Experimental analysis of direct current corona discharge

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Abstract. This paper presents the experimental analysis of current-voltage characteristic of DC corona discharge. In experiments were used an electrostatic discharge system, consists of an active brass electrode, and a passive copper electrode (plane). A high-voltage source has been used to produce the positive or negative DC discharge. To analyse the influence of active electrode surface were used a conical and a spherical electrode, with small radius of curvature. The gap between the electrodes was varied by moving the passive electrode. Current-voltage characteristics of DC corona discharge were obtained at a constant distance between the discharge electrodes, by changing the amplitude of supply voltage. Corona current and voltage were acquired using a digital oscilloscope. Experiments allowed the study of the effects due to the active electrode and the air gap between the electrodes, on the onset voltage and the current of corona discharge.

1. Introduction
Direct current (DC) corona discharge has numerous applications, such as in electrostatic precipitation (ESP), electrostatic separation, photocopying, laser print, generation of ozone, sanitization of pool water, decomposition of toxic gases, etc. [1-9].

Industrial ESPs reduce the emissions of fumes and dust, playing an important role to maintain a clean environment. ESPs are used in electric power plants, cement production, chemical processing and domestic air cleaning [2-4], [8].

The process of corona generation in the air at atmospheric conditions requires a non-uniform electrical field, which can be obtained by using a small diameter electrode (active or emission electrode), energized from a high-voltage supply, and a metallic plate (used as collecting electrode) connected to the ground [5], [6].

Corona discharge presents the following major advantages: can be used easily in forming non-thermal plasmas, with high rates for gases flowing between electrodes, is stable at atmospheric pressure and operates at low currents and power consumption [5], [9].

The disadvantage is that the active volume of the ionization region, surrounding the high electric field electrode, is very much smaller than the total discharge volume, between the electrodes [1], [6], [7], [9].

The wires-to-planes is the most used configuration in ESPs. It consists of high-field parallel active wires, located midway between the collecting electrodes. When the gas flows through the discharge electrodes, the ions produced by the corona discharge (near the active electrodes) charge the dust particles, which are driven toward the collecting electrodes, where their charges is neutralized, dust particles being thus collected [1].
The onset voltage of corona discharge is a prior condition for calculating the corona current at a
given voltage applied to the discharge electrodes [6].

This paper aims at experimental analyzing the current-voltage characteristics of positive and
negative DC corona discharges.

2. Experimental setup
In experiments were used an electrostatic discharge system (ESD, Figure 1), consists of an active brass
electrode, and a passive copper electrode (plane).

To analyse the influence of active electrode surface were used a conical electrode and a spherical
electrode, with small radius of curvature. The gap between the electrodes was varied between 10...30
mm, by moving the passive electrode.

In order to change widely the voltage on discharge system, was used an autotransformer (AT,
Figure 1). Variable low voltage was applied to the primary of an elevator transformer (T, Figure 1)
whose secondary was connected to a rectifier bridge (P, Figure 1). This high-voltage source has been
used to produce the positive or negative DC discharge. The active electrode was connected to the DC
high-voltage installation which has a voltage between 0 and ±12 kV.

![Figure 1. Electrical diagram of experimental setup](image1)

![Figure 2. High-voltage probe (resistive divider) used to measure the DC voltage](image2)

The corona discharges operate at low currents (μA) and high voltages (kV). Measuring of DC
voltage was performed using a high-voltage probe (resistive divider, S, Figure 2). The value of the
discharge current was measured with a micro-ammeter.

3. Waveforms of voltage and current at negative and positive corona discharges
Corona current and voltage were acquired using a digital oscilloscope (25 MHz). The data is then
transferred to a personal computer (PC). For the measurement of the corona current was used a
resistance load of \( R_s = 120 \text{ kΩ} \).
Figure 3. Conical electrode (a) and spherical electrode (b), with small radius of curvature, used to analyse the influence of active electrode surface.

Figure 4. Waveforms of voltage and current at negative corona discharge in the case of conical (peak)-plane electrodes at d=25 mm: (a). $U^-=5$ kV, (b). $U^-=10$ kV.

Figure 5. Waveforms of voltage and current at negative corona discharge in the case of conical (peak)-plane electrodes at d=30 mm: (a). $U^-=5$ kV, (b). $U^-=10$ kV.
Figure 6. Waveforms of voltage and current at positive corona discharge in the case of conical (peak)-plane electrodes at d=25 mm: (a). U^+=5 kV, (b). U^+=10 kV

Figure 7. Waveforms of voltage and current at positive corona discharge in the case of conical (peak)-plane electrodes at d=30 mm: (a). U^+=5 kV, (b). U^+=10 kV

The waveforms of voltage and current at negative and positive corona discharges are shown in the Figures 4-7. Measurements were carried out for different voltage values (5 kV and 10 kV) applied to the discharge electrodes (conical-plane), at distances of 25 mm and 30 mm between them.

