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Corona discharges in asymmetric electrode configurations

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ABSTRACT

The dual electrode, which consists of an ionizing wire in parallel with a metallic cylindrical support, both connected at same high voltage supply, has been extensively studied in relation with various electrostatic applications. In practical situations, the dual electrode may be installed in the proximity of metallic objects that will affect the electric field repartition and, hence, the development of the discharge. The aim of the present work is to analyze the operating conditions of such electrodes in the presence of metallic rods or plates connected at fixed or floating potentials. The Superficial Charge Simulation Method was then employed for the numerical analysis of several electrode arrangements involving a dual corona electrode and a metallic rod parallel to it. The paper also reports the results of current–voltage characteristics and current density repartition measurements for the dual corona electrode alone or in the presence of other bodies at same or floating potential. The proximity of metallic objects leads to the increase of corona inception threshold and shifts the I–V characteristics to higher voltages. The objects at floating potential may reduce the discharge current to very low values, while those energized at the same voltage as the ionizing wire may simply anneal the discharge.

1. Introduction

Various corona electrode arrangements have been developed and extensively studied in relation with such electrostatic applications as separation of granular materials, charging of electrets air filters, or neutralization of charged insulating materials [1–9]. The efficiency of corona charging or neutralization processes depends on a multitude of factors, including the level, polarity or frequency of the high-voltage, as well as on the geometry of the electrode system [10–15]. Corona neutralization electrodes, for instance, are commonly employed in electrostatic separation installations as means to reduce the residual charge of the granular products collected after processing in a high-intensity electric field [16]. The accumulation of residual charge can be accompanied by electrostatic hazards, such as spark discharges that might ignite a flammable atmosphere or affect the operation of electronic devices.

Many electrode arrangements, using needles, pins or wires as corona emitting elements, are commonly employed in industrial applications [16,17]. In such configurations, the electric field distribution and hence the corona discharge are symmetrical with respect to the electrode axis. In pin-plane or wire-plane electrode system, the current density distribution can be described by the empirical Warburg law [18]. Other symmetrical configurations have also been characterized in relation with various industry applications [19–21]. Recently, the modification of corona electrode by connecting a metallic cylinder in parallel with the energized wire was suggested as a solution to enhance the charge process of non-woven filter media [22,23].

In practical situations, the corona electrode may be installed in the close vicinity of metallic objects, such as metallic rods or plates connected at fixed or floating potential. This will modify the symmetry of the electric field repartition and, hence, the characteristics of the corona discharge. With no such study available in the literature, the primary objective of this paper was to quantify the effect of asymmetry on the current–voltage characteristics of the electrode system and on the repartition of current density at the surface of the non-ionizing (collecting) electrode.

The present work was also aimed at evaluating the impact of electrode asymmetry on the effectiveness of corona discharge applied in order to neutralize the charge deposited on the surface of granular insulating materials. In this study, four electrode arrangements were considered (Fig. 1). Numerical simulation of the electric field and experimental measurement of surface potential, current–voltage characteristics and current density repartition were carried out in order to characterize the corona discharge in each of these cases.

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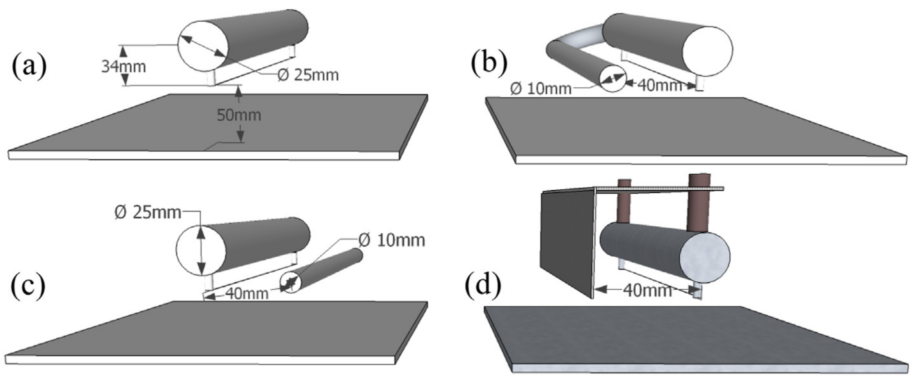

Fig. 1. "Standard" wire-type symmetric electrode arrangement (a) and asymmetric electrode arrangements, with cylindrical rod energized at the same voltage (b), with floating cylindrical rod (c) and floating plate (d).

