

# Experimental and Numerical Study of Corona Discharge Generated by a Wire-Type Dual Electrode Located Between Parallel Grounded Strips

Abdeljalil Reguig<sup>1</sup>, Abdelber Bendaoud<sup>1\*</sup>, Peyman Dordizadeh<sup>2</sup>, Lucien Dascalescu<sup>3</sup>

<sup>1</sup>APELEC Laboratory, Djillali Liabes University of Sidi Bel-Abbes, Algeria

<sup>2</sup>Department of Electrical and Computer Engineering,

Western University, London, Ontario, Canada

<sup>3</sup>PPRIME Institute, University of Poitiers – IUT, Angoulême, France

e-mail: abdelber.bendaoud@univ-sba.dz

*Abstract*— Several electrode arrangements have been proposed to enhance the efficiency of insulating materials charging by corona discharge. Recent studies pointed out that the presence of a grounded metallic shield in the proximity of the high voltage corona electrode increases the total current measured at the surface of the collecting electrode decreases the corona onset voltage value and enlarges the repARATION of current density as well. The aim of the present paper is to analyze the effect of replacing the shield by two parallel grounded strips located in the horizontal plan of the ionizing wire. The experimental results obtained show that the presence of the shield or the two parallel strips in the proximity of the dual wire electrode increases in the same way the corona current at the surface of the plate electrode. Varying the height of the strips and the wire-strips distance could modify significantly the behavior of the corona discharge in such electrode arrangements, for both polarities. The characterization of this new electrode configuration could be very useful to the corona charging of different insulating materials in various electrostatic processes. These experiments are discussed in relation with the results of the numerical analysis of the electric field generated by the different previously-described electrode configurations. The equipotential lines plots and the electric field lines orientation explain the peculiarities of the corona discharge generated by this electrode arrangement.

*Keywords*- Corona discharge, electrode, electric field.

## I. INTRODUCTION

Corona discharge is employed in a large variety of electrostatic processes [1]-[3], such as the precipitation of dust [4], separation of granular mixtures [5], charging of electrets for air filters [6]-[8] and photocopying processes [9]. Many corona electrode arrangements have been developed and extensively studied in relation with such electrostatic applications [10], [11].

The configurations mostly used in electrostatic separators and as devices for corona charging of non-woven media for air filtering applications are the wire-type “dual electrode”, and the “triode-type electrode system” [12, 13].

Recent studies pointed out that the presence of a grounded metallic shield in the proximity of high voltage corona electrode could enhance the efficiency of corona charging of polymer films and non-woven media posed on the surface of the grounded plate electrode in such electrode configurations [14]. The present paper aims to analyze the effect of the presence of a metallic grounded shield or grounded strips in the proximity of a “dual electrode”. In addition to the plot of the respective current-voltage characteristics, the experimental set-up enabled the measurement of the repartition of the corona current density at the grounded electrode, which makes possible an evaluation of the charging zone extension on the surface of the samples exposed to corona discharge in such electrode configurations. The study was carried out for various values of the geometrical parameters that characterize the three electrode arrangements: “dual electrode”, “dual electrode” + grounded shield, and “dual electrode” + grounded strips.

## II. EXPERIMENTAL PROCEDURE

All the experiments were conducted with a wire-type “dual e electrode” that consists in a tungsten wire (diameter of 0.2 mm) supported by a metallic cylinder (diameter of 26 mm) and distanced at 34 mm from its axis. The wire and the cylinder were energized from the same adjustable high-voltage supply 100 kV, 3 mA (model SL 300 Spellman, Hauppauge, NY), as shown in Fig. 1 [10]-[16].

In some experiments, the corona discharge was generated by the “dual electrode” located at a distance  $D$  from a grounded plate electrode (250 mm  $\times$  160 mm), in the presence or not of a grounded metallic shield in the proximity of the ionizing wire (Fig. 1, a). Other experiments were conducted in the presence of two symmetric grounded metallic strips, located at a distance  $D_b$  from the ionizing wire of the dual electrode. The lower limits of strips and the axis of the wire were adjusted to be in the same horizontal plan as shown in Fig. 1, b. Basically, the height, the thickness and the length of each strip were respectively  $L_b = 10$  mm,  $\phi = 1$  mm and  $h = 120$  mm.

