Corona Discharge as Affected by the Presence of Various Dielectric Materials on the Surface of a Grounded Electrode

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ABSTRACT

This paper is aimed at the characterization of the corona discharge generated from a high-voltage wire electrode facing a grounded plate that carries dielectric layers composed of granules, sheets, and non-woven media. Current-voltage and current-frequency characteristics were measured, respectively in DC and AC modes, for several values of the thickness of the PE granular layer, PET sheets and PP non-woven media considered in the present study. The measurements show that the corona onset voltage and the behavior of the current-voltage characteristics are dependent on both nature and thickness of the dielectric layer. Both the estimated capacitive component and the ionic component in AC mode vary with the amplitude and the frequency of the voltage. The ionic component is particularly affected by material non-uniformity.

Index Terms — **Corona discharge, current-voltage characteristics, dielectric materials, insulating sheet, insulating granules, non-woven insulating media.**

1 INTRODUCTION

SEVERAL industry applications like xerography, electret filters and electrostatic separators require the charging of dielectric materials [1, 2], using the tribo-electric effect, the corona discharge, or the electron beam. Among these techniques, the corona effect is widely used to generate the required electric charge that can be deposited on the surface of the dielectric material when present in the discharge zone [3]. Corona discharge is also effective in the neutralization of electric charges at the surface of dielectric materials. The neutralization is a consequence of the recombination process between these charges and the ions generated by corona discharge [4, 5]. Corona discharge based neutralizer can be a very efficient tool when using appropriate voltage levels and frequencies. Indeed, previous studies have shown that the increase in frequency enhances significantly the neutralization efficiency [6, 7]. Nevertheless, the role of applied voltage frequency and the link with the amount of neutralized charge needs to be clarified. In either situation, charging or neutralization, the dielectric materials laid on the surface of the grounded electrode facing the corona electrode can alter the behavior and characteristics of the discharge.

Indeed, various secondary phenomena can take place during charging/neutralization process, like back-corona discharge [8, 9]. In fact, the corona discharge in the presence of a dielectric material, also called barrier corona [10], has already been the object of study, especially in relation with material charging characteristics [11-18].

The aim of the present paper is the characterization of corona discharge when a dielectric material is placed on the grounded electrode. More specifically, the study has in view to determine the influence of several forms of dielectric materials (sheets, granule and nonwoven media) on the corona discharge current, at different voltage amplitudes and frequencies. The current-voltage and current-frequency dependences are employed to characterize the global behavior of the corona electrode system, by measuring the mean and RMS values of the discharge current for DC and AC voltage, respectively. Characterization of corona discharge behavior is expected to be helpful in the analysis of the charging or neutralization process of dielectric materials.

2 METHODOLOGY

Three dielectric materials are used in this study: polyethylene terephthalate (PET) sheets, polyethylene (PE) granules and polypropylene (PP) non-woven media (Figure 1a). These materials present the most common forms employed in different industrial applications. Thus, PET sheets are widely used in packaging, the plastic processing industry makes use of polymers in granular form, and waste plastics are grinded in view of recycling by means of

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electrostatic separation technologies. As for the non-woven media, they are commonly employed as filters, which are often electrostatically charged to enhance their efficiency [19]. The three considered materials have quite close relative permittivity values: ε_{rPE} =2.3-2.4, ε_{rPP}= 2.2-2.6 and ε_{rPET}=3 [20].

The samples dimensions are taken large enough to cover the lower grounded electrode: PET sheet (200 mm x 200 mm; thickness: 2 mm and 3 mm); PE granular layer (110 mm x 125 mm; weight: 18 g), composed of quasi spherical particles 3 mm in size; PP non-woven media (200 mm x 240 mm; thickness: 0.4 mm).

The corona discharge is generated in a wire-plane electrode configuration, energized from AC or DC high voltage supplies (Figure 1b).The current-voltage characteristics are measured in the DC mode for the three types of considered dielectric materials, with thickness varying in each case. In the AC mode, the influence of the frequency on the discharge current is measured.

