Study of DBD electrostatic precipitator under different high voltage waveforms

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1 Abstract:

This experimental work is aimed at evaluating the effects of the high voltage waveforms (sine, square and stair) on the efficiency of a wire-to-square tube electrostatic precipitator using dielectric barrier discharge. The input parameters under study are: the high voltage magnitude, its frequency and the tube section. The collection efficiency of the electrostatic precipitator is calculated by measuring the concentration of incense particles (average diameter of 0.3 µm) at the outlet using an aerosol spectrometer.

2 Introduction

The increasingly rigorous standards on air pollution stimulate the development of appropriate technologies for collecting the impurities present in exhaust gases [1]. Thus, the use of Electrostatic Precipitators (ESP) that would guarantee high collection efficiency with minimum capital and running costs is a big challenge.

In a previous experimental works [2-6], it has been shown that the Dielectric Barrier Discharge (DBD) can be used with success for the collection of submicron particles. In the case of a wire-to-cylinder ESP, the collection efficiency reaches 99 %. However, wire-to-cylinder geometry is not suitable for the implementation in an industrial environment, especially for high flow rates. A Wire-to-Square Tube or WST ESP, which allows us to put in parallel several ESPs, may be a solution to the problem of industrial scaling.

In this study, the effects of the high voltage waveforms on the efficiency of a lab-scale WST-ESP are investigated. The discharge is generated using sine, square and stair high voltage waveforms. The input parameters under study are: the high voltage magnitude, its frequency and the tube section.

3 Experimental setup

The experimental setup is illustrated in Fig.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 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 flow rate inside the measurement cell is fixed at 5 l/min. However, the flow rate (Q) 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 (Fig. 2) consists of a glass square tube (300 mm length) 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 aluminium 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 ESP is studied at different values of HV amplitude and frequency. All the experiments are carried out at atmospheric pressure and room temperature with controlled air flow rate.