In the first set of experiments, a micro-ammeter was inserted between the plane and the grounded electrode to measure the corona current  $I_m$  in different electrode configurations [16]. The current-voltage characteristics were recorded in all configurations under study (i.e., wire-type dual electrode with and without shield or strips), for a given inter-electrode spacing  $D = 30$  mm, at positive and negative polarities. The experiments were performed in relatively stable climatic conditions: relative humidity  $RH = 40\text{-}50\%$  and temperature  $T = 16\text{-}17^\circ\text{C}$ .

In a second set of experiments, the study of the distribution of current density at the surface of the collecting electrode proved to be an effective method for the evaluation of corona charging efficiency of this type of electrode configuration as explained in several previous papers [17], [18]. The experimental setup is shown in Fig. 2. The current density in different areas of the grounded electrode was measured using a special designed printed circuit board (PCB) plate (70 mm  $\times$  2 mm) with seven strips current probes. The probes are electrical isolated from each other and from the rest of the PCB and connected successively to the ground through an electrometer (Keithley Instruments, model 6514).

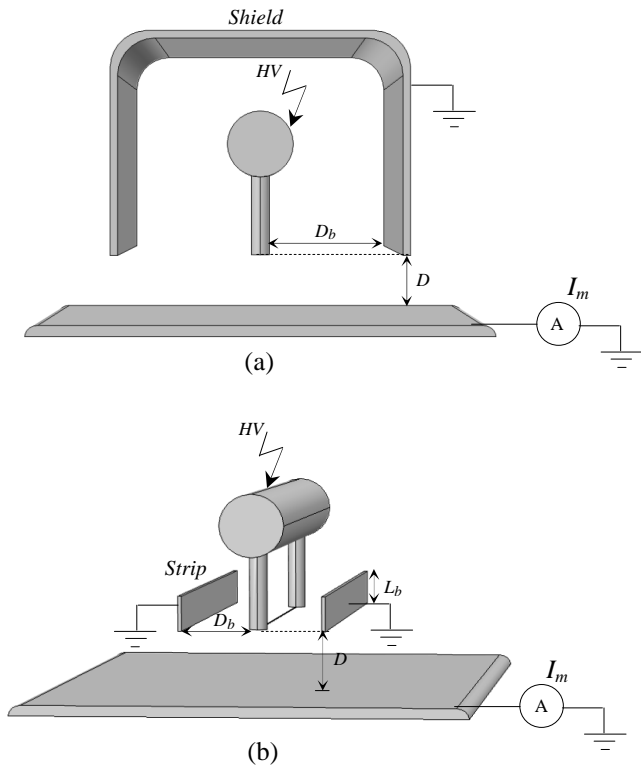


Fig. 1. Wire-type dual arrangement: (a) with grounded shield and (b) with grounded parallel strips in proximity of the high-voltage “dual electrode”.

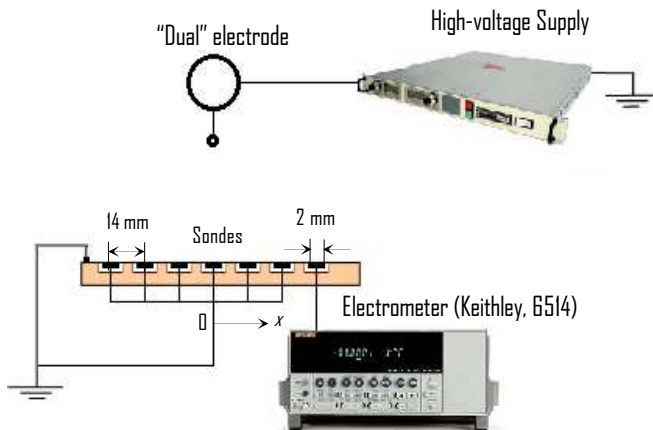


Fig. 2. Experimental setup for measurements of current density distribution on the grounded plate electrode.

