun[1], A. Tilmatine[2], A. Zouaghi[3, 4], N. Zouzou[4]

[1] *LSTE Laboratory, Department of electrical engineering, M. S. University of Mascara, 29000, Mascara, Algeria*
[2] *APELEC Laboratory, Djillali Liabes University of Sidi Bel-Abbès, 22000, Sidi-Bel-Abbès, Algeria*
[3] *Laboratoire de Recherche en Electrotechnique, Ecole Nationale Polytechnique d'Alger, 16200, Algiers, Algeria*
[4] *Institut Pprime, CNRS – Université de Poitiers - ENSMA, F86962, Futuroscope Chasseneuil, France*
Corresponding author: *kherbouche.fouad@gmail.com*

Abstract In this paper, a new electrostatic precipitator (ESP) with asymmetrical wire-to-cylinder configuration is investigated experimentally. The main objective is to evaluate the collection efficiency of high resistivity particles such as the ones released from cement manufacturing processes. The experiments are performed with cement particles ranging from 0.18 to 5 µm with a mean size of about 0.4 µm. An aerosol spectrometer is employed for characterizing the size distribution of these particles at the outlet of the ESP. The collection efficiency is estimated for various DC applied voltage magnitudes and for both positive and negative polarities. The electrical measurements show that the behavior of corona discharges is similar to that obtained in symmetrical wire-to-cylinder configuration. Results show that the particle collection efficiency of the ESP can reach 95% in the case of negative corona discharge.

Keywords: Electrostatic Precipitator, corona discharge, high resistivity particles, rotating collecting electrode

1. Introduction

The electrostatic precipitators (ESP) are a universal apparatus for industrial gas cleaning of solid and liquid particles. High collecting efficiencies (more than 99%) and low energy expenditures are the main benefits of ESPs [1].

The ESPs can be classified according to the collecting electrode geometry (cylindrical or plate type), the direction of gas flow (vertical or horizontal flow), particles recuperation system (dry ESPs using rappers or wet ESPs using water) [1, 2].

In recent investigation, H. Ando *el al.* [3] developed an electrostatic precipitator based on moving electrode (MEEP) and rotary brush to remove the collected dust. This device meets the need of some factories that eject high resistive dust particles in order to resolve the problem of re-entrainment due to back corona discharge [3, 4].

One of the simplest and interesting new geometries allowing the movement of the collection electrode is the use of an asymmetrical wire-to-cylinder ESP.

The particles are charged due to the corona discharge generated near the wire connected to the high voltage. Then, they are collected on the whole surface of the cylindrical collection electrode. Thus, the rotation of the cylinder enables the homogenization of dust layer and the cleaning of the surface using a static brush.

In this paper, the asymmetrical wire-to-cylinder ESP is studied experimentally in order to evaluate the collection efficiency in a static situation (the cylinder is immobile) for one wire-ESP and three wires-ESP.

First, the current-voltage characteristics are measured with and without the presence of particles for both positive and negative polarities. Then, the collection efficiency of cement particle under various electrical conditions and flow rates is investigated by means of an aerosol spectrometer that measures the particle size distribution at the outlet of the ESP.

2. Experimental setup

The schematic representation of the asymmetrical wire-to-cylinder ESP used in this investigation for both one wire-ESP and three wires-ESP are shown in Fig. 1. The high voltage electrode consists of stainless steel wire (0.2 mm-diameter and 132 mm-length). The collecting electrode made of stainless steel cylinder (50 mm-diameter) is connected to ground and placed at about 30 mm from the high voltage electrodes. The distance between two successive corona wires is set at 20 mm.

The origin of the coordinates corresponds to the center of the wire and the airflow is directed from the wire toward the cylinder (ox direction).

The complete experimental bench illustrated in Fig.2 is divided into 4 parts: the power supply unit, the particle detection instrumentation, the particle supply and the wind tunnel.