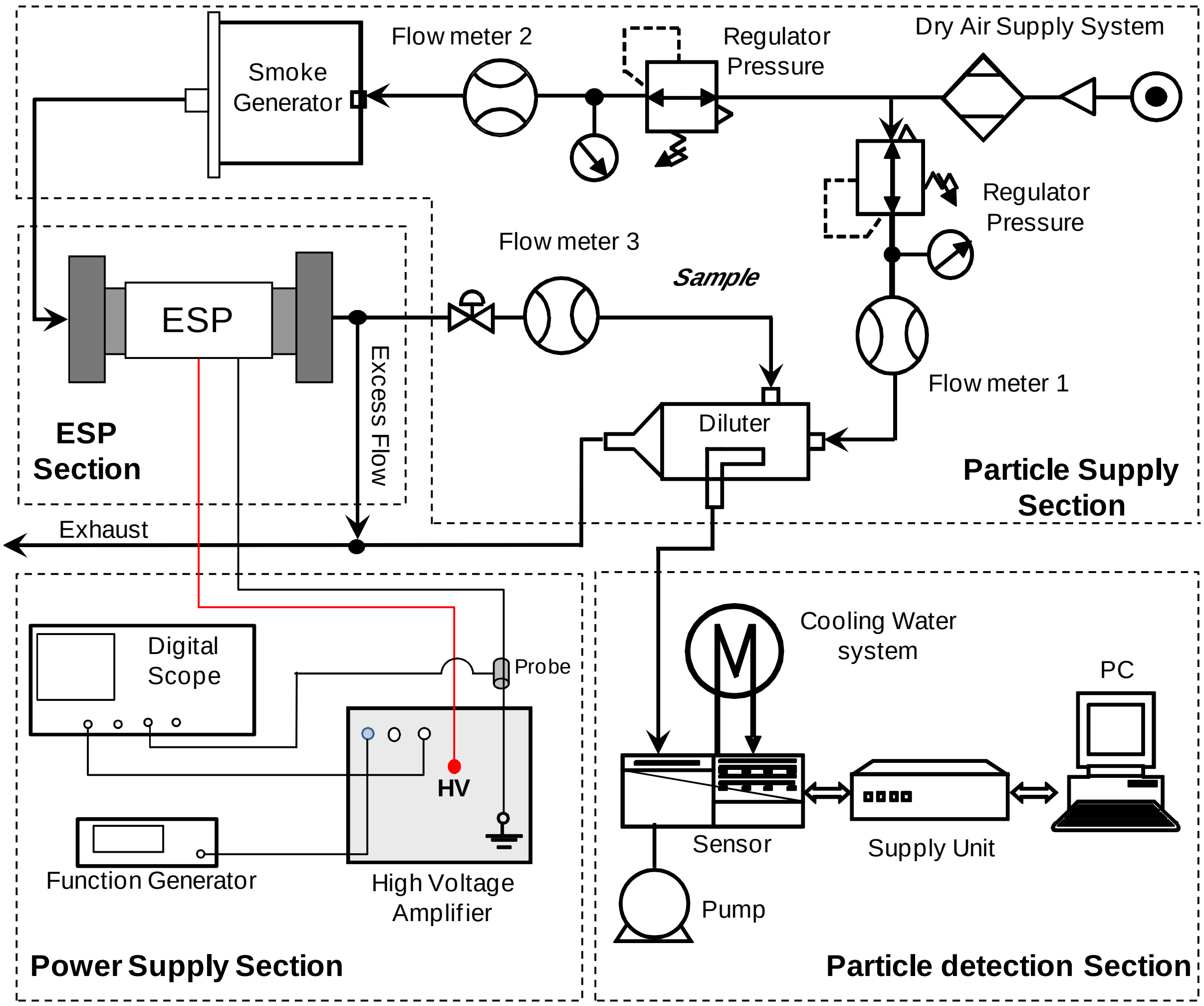

Fig. 1: Schematic illustration of the experimental setup.

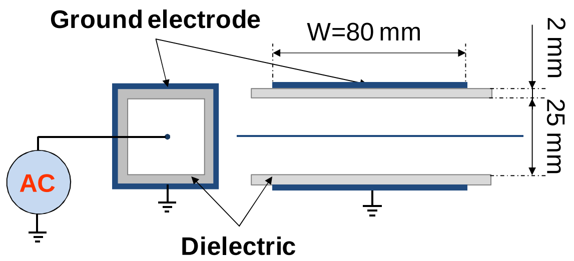

Fig. 2: Cross-view of the WST-ESP.

4 Results and discussions

4.1 Characterization of the WST-ESP

a. Current waveform

Fig. 3 shows a typical time evolution of the discharge current and the applied voltage. The discharge current of the ESP includes only a few current pulses during the positive half-cycle, while there are numerous current peaks during the negative one. 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. Similar behavior of the DBD has been observed in point-to-plane and wire-to-cylinder configurations [3, 7]

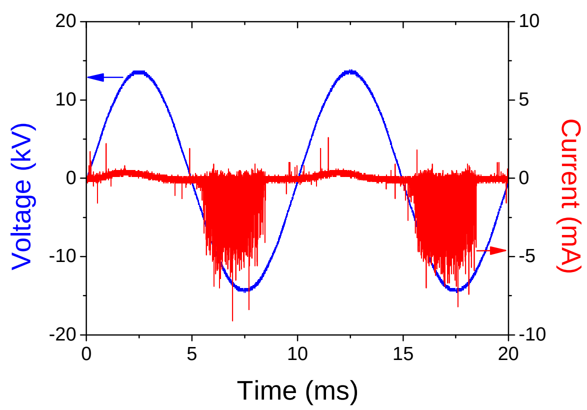

Fig. 3: Time evolution of the voltage and discharge current. Conditions: V=14 kV, f=100 Hz, Q=10 l/min.

b. Collection efficiency

The total-number collection efficiency (η) is defined as follows [8]:

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

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

To highlight the variations of the collection efficiency, especially when it is between 90 % and 100 %, the characterization of the precipitator is done in terms of penetration:

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

Fig. 4 (a) illustrates the evolution of particle penetration as a function of the applied voltage in log-linear scale at three frequencies (10, 100 and 1000 Hz). The collection efficiency is greater at high voltage magnitudes; it can even exceed 99 % (penetration less than 1 %). However, curve tendencies are influenced by the frequency value.