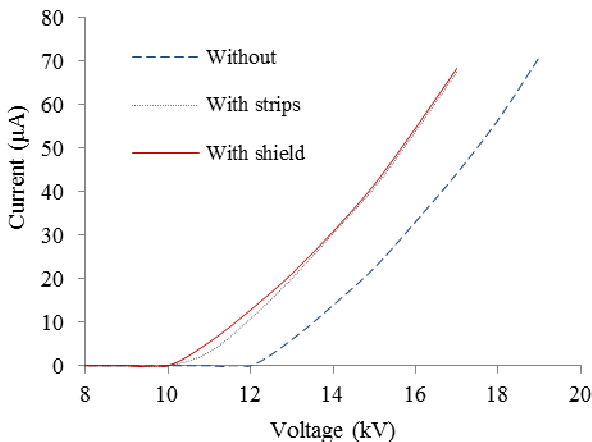
The electric field at the surface of the corona wire is affected by the proximity of metallic objects. The present study is focused on the comparison between the three electrode arrangements ( “dual electrode”, in the presence of shield or strips) in order to reveal the modification of the corona current produced in these different circumstances.

### III. RESULTS AND DISCUSSION

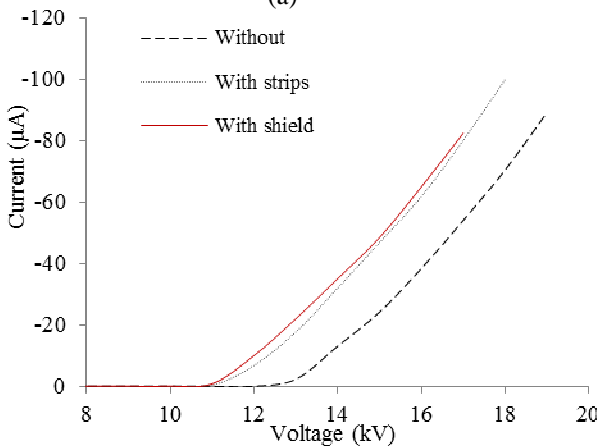
#### A. Current – voltage characteristics

##### 1) Comparison between the shield and parallel strips

The current–voltage characteristics obtained for these experiments can be examined in Fig. 3, for both positive and negative polarities.



(a)



(b)

Fig. 3. Current-voltage characteristics of the wire-type “dual electrode” arrangement with and without shield or strips for  $D = 30$  mm and  $D_b = 40$  mm at positive (a) and negative voltage (b).

The current  $I_m$  recorded in presence of the shield or strips located at the same distance to the wire  $D_b = 40$  mm, was clearly higher than the one obtained for the “standard” wire-type “dual electrode” arrangement without presence of grounded metallic objects in proximity. In the case of the presence of the shield, the current was slightly higher than with the strips, because of the intensification of the electric field caused by the configuration of the shield.

## 2) Wire-strip distance effect

The experimental results presented in Fig. 4 for both positive and negative polarities show that the corona onset ( $V_{onset}$ ) and the corona current depend on the distance between the wire and the strips  $D_b$ .