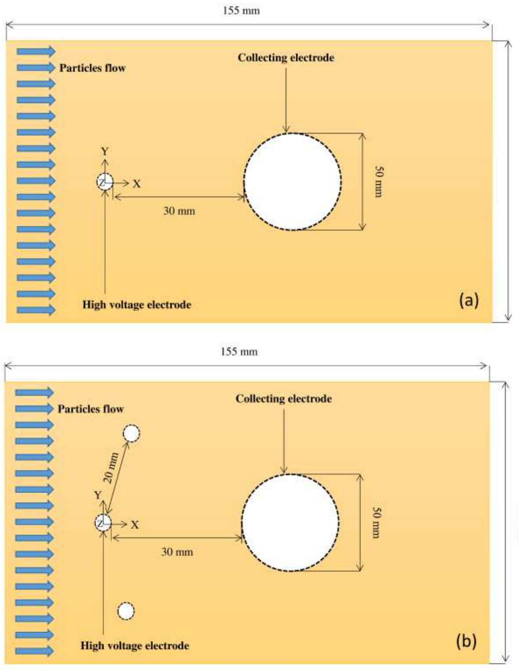

Figure 1. Schematic representation of the ESP, (a) case of 1 wire-ESP and (b) case of 3 wires-ESP

A. Power supply section

In this study, both positive and negative dc high voltage polarities are used. The dc high voltage is provided by two power supplies for each polarity (Spellman SL 1200, +100 kV, + 12 mA for positive voltage and Spellman SL 150, −40 kV, – 3.75 mA for negative one) with an accuracy of 0.1 kV. They are protected by a ballast resistor of 10 kΩ. The time-averaged current is measured using a digital multimeter.

B. Particle supply section

In order to analyze the ESP performance, cement particles are introduced into the wind tunnel through a dust feeder. They are generated by using an industrial dust generator (Topas SAG, model 410) that allows the dosing and the dispersing of powders with mass output range from 0.05 to 6000 g.hour^{-1}.

The cement particles used for the experiments underwent a size classification using an automatic sieving device (Endecotts, model Octagon 200). Several classification levels are carried out between 0.1 and 150 µm. For our experiments, only the particles with sizes less than 32 µm are used to feed the dust generator.

Fig. 3 shows the mass classification as function of diameter after a several sieving operation, we can notice that the particles mass with diameters less than 32 µm and 50 µm are important than the other sizes.

C. Particle detection section

Inside the ESP, the particles are electrically charged and collected on the cylindrical electrode. In order to calculate the collection efficiency of the ESP, the particle concentration in the exhaust gas sample is measured using an aerosol spectrometer (Pallas, Model Wellas-1000, sensor range of 0.18-40 µm, concentration up to 10^5 particles.cm^{-3}). The counting technique is based on the use of a white light source. A small measurement volume defined optically is illuminated with white light to analyze the scattered light and determine the number and size of particles. The counting system includes four main organs: the optical assemble the electronic circuitry, the pump unit and the cooling device.