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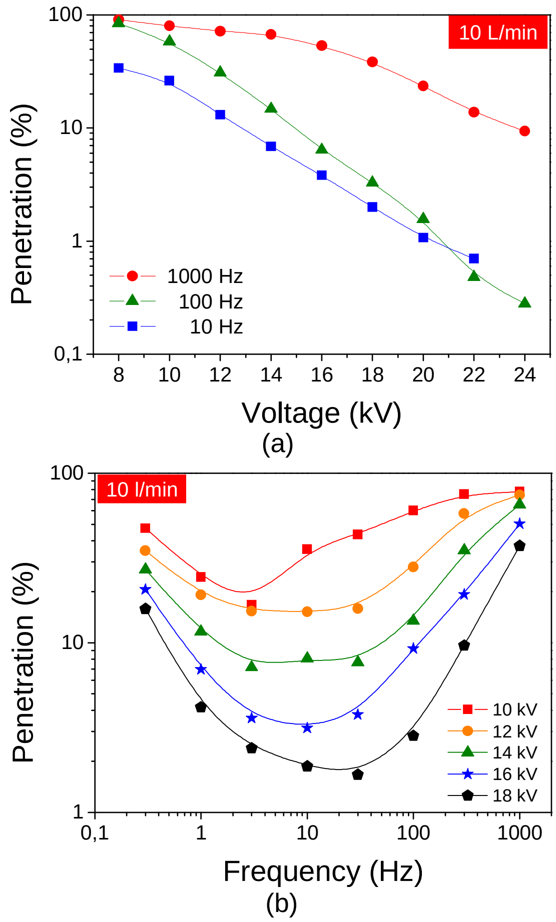

Fig. 4: Voltage (a) and frequency (b) effects on the particle penetration of the WST-ESP.

Fig. 4 (b) shows the particle penetration as a function of the frequency at different applied voltages in log-log scale. The results show clearly that the performance of the ESP depends on the frequency range. The penetration of the ESP increases for high and low frequencies. The optimum performance of the ESP can be reached at a frequency in the range from 3 to 100 Hz.

At low frequency (< 3 Hz), the ESP performance falls down because of the intermittent nature of the discharge. However, at high frequency (> 100 Hz), a half-cycle is shorter than the necessary time for the particles to be collected, so they oscillate between the electrodes [3, 4].

4.2 Effect of the waveform on the ESP performance

a. Current waveforms

Fig. 5 shows the time evolution of the applied voltage and the discharge current for square and stair input waveforms. The high voltage magnitude is fixed at 14 kV.

During the positive half cycles, one can clearly identify the positive glow corona although the discharge activity is depending on the input waveforms. During the negative half cycles, the Trichel pulses occur.

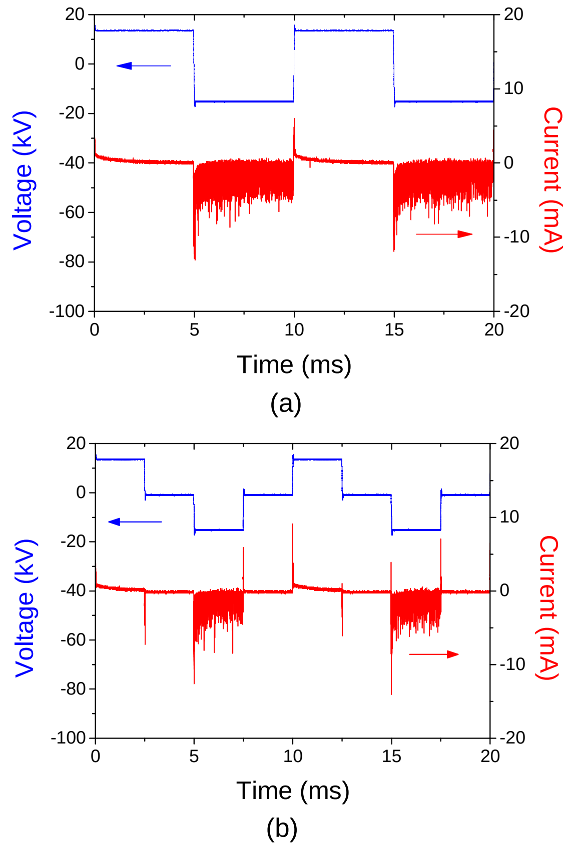

Fig. 5: Time evolution of the applied voltage and discharge current for different input waveforms: (a) Square and (b) Stair. Condition: V=14 kV, f=100 Hz, Q=10 l/min.

With both square and stair input waveforms, high current peaks occur at each positive or negative going cycles with fast rise and fall times. These current peaks are due to the combined effect of capacitive and discharge currents. It seems that the positive current peaks are clearly smaller that the negative ones. Furthermore, the duration of discharge activity varies according to the high voltage waveforms and the considered half cycle.

b. Collection efficiency

Fig. 6 shows the evolution of the penetration as a function of the electrical power consumption for sine, square and stair waveforms. The frequency is fixed at 100 Hz. Whatever the high voltage waveform, the ESP performance increases with the electrical power consumption. Furthermore, the penetration may be lower than 1 % for the tested waveforms if the necessary power is provided.