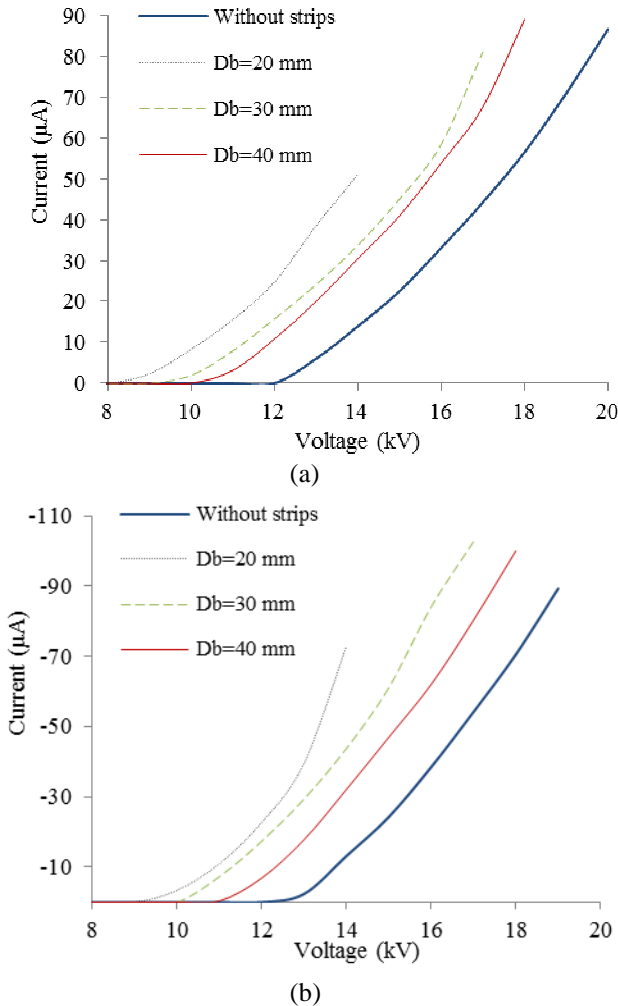


Fig. 4. Current–voltage characteristics of the wire-type dual electrode with strips at different distances  $D_b$  for  $D = 30$  mm at positive (a) and negative voltage (b).

For the same distance between electrodes  $D = 30$  mm, the smaller the distance  $D_b$ , the lower is the corona onset voltage  $V_{onset}$ .

At a given voltage and for the same spacing between electrodes  $D$ , the corona current is higher at smaller distances wire-to-strip  $D_b$ . Indeed, the discharge current decreases rapidly by increasing the distance between the wire and the strips.

### 3) Strips height effect

The corona  $I$ - $V$  characteristics shown in Fig. 5 exhibit the effect of the height of the strips, connected to the ground and situated at a constant distance  $D_b = 40$  mm from the ionizing wire. Under the same conditions, the increasing the strips height from  $L_b = 10$  mm to  $L_b = 30$  mm do not produced any significant modification of the corona current  $I_m$ . The increase of the ions production by corona discharge in such electrode configurations seems to depend to a little extent on the geometrical dimensions of the strips.

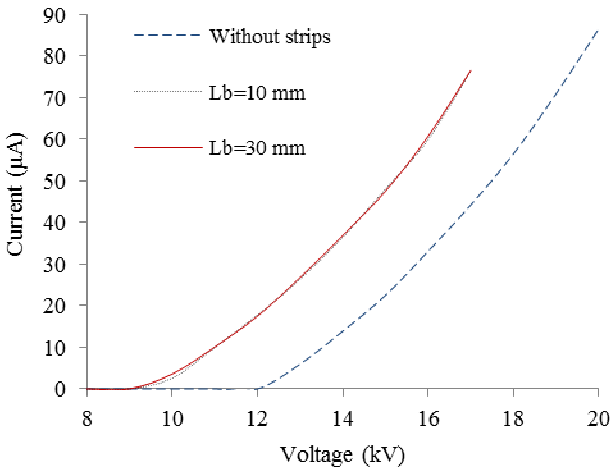


Fig. 5. Current–voltage characteristics of the wire-type dual arrangement with strips for different heights  $L_b$  ( $D = 30$  mm and  $D_b = 30$  mm).

### B. Current density repartition measurements

The study of corona current density distribution at the surface of the grounded plate electrode is an effective method for evaluating the charge density generated by the “dual electrode”. Measurements were made for the three electrode configurations (“dual electrode”, with and without shield or strips) and then for various distances wire-to-strip  $D_b$  at a given inter-electrodes spacing  $D = 30$  mm. The current density distribution on the surface of the grounded electrode (Fig. 6) indicates that the corona zone is larger for an electrode configuration with strips ( $D_b = 40$  mm) than for the wire-type “dual electrode” without strips. The presence of the shield with  $D_b = 40$  mm as well, produces a slightly higher current in the zone of the plate surface opposing the wire electrode. Decreasing the wire-to-strip distance  $D_b$  causes a wider corona discharge and higher current density values at the surface of the plate electrode as shown in Fig. 7, for both positive and negative polarities.