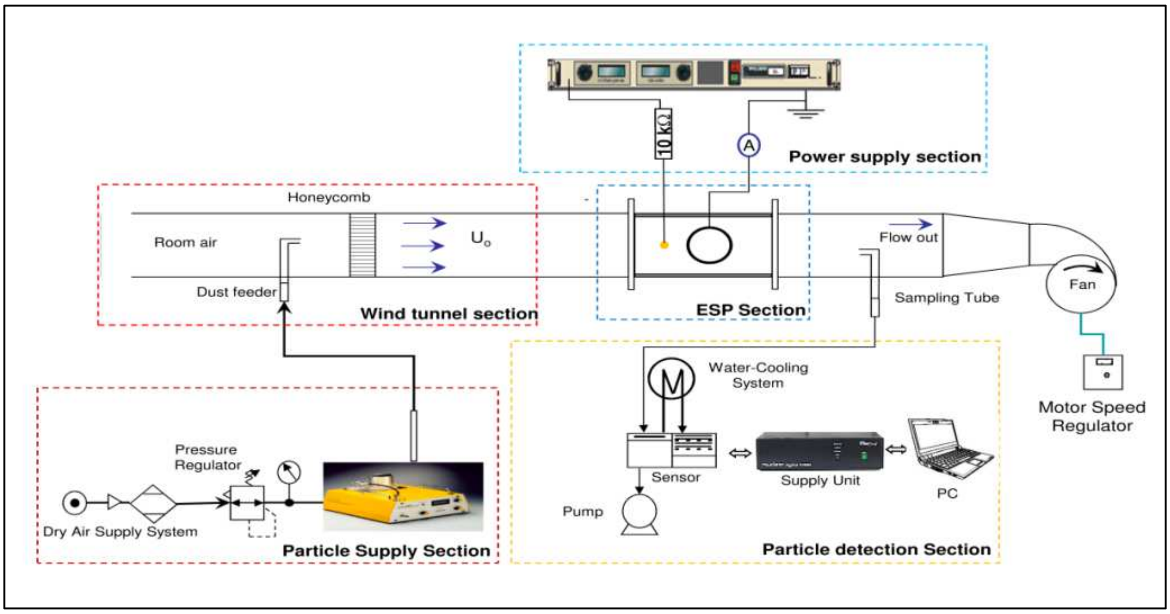

Figure 2. The experimental setup

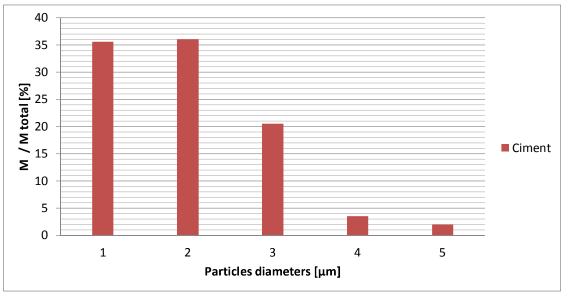

Figure 3. Mass classification as function of particle diameter

D. Wind tunnel section

The experiments are conducted in a wind tunnel made of polymethyl methacrylate (PMMA). The test section of the wind tunnel has a square section (132 mm-width and 132 mm-height). The length of the overall tunnel is about 2 m. A centrifugal fan, controlled by a speed regulated motor, generates a time averaged velocity (U_o) within the test section of about 0.1 m.s^{-1}. Flow measurements are undertaken to obtain this velocity by using a hot wire anemometer (Testo, model 405-V1, 10 m.s^{-1} full scale, and a resolution of 0.01 m.s^{-1}).

3. Results and discussion

A. Electrical characteristics

Fig. 4 and Fig. 5 Show the current-voltage characteristics of the ESP for both high voltage polarities, with and without the presence of particles in case of 1 wire-ESP and 3 wires-ESP. As expected, the discharge current increases gradually with the applied voltage when it exceeds the corona onset voltage. At a given voltage, the discharge current is higher with the negative polarity, which is due to the difference between the apparent mobility of negative charge carriers compared to positive ones [5-7].

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 ($I_{1\text{wire}} < I_{3\text{ wires}} < 3\ I_{1\text{wire}}$).This is due to the electric field interaction between two successive high voltage wires.

The averaged discharge current (I) is a non-linear function of the applied voltage (V), the relationship between the current and the voltage can be expressed by a simple formula developed theoretically for the case of symmetrical wire-to-cylinder and wire-to-plane configurations [8].

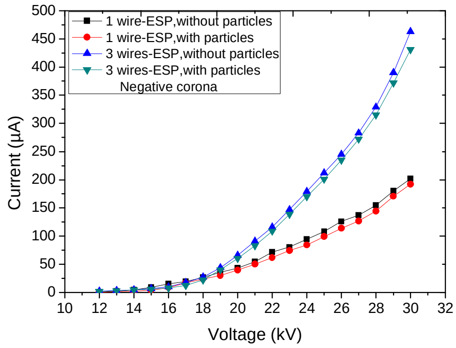

Figure 4. Current-voltage characteristics for negative corona discharge (T = 23 °C, RH = 44 %)

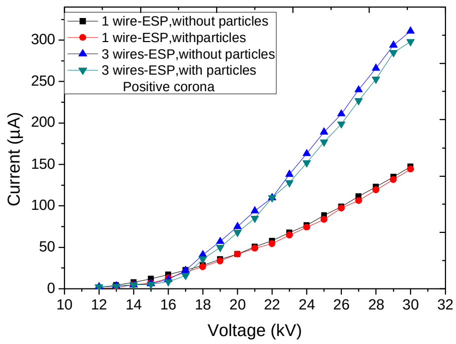

Figure 5. Current-voltage characteristics for positive corona discharges (T = 23 °C, RH 44 %)

$$I = CV(V - V_0) \qquad (1)$$

Where V_0 is the corona onset voltage and C is a constant that depends on the electrode configuration and the mobility of charge carriers, among other parameters

Furthermore, at a given high voltage, the corona discharge value decreases with the presence of particles in the gap, due to lower mobility of particles compared to that of ions [9, 10].

