Journal of Electrostatics 67 (2009) 117–122

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Electrostatic precipitation in wire-to-cylinder configuration: Effect of the high-voltage power supply waveform

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A R T I C L E I N F O

Article history:
Received 17 September 2008
Received in revised form
14 January 2009
Accepted 18 January 2009
Available online 5 February 2009

Keywords:
Corona discharge
Dielectric barrier discharge
High-voltage waveform
Electrostatic precipitation

A B S T R A C T

The purpose of this paper is to study the effect of the high-voltage power supply waveform and the presence of a dielectric barrier on the collection of submicron particles in a wire-to-cylinder electrostatic precipitator. The experiments are carried out on two reactors (with or without dielectric barrier on the surface of the cylindrical collector electrode) with the same active section and volume. The results show that the highest collection efficiency is obtained with the negative dc corona. At equivalent electric power consumption, the Dielectric Barrier Discharge (DBD) is as effective as the positive dc corona and the ac corona. The efficiency can reach 99% with both studied reactors, if the necessary power is provided.

1. Introduction

The quality of air is a major concern in a large majority of industrialized countries. The pollution standards are more and more demanding and constrain the car manufacturers to develop sophisticated systems for flue gas treatment. In spite of considerable progress, reducing the pollution caused by the exhaust gases continues to be a very active field of research [1–3]. Under these circumstances, electrostatic precipitation reveals itself as a very promising technology for the filtration of car exhaust gases. Indeed, electrostatic forces can be employed to collect the particles suspended in the exhaust gases, after charging them with the help of corona discharges generated by various electrode systems powered with DC or AC high-voltage supplies [4–7]. The current–voltage characteristics of these electrode systems influence to a great extent the particle collection efficiency, and depend on the shape of the electrodes and the spacing between them, as well as on magnitude and polarity of the applied voltage [8].

The present experimental study investigates the effect of the applied voltage waveform on the particle collection efficiency. The experiments are carried out in two reactors characterized by wire-to-cylinder electrode configurations, and same internal cross-sections. Within the first reactor, a corona discharge is generated by using a dc high voltage (positive or negative) or an ac high voltage (sine wave). A Dielectric Barrier Discharge (DBD) is generated in the second reactor using the same ac high-voltage waveform.

It is known that the particle collection efficiency of an electrostatic precipitator decreases when particle diameter ranges from 0.1 to 1 μm [9,10]. Therefore, incense smoke with an average diameter of 0.3 μm is used in the present experiments. The concentration of particles at the reactor outlet is measured using an aerosol spectrometer. Then, the collection efficiency of each reactor is calculated and discussed.

2. Experimental setup

2.1. Experimental apparatus

Fig. 1 shows the experimental setup used in this investigation. The flow rate (Q) varies from 8 to 24 l min^{-1}. The reference rate is set at 16 l min^{-1}. The experiments are carried out at room temperature. Incense sticks are burned in air in the particle generator. In fact, clean air is dried with $CaSO_4$ desiccant (relative humidity <5%) and mixed with the incense smoke before the introduction into the reactor. The flow at the reactor output is sampled and diluted before the analysis with the aerosol spectrometer.

2.2. Schematics of the reactors and particle counting technique

The cross-sections of the reactors are shown in Fig. 2. The active section of each reactor is 200 mm^2; the dimensions of the active

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doi:10.1016/j.elstat.2009.01.022

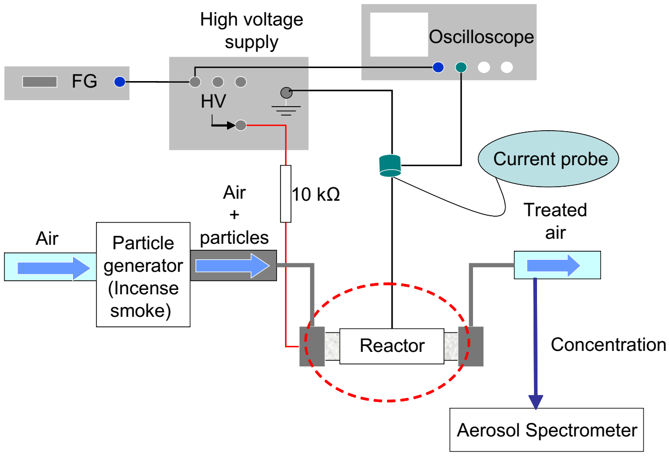

Fig. 1. Experimental setup.

volume are as follows: length of 80 mm, internal radius of 8 mm. The corona reactor electrodes are composed of a stainless steel wire (0.2 mm diameter) which is the active (ionizing) electrode, and a grounded copper tube as collecting electrode (Fig. 2a). Its internal diameter ϕ_{int} is 16 mm and its thickness is equal to 2 mm. The DBD reactor is composed of a 2 mm thick Pyrex tube, a 0.2 mm diameter stainless steel wire and a 0.08 mm thick copper foil wrapped on the outer surface of the Pyrex tube (Fig. 2b). The size distribution of particles is measured using a white light aerosol spectrometer (PALAS, Welas 1000), which is able to measure particle size in the range between 0.18 and 40 μm with a density of particles ranging from 5 to 10^5 particles cm^{-3}.