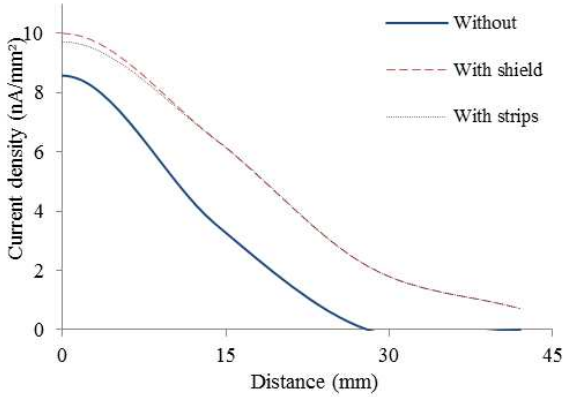
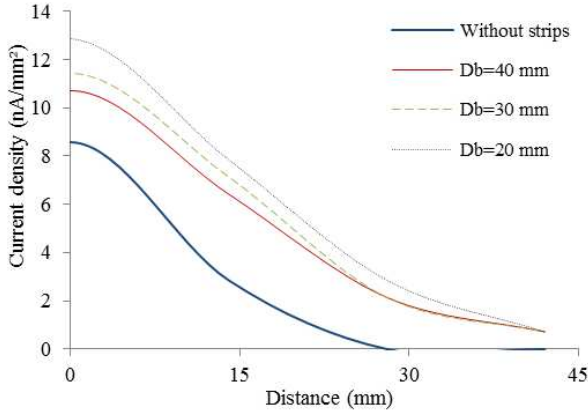
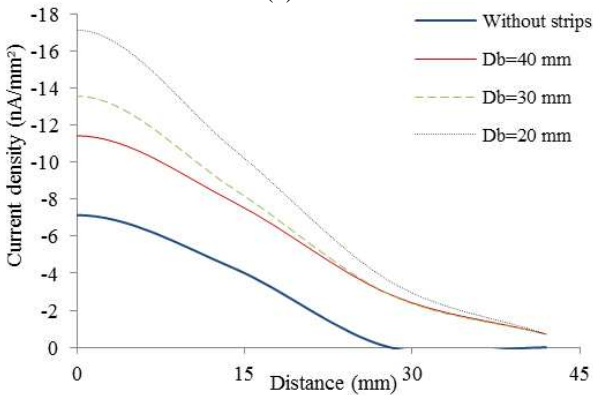


Fig. 6. Current density repartition along the  $x$  axis, for the wire-type "dual electrode" configuration with and without shield or strips ( $D = 30$  mm and  $D_b = 40$  mm).



(a)

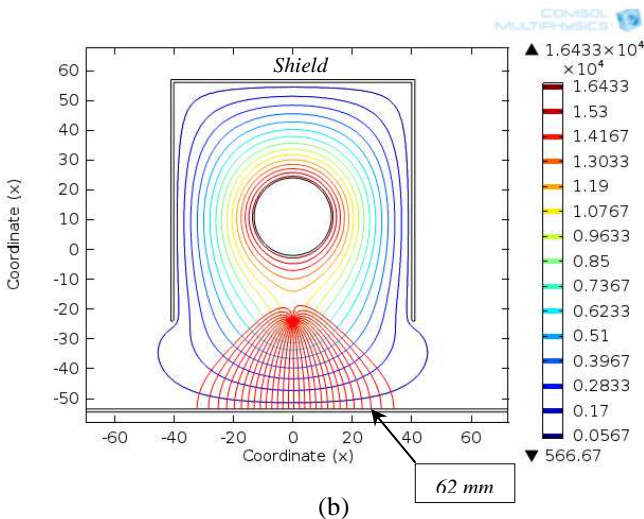
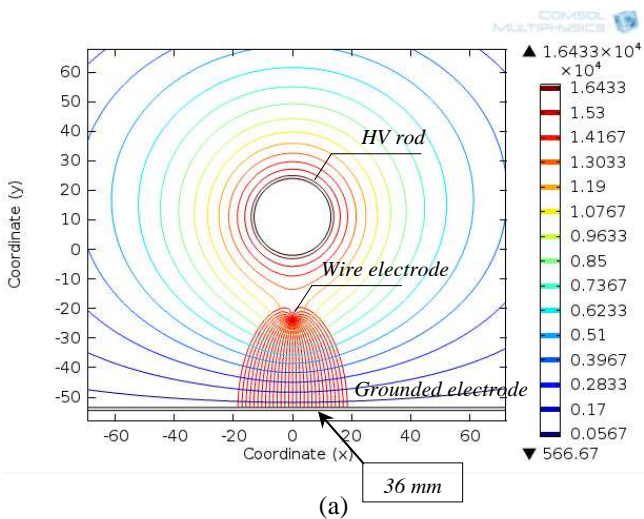