2. Experimental procedure

2.1. Electrode arrangements.

The "standard" wire-type dual electrode consisted in a tungsten wire (0.2 mm in diameter) attached to a metallic cylinder (25 mm in diameter) and distanced at 34 mm from its axis (Fig. 1, a). Two such electrodes were used in the present work: one to charge the samples, the other to neutralize them. If not otherwise specified, in all the cases the wire was located at 50 mm above the grounded electrode (aluminum plate, dimensions: 120 mm × 90 mm).

Two asymmetrical electrode arrangements were obtained by attaching a copper cylindrical rod (diameter: 10 mm) to the dual electrode. The rod, the axis of which was located at 40 mm from the wire, was either energized at the same voltage as the "standard" symmetric electrode (Fig. 1, b), or left at a floating potential (Fig. 1, c). For the third asymmetrical electrode arrangement, the rod was replaced by a profiled aluminum plate, at floating potential (Fig. 1, d).

2.2. Current density repartition measurements

The repartition of corona current produced by the wire-type dual electrode was measured for both symmetric and asymmetric arrangements using a custom-designed printed circuit board (PCB) as collecting electrode (Fig. 2). Three voltage levels were considered, at both positive and negative polarity: 18 kV, 21 kV, and 24 kV; they were provided by a reversible-polarity high voltage supply 100 kV, 3 mA (Model SL 300, Spellman Inc). The current probe consisted in a rectangular sector (19 mm × 14 mm), insulated from the rest of the conductive plate, and connected to an electrometer (Model 6514, Keitheley Instruments).

The PCB was mounted on a conveyer belt, so that the probe could modify its position with respect to the corona electrode system (Fig. 3). The measured current values were continuously recorded via a virtual instrument developed in LabView environment. Current density was then obtained by dividing the measured current by the surface of the probe.

2.3. Current–voltage characteristic measurements

The current–voltage characteristic was measured for the symmetric dual electrode in Fig. 1, a, and for the asymmetrical electrode arrangement in Fig. 1, c. The electrometer that was used for the measurement of the discharge current (Model 6514, Keitheley Instruments) was placed between the collecting electrode and the ground. The high-voltage was read on the front panel of the DC power supply (Model SL 300, Spellman Inc).

2.4. Surface potential measurements and neutralization efficiency evaluation

The experimental setup is given in Fig. 3. The granules of virgin polyethylene employed in the present study were quasi-spherical in shape and had a typical size of 3 mm. They were deposited as a mono-layer on a rectangular area of 7.5 cm × 8 cm on the surface of grounded plate electrode. The mass of such sample was 11 g.

The samples were first charged for 10 s from a wire-type "dual" corona electrode, using the triode-type electrode arrangement. A metallic grid was placed between the energized wire and the ground in order to control the corona charging process, as explained in two previous papers [7,14]. The metallic grid consists of rhombic form loops (the distances between two adjacent nodes of the grid were respectively 6.4 mm and 4 mm). The charging electrode was energized at positive polarity by a high voltage supply (Model SL 300, Spellman Inc). During the charging process the sample was placed, in fixed position, so that the central transverse axis of the granular layer was in the plane of symmetry of the electrode system.

As soon as the charge process was over, the belt conveyor moved the sample at constant speed (3 cm/s) beneath the probe (model 3450, Trek Inc.) of an electrostatic voltmeter (model 341B, Trek Inc.) to measure the repartition of the electric potential at the surface of the granular layer. The voltmeter was connected to a custom-designed data acquisition system, as described in Ref. [22].

After that, the belt conveyor moved the sample beneath the neutralization electrode, at the same constant speed (3 cm/s). In this way, the charged granular layer was exposed to the AC corona discharge generated by each of the four electrode arrangements in Fig. 1, which were energized by a high-voltage amplifier 0 to ±30 kV, 0 to ±20 mA (model 30/20A, Trek Inc), as shown in Fig. 3. In all cases of surface potential measurements, the wire electrode was situated at 5 cm above the charged sample and the sinusoidal neutralizing voltage had a peak value of 18 kV.

Finally, the efficiency of the neutralization was evaluated by measuring again the repartition of the potential due to the residual charge at the surface of the granular layer, using the electrostatic voltmeter probe, as described above. The surface potential measurements allow the quantification of the efficiency of neutralization process by comparing potential prior and after exposure to the corona discharge. The neutralization rate may be calculated as the ratio of maximum recorded potentials before and after neutralization [9,15]:

$$N(\%) = \left(1 - \frac{V_{after}}{V_{before}}\right) 100$$