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Collection of submicron particles using DBD electrostatic precipitator in wire-to-square tube configuration

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Abstract. The aim of the present work is to investigate the capability of a Wire-to-Square Tube Electrostatic Precipitator (or WST-ESP) to collect submicron particles using a Dielectric Barrier Discharge (DBD). A parametric study is carried out to evaluate the effects of four control variables that might affect the collection efficiency of the WST-ESP: diameter of the corona wire electrode, width of the ground electrode and the area of the tube section. The experimental data show that the wire diameter has a negligible effect on the WST-ESP collection characteristics. However, better overall performances can be obtained by putting in parallel several WST-ESPs with reduced section. The extension of the ground electrode and its discretization increase the collection efficiency.

1. Introduction

Increasing the collection efficiency of electrostatic precipitators with minimum capital and running costs is a big challenge [1]. In previous experimental work [2-3], it has been shown that the DBD can be successfully employed for the collection of submicron particles. In the case of a wire-to-cylinder ESP, the collection efficiency reaches 99 %. The problem is that this geometry is not suitable for implementation in an industrial environment, especially at high flow rates. A WST-ESP, which allows us to put in parallel several ESPs, may be a solution to the problem of industrial scaling.

The goal of the work presented in this paper is to evaluate the collection efficiency of submicron particles in a lab-scale dielectric barrier discharge ESP. A parametric study was carried out, in order to point out the effect of wire diameter, ground electrode size and tube section on ESP performances.

2. Experimental set-up

The experimental setup is illustrated in figure 1. Dry clean air (relative humidity < 5%) is introduced into a custom-designed smoke generator, where burning of incense sticks generates submicron particles with a mean size of about 0.3 μm . The particles are entrained by the airflow through the ESP. A small amount of the exhaust is connected to a diluter with 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 flow rate inside the measurement cell is fixed at 5 l/min. However, the flow rate inside the ESP is adjusted between 1.6 and 20 l/min and measured using a floating ball flow meter.

The basic configuration of the WST-ESP (Figure 2) consists of a glass square tube provided with two electrodes, one of which is grounded and the other is connected to a High Voltage (HV). The HV

electrode consists of a stainless steel wire (0.20 mm in diameter) aligned on the central axis of the dielectric tube. The grounded electrode is made of aluminum tape strips (80 mm width and 80 μm thick) and is placed on the external surface of the tube.

The power supply system consists of a high voltage power amplifier (Trek, 30/20C, ± 30 kV, ± 20 mA), a function generator (TTI, TG1010, 10 MHz), a current probe (shunt resistor of 100 Ω), a high voltage probe (internal probe of the amplifier, and a digital oscilloscope (Lecroy 424, 200 MHz, 2 GS/s). The performance of the ESPs is studied at different values of HV amplitude (4-26 kV) and frequency (0.3-1000 Hz). All the experiments are carried out at atmospheric pressure and room temperature with controlled air flow rate.

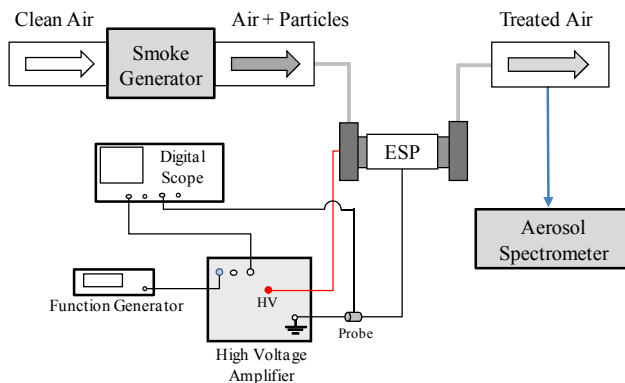


Figure 1. Schematic illustration of the experimental setup.

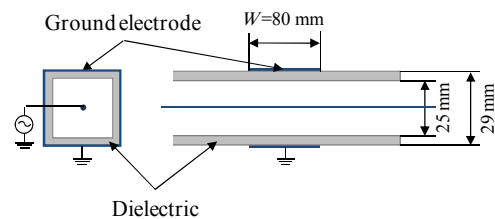


Figure 2. Cross-view of the WST-ESP

3. Results and Discussion

3.1. Current waveform

The current of the ESP includes only a few current pulses during the positive half-cycle, while there are numerous current pulses during the negative one (Figure 3). In the positive voltage half-cycle, the plasma is characterized by a glow-like regime. However, the Trichel pulses dominate the negative voltage half-cycle.