Fig. 6 shows the evolution of the average power consumption as function of applied voltage for both positive and negative polarities.

The power consumption is obviously lower in the case of positive polarity both for the one wire-ESP and three wires-ESP configurations. Moreover, the maximum values obtained before the occurrence of the disruptive discharge (breakdown) did not exceed 0.2 W for the negative polarity in the case of one wire –ESP and 0.45 W for three wires-ESP.

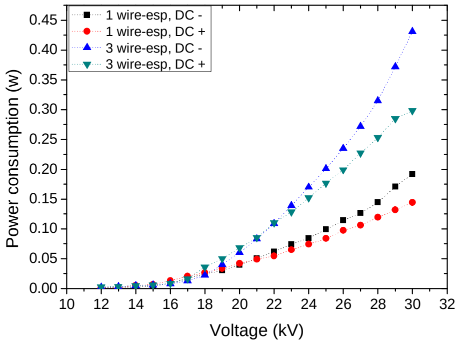

Figure 6. The average power consumption as function of negative and positive applied voltage (T 23°C, RH 44 %)

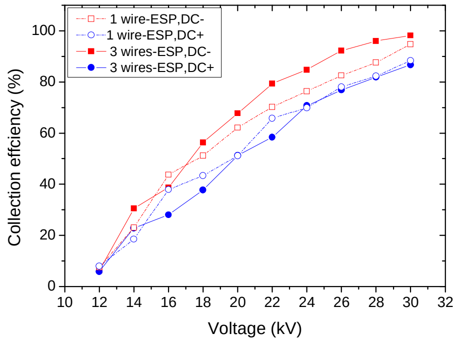

Figure 7. Collection efficiency versus applied voltage comparison for three and one wires-ESP

B. Collection efficiencies

The total number collection efficiency η of the ESP in terms of number/volume is defined as follows:

$$\eta = \left[1 - \frac{N_{On}}{N_{Off}}\right] \cdot 100\ \% \qquad (2)$$

Where N_{On} and N_{Off} are the number of particles per cm^3 for all particle classes with and without corona discharge, respectively.

Using the same methodology, the fractional number collection efficiency for the size class i (η_i) can be defined using the following equation:

$$\eta_i = \left[1 - \frac{N_{on,i}}{N_{Off,i}}\right] \cdot 100\ \% \qquad (3)$$

Here, $N_{on,i}$ and $N_{Off,i}$ are the number of particles per cubic centimeter for the size class i with and without corona discharge, respectively.

Fig. 7 shows the evolution of the collection efficiency as a function of the applied voltage for both negative and positive corona discharges. With increasing the applied voltage, the collection increases and can reach 95% in the case of one wire-ESP and 98% in the case of three wires-ESP under –30 kV.

For a given voltage, the collection efficiency is clearly higher in case of negative polarity compared to positive one for both configurations. Due to high mobility of negative ions, the particle charging process leads to upper values of charges in the case of negative corona [11, 12].

Furthermore, the interaction between the primary flow and the secondary flow (electric wind) seems to be relatively strong in the case of negative corona due to the difference between the spatial distributions of positive or negative corona discharges along the wire [13].

Fig. 8 shows the collection efficiency evolution as function of the electric power consumption in both configurations. Results show that high collection efficiency can be reached with relatively low power consumption (less that 0.2 W).

In addition, for the same efficiency, the one wire-ESP is clearly less power consuming compared to the three-wires-ESP.

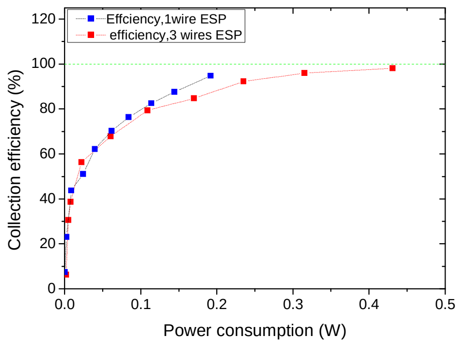

Figure 8. Collection efficiency as a function of power consumption

The evolution of the fractional collection efficiency as a function of particles size for different applied voltage is illustrated in Fig. 9.