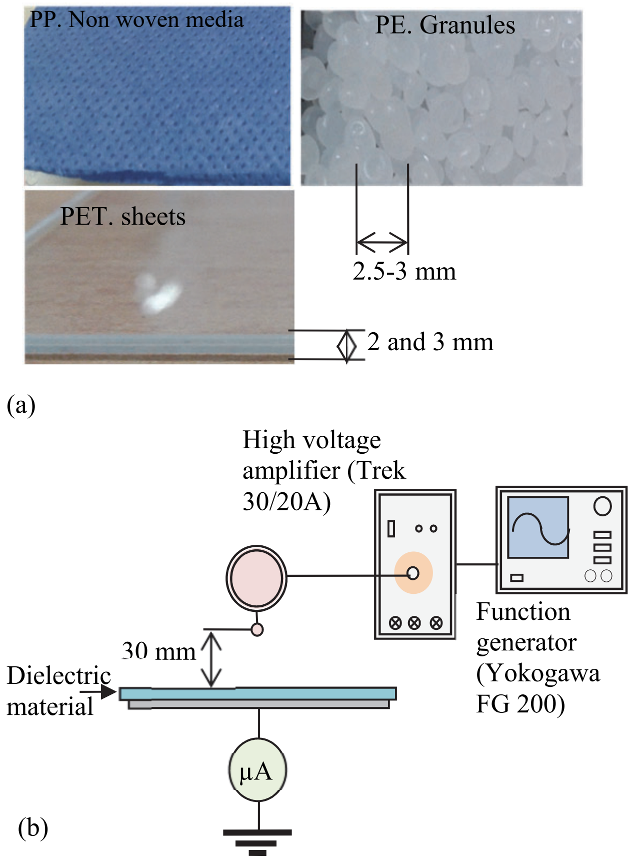


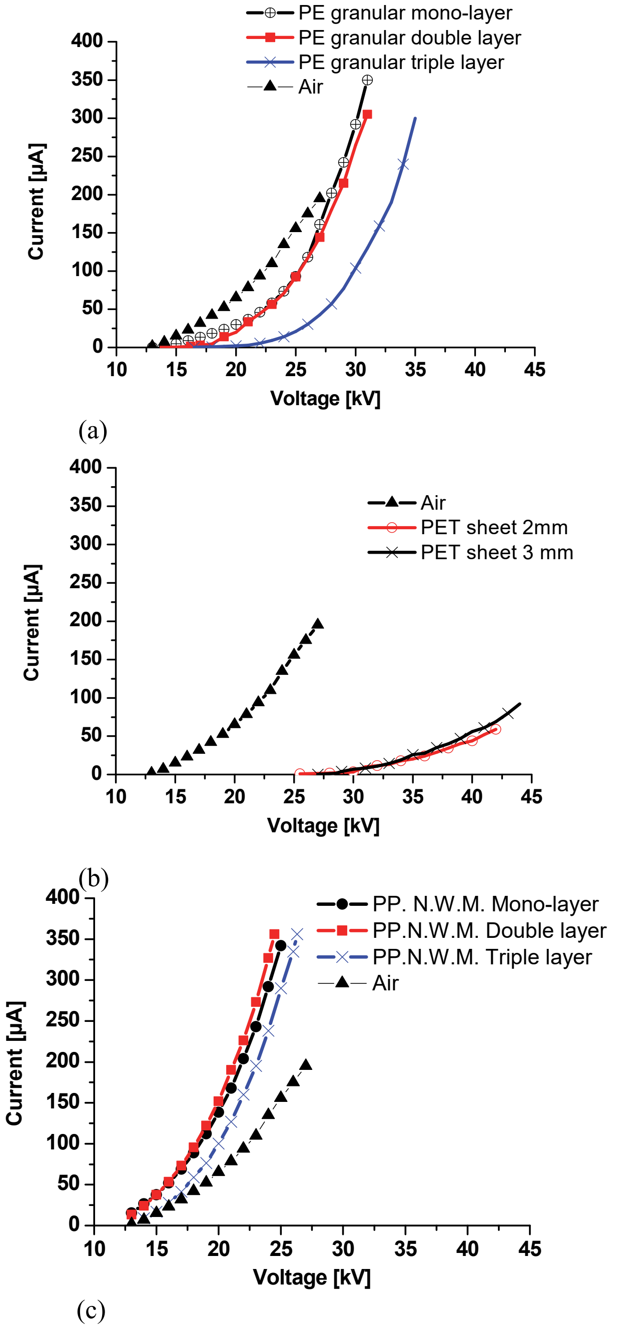
Figure 1. (a) Photography of the used dielectric materials, and (b) Schematic representation of the experimental set up.