Notations have the following meanings: d - distance between the electrodes; U^- applied voltage to the discharge electrodes, when active electrode was connected to the positive polarity of DC high-voltage installation; U^- applied voltage to the discharge electrodes, when active electrode was connected to the negative polarity of DC high-voltage installation.

Partial electrical discharges are shown clearly in the corona current waveforms from Figures 4-7.

4. Experimental analysis of DC corona discharge current-voltage characteristics
Further are present the current-voltage (I-V) characteristics of positive and negative Corona discharges, for different distances between the electrodes, and different configurations of them.

These characteristics were obtained at a constant distance between the discharge electrodes, by changing the amplitude of supply voltage.
If the distance between the discharge electrodes (conical-plane) was d=11 mm (Figure 8.a), it is found that current intensity as a function of applied voltage is in agreement with the Ohm’s law, for voltages in the range of 0-8 kV (current increases linearly with the applied voltage), for both polarities (positive and negative). The positive corona discharge occurs at a voltage of 8.3 kV, and the negative corona discharge occurs at a voltage of 8.84 kV.

If the distance between the discharge electrodes (conical-plane) was d=12 mm (Figure 8.b), positive corona discharge occurs at a voltage of 8.5 kV, and negative corona discharge occurs at a voltage of 9.12 kV.

As seen from Figures 8-12, the onset voltage and corona discharge occur at increasing tensions, if the inter-electrode gap increases, at both polarities.

Corona current decreases as the gap increases, for the same measurement conditions.
Figure 10. DC corona discharge I-V characteristics for conical-plane electrodes:
(a). d=16 mm, (b). d=17 mm

Figure 11. DC corona discharge I-V characteristics for conical-plane electrodes:
(a). d=18 mm, (b). d=19 mm

Figure 12. DC corona discharge I-V characteristics for conical-plane electrodes:
(a). d=20 mm, (b). d=21 mm
Significant differences between the positive (+) and the negative (-) corona discharges are observed at small values of the inter-electrodes gap (d=11...21 mm), in the case of conical-plane electrodes (Figures 8-12).

Corona onset voltage and electric discharge occur at higher voltages in the case of negative (-) polarity, compared to the positive (+) polarity.

Negative corona discharge is more intense than positive (negative current values are higher than positive current values at the same distance between the electrodes). Also, it is found that negative corona discharge is more stable than positive corona discharge.

Figure 13. DC corona discharge I-V characteristics for conical-plane electrodes:
(a). d=22 mm, (b). d=25 mm

Figure 14. DC corona discharge I-V characteristics for conical-plane electrodes:
(a). d=28 mm, (b). d=30 mm

Variation of the currents is linear at large distances between the conical-plane electrodes (d=22...30 mm); because the discharge is not autonomous, differences between the currents occur at positive and negative polarity in these situations, are not significant (Figures 13 and 14).

Because conical-spherical electrodes were not collinear in experiments, negative corona currents were smaller than the currents occurring between conical-plane electrodes, at the same distances (Figure 15).
Figure 15. DC corona discharge I-V characteristics for conical-spherical electrodes:

(a). d=11 mm, (b). d=12 mm

Figure 16. DC corona discharge I-V characteristics for spherical-plane electrodes:

(a). d=10 mm, (b). d=20 mm

Figure 16 shows that corona current is much lower for spherical-plane electrodes than for conical-plane electrodes, in the same measuring conditions, because corona discharge is even more intense as the electrode surface emission is lower.

5. Conclusions

Experiments allowed the study of the effects due to the active electrode and the air gap between the electrodes, on the onset voltage and the current of DC corona discharge.

The onset voltage of corona discharge is influenced by the active electrode surface and the inter-electrode gap, for the same applied voltage. At negative polarity, the onset voltage of corona discharge is greater than that of the positive polarity, for a given geometry.

Experimental results show that corona current is affected by the voltage between the electrodes, their shape and the inter-electrode gap. Significant differences between the positive and the negative corona discharge are observed at small values of the inter-electrodes gap (d=11...21 mm), DC corona currents being nonlinear functions of the applied voltages.
Currents through the inter-electrode gap increase linear with the applied voltage at large distances between the electrodes (d=22...30 mm); differences between the currents occur at positive and negative polarity in these situations are not significant, because the discharge is not autonomous.

Onset voltage and corona electric discharge occur at increasing tensions, if the inter-electrode gap increases, in the case of conical-plane electrodes (at both polarities), but corona current decreases as the inter-electrodes gap increases.

Surface of active electrode decisively influences the appearance of corona discharge. Corona discharge is even more intense as the surface of active (emission) electrode is less.

Negative corona discharge is more intense and more stable than positive. This is due to the existence of a difference between the positive and negative onset voltage; also the mobility of negative ions is higher than that of positive ions. Therefore, most industrial applications, including ESPs, use negative corona discharge.

Experimental study of DC corona discharge current-voltage characteristics is very useful to understand the phenomena that occur in wires-to-planes configuration of ESPs.

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