3.2. Collection efficiency

The total number collection efficiency (η) is defined as follows [4]:

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

where N_{ON} and N_{OFF} are the number of particles per cm^3 for a given size-class with and without plasma, respectively.

To highlight the variations of the collection efficiency, especially when it is between 90 % and 100%, the ESP performance will be characterized by the penetration (P), which is given by:

$$P = 1 - \eta \quad (2)$$

The time-averaged power consumption ($P_{elec.}$) of the discharge is calculated from the measurement of the current (I) and the voltage (V) measured over one cycle:

$$P_{elec.} = \frac{1}{T} \int_t^{t+T} I(t) \cdot V(t) \cdot dt \quad (3)$$

In order to improve the reproducibility of the average power calculation, 10 cycles are taken into account using an acquisition memory of 250 kpts/Ch.

3.2.1. Effect of the wire diameter Figure 4 shows the effect of the wire diameter on the particle penetration of the WST-ESP. The experimental data point out that this factor has no impact on the ESP performance. This is an interesting result which shows that it is possible to use bigger wire with better mechanical characteristics without deteriorating the ESP performance.

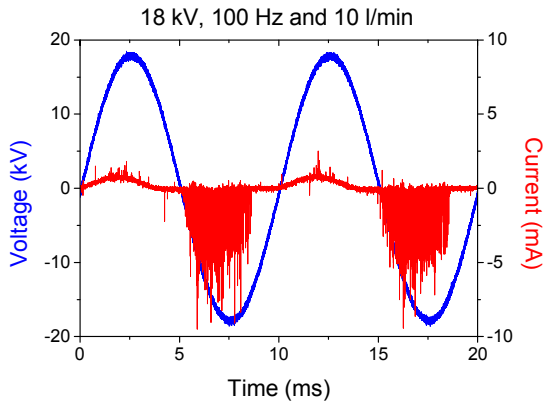


Figure 3. Time evolution of WST-ESP applied voltage and discharge current.

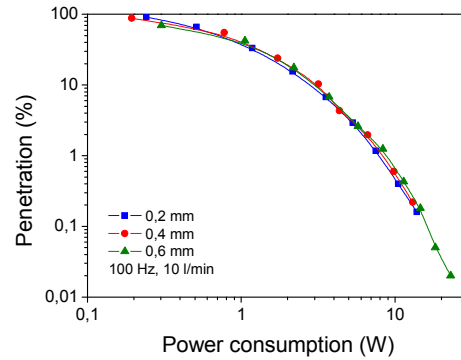


Figure 4. Effect of the wire diameter on the particle penetration of the WST-ESP.

3.2.2. Effect of the ground electrode Width Figure 5.a shows the particle penetration of the WST-ESP as a function of the power consumption for different ground electrode widths at 18 kV. Results show clearly a correlation between the performance of the ESP and the ground electrode width.

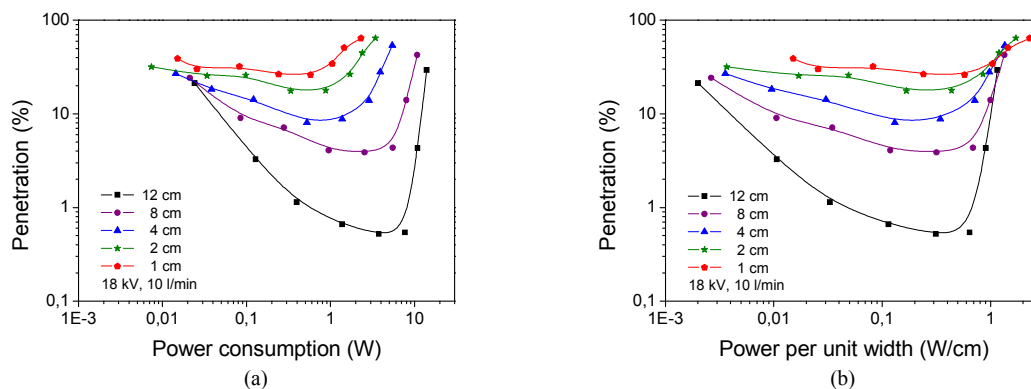


Figure 5. Effect of the ground electrode width on the particle penetration of the WST-ESP.