(b)

Fig. 7. Current density repartition along the  $x$  axis, for the wire-type "dual electrode" configuration with strips at different distances  $D_b$ , for  $D = 30$  mm at positive (a) and negative polarity (b).

## IV. NUMERICAL ANALYSIS OF THE ELECTRIC FIELD

The numerical analysis of the electric field is made with COMSOL MULTIPHYSICS; powerful software based on a finite element analysis to the calculation of the electrical quantities [19, 20]. The numerical results shown in Fig. 16 are the equipotential contours with the electric field lines originating from the ionizing wire for the three configurations under study. Indeed, under the widely accepted assumption that all the ions generated at the corona electrode follow the field lines to the plate electrode, the corona current should concentrate in a zone limited by the two aforementioned extreme field lines. As presented in Fig. 16, the plot of these lines exhibit the expanding of the discharge zone generated by both the shielded dual-type electrode and the configuration with strips in comparison with the standard “dual electrode” without metallic objects in proximity.





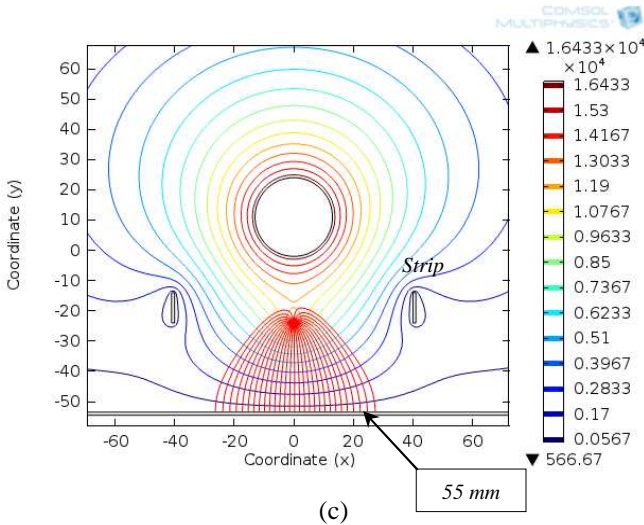


Fig. 16. Equipotential lines and electric field lines originating from the wire electrode for the three configurations ( $D = 30$  mm,  $V = 17$  kV): (a) without shield (b) with shield (c) with strips.

## V. CONCLUSION

The presence of metallic grounded bodies in the proximity of a wire-type dual electrode increases the magnitude of the electric field at the surface of the ionizing wire and hence modifies the conditions of corona discharge development. Thus:

1. The current-voltage characteristics point out that the presence of the grounded shield or strips near the corona discharge electrode is accompanied by the decrease of the inception voltage. The corona current measured at any given voltage is higher than for the “standard” wire-type “dual electrode”. There is no noticeable difference between the current-voltage characteristics of the configurations with shield or two strips.
2. The current density at the surface of the collecting electrode is drastically increased by the presence of grounded metallic objects in proximity of the corona wire. A significant modification of current repartition is recorded in the presence of the shield or the strips; this observation could be very useful in the optimization process of a new corona electrode system for different electrostatic applications, such as electrostatic separation..
3. The grounded strips with reduced surfaces could be more advantageous compared to the shield, in some situations where several high-voltage electrodes are located close to each other, as in the roll-type electrostatic separator.
4. Numerical analysis of the electric field may be used as a design tool in the development phase of new corona electrode systems. The repartition of the electric field predicted by numerical simulation may reveal the effects of presence of grounded metallic objects on the onset threshold and spatial repartition of the corona discharge.

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