Whatever the applied voltage, the efficiency increases clearly with the particles size in the range from 0.18 to 5 µm. In addition, the efficiency exceeds 99.9% for the particle size higher than 1 µm under –30 kV. This can be explained by the enhancement of particle charges with increasing particle diameter, predominantly due to the effect of field charging mechanism.

One can notice some fluctuation of the collection efficiency values due to the particle concentration changes during the experiments.

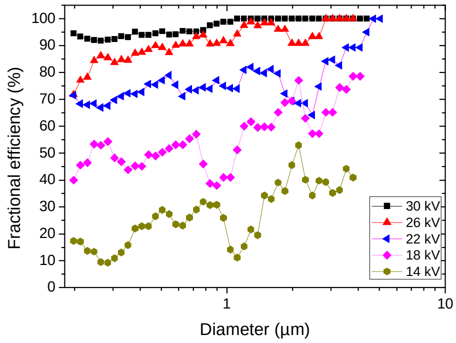

Figure 9. Fractional efficiency versus particles diameter

C. Particle flow rate effect on the collection efficiency

The effect of the flow rates of particles on the collection efficiency is illustrated in Fig. 10. The flow rate of the gas varies from 0.1 m/s to 0.3 m/s. As expected, the collection efficiency decreases with increasing the flow rate, because the residence time of particles in the active part is reduced [14].

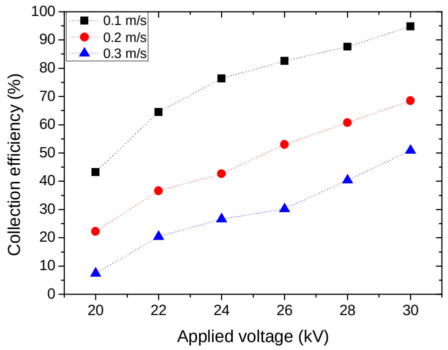

Figure 10. Collection efficiency as a function of negative dc applied voltage for three flow rates

D. Time operation effect on the collection efficiency

Fig. 11 shows the evolution of the collection efficiency with time in the case of one wire-ESP, with negative applied voltage (–30 kV). In beginning of the operation, the collection efficiency is slightly lower that about 90%, because the collection electrode is clean. With increasing the functioning duration, the collection efficiency decreases gradually. After about 9 h of operation, the efficiency falls to down 45%, which indicates that the collecting electrode is covered by a thick layer of cement particle.

The purpose of this experiment is to determine the critical time operation (roughly 3 h) that can be used in our cleaning system in further study.

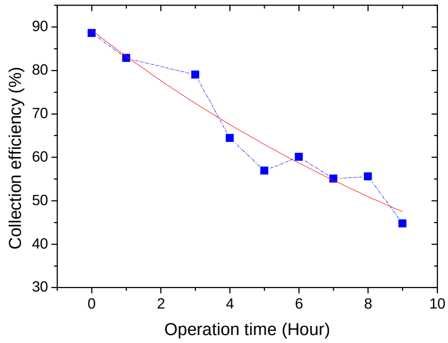

Figure 11. The evolution of the collection efficiency with time in the case of one wire-ESP, with negative applied voltage

4. Conclusion

In this paper, experimental investigation is carried out on an electrostatic precipitator with asymmetrical wire-to-cylinder in one wire-ESP and three wires-ESP configurations. The main objective is to evaluate the collection efficiency of high resistivity particles such as the ones released from cement manufacturing processes.

The collection efficiency of cement particles ranging from 0.18 to 5 µm have been estimated for various dc applied voltage magnitudes for both positive and negative polarities. The effect of the flow rate and the operation time are also taken into consideration. The main results of this investigation are as follows.

1. The electrical measurements show that corona discharge behavior is similar to that obtained in symmetrical wire-to-cylinder configuration for both configurations.
2. Particle collection efficiency of the ESP can reach 95% in the case of one wire-ESP and 98% three wires-ESP for negative corona discharge, which confirms the potential of the asymmetrical wire-to-cylinder geometry. However, the fractional collection efficiency is limited to about 90% for particles of about 0.2 µm because of breakdown voltage.
3. The collection efficiency decreases with increasing the flow rate. This indicates the need to expand the active region for particle charging by adding more corona wires.

Further investigations are planned to evaluate the effect of the collection electrode rotation on the collection efficiency of cement particle in particular for long-term conditions.

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