In figure 5.b the penetration is represented as a function of the power per unit width (Power consumption divided by ground electrode width). The performance of the WST-ESP increases with the ground electrode width. This is due to the increase of the residence time of the particles inside the collection volume.

3.2.3. Discretization of the ground electrode The effect of the ground electrode discretization on the collection efficiency of the WST-ESP is studied in this section. The initial ground electrode is divided into four strips of 20 mm width (Figure 6). The distance between two successive strips is set at 4 cm. Figure 7 shows the effect of the ground electrode discretization on the performance of the WST-ESP. The new ground electrode shape improves the efficiency of the WST-ESP at the same input power. This could be due to the tape edge effect. By increasing the number of edges, more power is injected in the inter-electrode gap and the areas where the electric field strength is intensified (between the wire and the tape edge) are more numerous. In addition, the residence time of particles between the first and last edges increases by discretizing the ground electrode.

3.2.4. *Section of the tube* Experiments were performed with three glass tubes with different internal sections ($S_{T1}=1 \times 1 \text{ cm}^2$, $S_{T2}=1.8 \times 1.8 \text{ cm}^2$ and $S_{T3}=2.5 \times 2.5 \text{ cm}^2$). In order to have the same air flow velocity inside the three ESPs (about 0.267 m/s), the tests were carried out at different flow rates: 1.6 l/min for the first, 5.1 l/min for the second and 10 l/min for the last one.

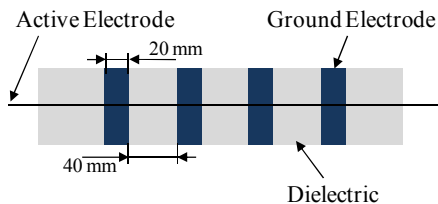


Figure 6. Side view of the WST-ESP with discretized ground electrode.

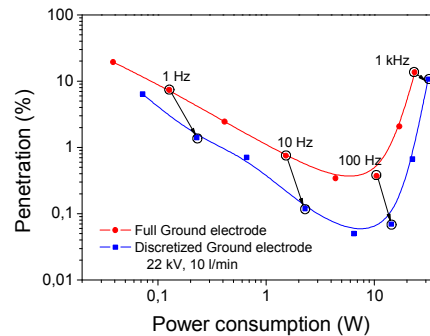


Figure 7. Effect of the ground electrode discretization on WST-ESP performance.

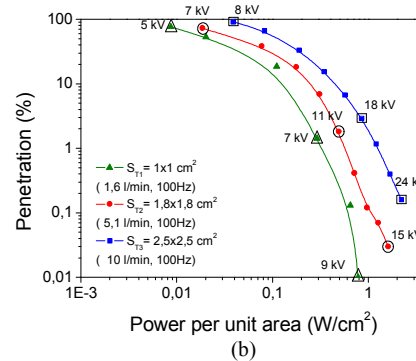
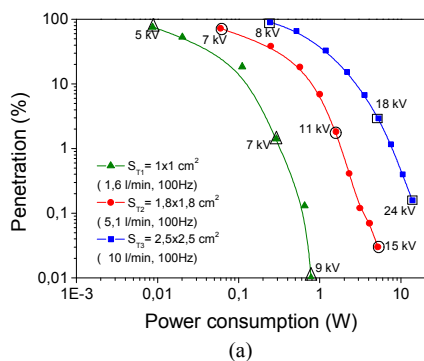


Figure 8. Effect of the section of tube on the performance of the WST-ESP.

The particle penetration varies with the power consumption (figure 8.a). Considering the fact that the volume of gas treated by the three ESPs during the same time interval is different, the particle penetration (figure 8.b) is represented as a function of the power per unit area (Power consumption divided by the section of the tube). The efficiency of the WST-ESP seems to be increased by using smaller sections. This result confirms the interest of clustering several WST-ESP in parallel.

4. Conclusion

The collection of submicron particles by using a lab-scale barrier discharge ESP was investigated in the case of wire-to-square tube configuration. The parametric study of the WST-ESP shows that using bigger wire diameter does not deteriorate the ESP performance. The penetration decreases with larger or discretized ground electrode. The collection efficiency increases by using smaller sections.

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