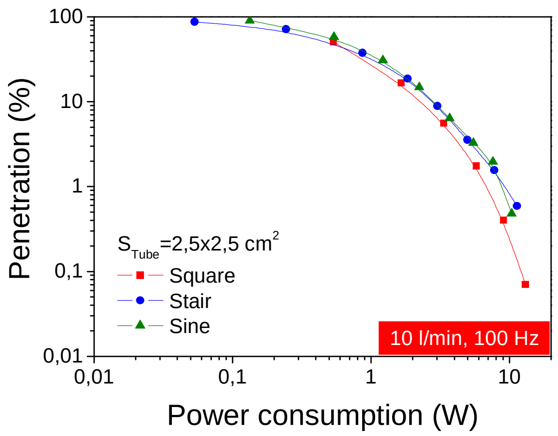

Fig. 6: Effect of high voltage waveform on the particle penetration.

At a given electrical power, the square wave offers the best ESP performance. This is probably related to the period of discharge activity which is longer in the case of square wave. In addition, the electric field remains strong during both half cycles.

c. Effect of tube section on the collection efficiency

Additional experiments were performed using three glass tubes with different internal sections (S_{T1}=2.5×2.5 cm^2, S_{T2}=1.8×1.8 cm^2 and S_{T3}=1×1 cm^2). The cross section view of these configurations is shown in Fig. 7. In order to have the same residence time of particle inside the three ESPs (about 0.3 s), the experiments were carried out at different flow rates 10 l/min for the first, 5.2 l/min for the second and 1.6 l/min for the last one.

As shown previously, the particle penetration varies with the averaged power consumption (Fig. 6). Considering the fact that the volume of the gas treated by the three ESPs during the same time interval is different, the particle penetration is represented as a function of energy density (Fig. 8).

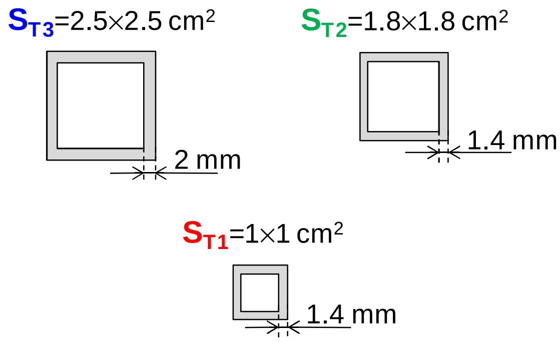

Fig. 7: Cross section view of the tested ESPs.

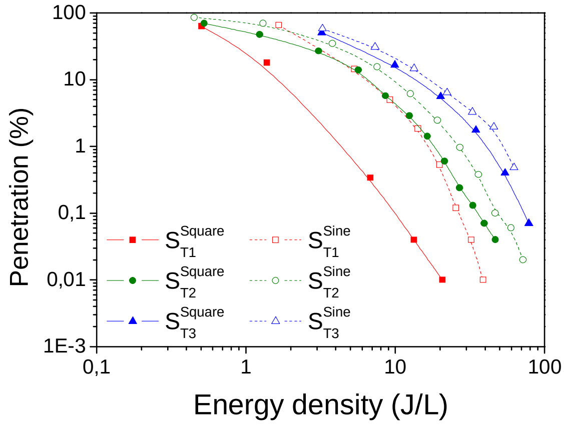

Fig. 8: Effect of the section of tube on the performance of the ESP.

At same input energy density, the ESP performance seems to be increased by using smaller sections. In addition, the difference between the performance of the ESP using sine and square waveforms is more pronounced for smaller tubes.
The results of this section are of great interest. On one hand, they demonstrate that the WST-ESP can be optimized by adjusting the applied waveform, which plays an important role on the duration of the discharge activity. On the other hand, it confirms the interest of clustering several WST-ESPs in parallel with smaller size.

5 Conclusion

In this paper, the effect of the input waveform on the performance of a lab-scale barrier discharge ESP has been investigated in the case of wire-to-square tube configuration.

The main results are the following:

(1) For a given barrier discharge ESP construction an optimum frequency should be found, because the ESP performance falls down at low frequency because of the intermittent nature of the discharge and at high frequency due to particle oscillation.

(2) It is better to use square high voltage waveform instead of sine one. The fast rise time generate significant space charges, on one hand, and the electric forces remains strong during the half cycles, on the other hand.

(3) The ESP performs better with smaller tubes especially with square wave. Therefore, the optimum construction of barrier discharge ESP is made by clustering several square tubes with smaller sizes.

6 Literature

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