2.3. Electrical device

In this study two types of high-voltage waveforms are used: dc and ac. The ac high-voltage power supply system consists of a high-voltage power amplifier (TREK, 30/20C, ±30 kV, ±20 mA), a function generator (HAMEG, HM8130), a shunt resistor of 100 Ω, a voltage probe (internal probe of the amplifier) and a digital oscilloscope (LECROY 424, bandwidth 200 MHz), as shown in Fig. 1.

The dc high voltage is applied using a dc power supply (SPELLMAN SL 150, ±40 kV; ±3.75 mA, accuracy ≈ 0.1 kV). The power supply is protected by a ballast resistor of 10 kΩ. The current is measured with a digital multimeter (METERMAN 37 XR, accuracy ≈ 10 μA). Currents below 10 μA are measured using a low current electrometer (KEITHLEY 6514).

3. Experimental results

3.1. Particle size distribution

The incense smoke is constituted by particles of solid and liquid matters. An example of the size distribution of these particles is illustrated in Fig. 3, where we can see the particle size distribution without plasma discharge and with plasma discharge in the indicated conditions. Zukeran et al. [11] have shown that the size distribution of solid particles of incense smoke after drying reached a maximum between 0.2 and 0.3 μm diameter. Then, we can assimilate whole particles contained in the incense smoke to solid particles.

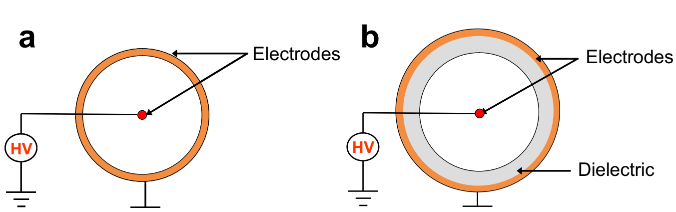

Fig. 2. Schematics of both reactors: (a) Corona discharge and (b) Dielectric Barrier Discharge setup.

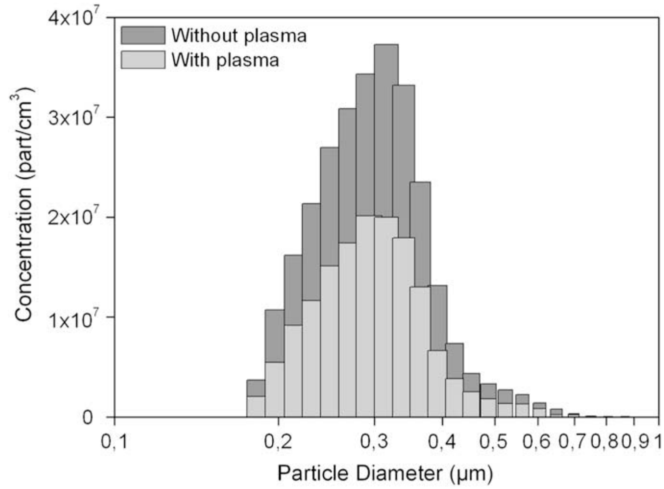

Fig. 3. Particle size distribution of incense smoke (DBD, $V = 8$ kV, $f = 1$ Hz and $Q = 8$ L min^{-1}).

3.2. Current–voltage characteristics of the dc corona discharge

Figs. 4 and 5 show the current–voltage characteristics for both types of discharge. The discharge current increases with the applied voltage when it exceeds the ionization threshold value (V_s) until gas breakdown occurs.

The time-averaged discharge current, which crosses the inter electrode gap is a non-linear function of the applied voltage.

Although the discharges include complex phenomena, a simple empirical relationship between current (I) and voltage (V) is generally used [12]. It is expressed by:

$$I = C \cdot V \cdot (V - V_s) \tag{1}$$

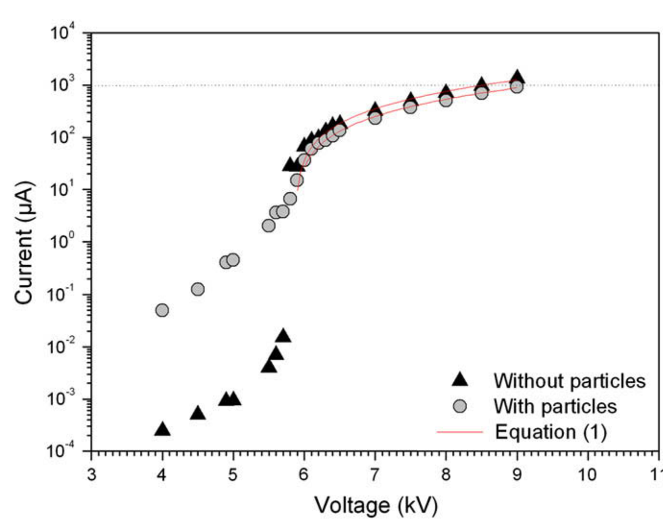

Fig. 4. Current–voltage characteristics under negative dc excitation at $Q = 16$ L min^{-1}.