The dielectric material is laid on a metallic plate (aluminum, dimensions: 120 mm x 90 mm) connected to the earth through an ammeter. The “standard” corona dual-type electrode employed in all the experiments is positioned at 3cm above the dielectric; it consists in a tungsten wire (0.2 mm in diameter)attached to a metallic cylinder (25 mm in diameter) and placed at 34 mm from its axis. The dual electrode is energized either from a high voltage amplifier (Trek Inc, 30/20A), delivering an AC voltage (Figure 1b), or from a positive DC high voltage power supply (Spellman, SL 300).

3 RESULTS AND DISCUSSION

3.1 DC CORONA DISCHARGE

Figure 2 shows the current-voltage characteristics of the DC corona discharge with the grounded collecting electrode covered by PE granular material, PET sheets and PP non-woven media.



(a)

(b)

(c)

Figure 2. I–V characteristics: (a) PE granular material, (b) PET sheet and (c) PP Non-Woven Media.

The characteristics of the corona discharge are dependent on the type of the dielectric material. Indeed, in the case of PP non-woven media, the discharge process begins earlier and progresses more rapidly than with the other materials. For the PE granular material, the corona onset voltage is close to that recorded in the case of PP non-woven media, but the current-voltage characteristics is less steep. In the case of PET sheets, the onset voltage is much higher than in the previous cases; the sheets hinder the discharge development and limit the current growth. The observed behavior in the three types of dielectric materials may be explained by the modification of the electric field intensity in the air gap between the dielectric media and the wire. Besides the presence of dielectric media with different values of permittivity, the accumulation of electric charges deposited on the surface of the material will diminish the potential difference across the air gap, and hence the electric field strength. As consequence, the breakdown voltage is drastically increased [21]. Another observation that can be made is that the dielectric media uniformity seems to play an important role in the discharge development. Indeed, the current increases more with respect to the applied voltage, in the case of PP non-woven media then in PE granular material or the dielectric sheet. The reason is, on one hand, that the interstitial paths in PP non-woven media and PE granular layer facilitate current flow, and on the other hand, that the electric charge accumulation is more important and more uniform on sheets than on the other materials, which means that the barrier effect is accentuated in this latter case. Other secondary phenomena due to material non-uniformity can also lead to the current increase: back-corona and partial discharges dues to the granular or fibrous structure of the PE and PP samples [22].

3.2 AC CORONA DISCHARGE

The variation of corona discharge current (R.M.S value) as function of the frequency of applied voltage is shown in Figure 3. The relationship between the discharge current and the frequency is almost linear whatever the material is; the higher the frequency, the higher is the current at the collecting electrode. The voltage magnitude affects mainly the slope of the current-frequency curves. As the voltage is raised, the measured current increases more steeply with the frequency. This result can be explained by taking into account the two components that can form the current in the drift region near the grounded electrode: the ionic component (i_{ionic}) and displacement component (i_{disp}) [23]. So, in the time domain, the total current is:

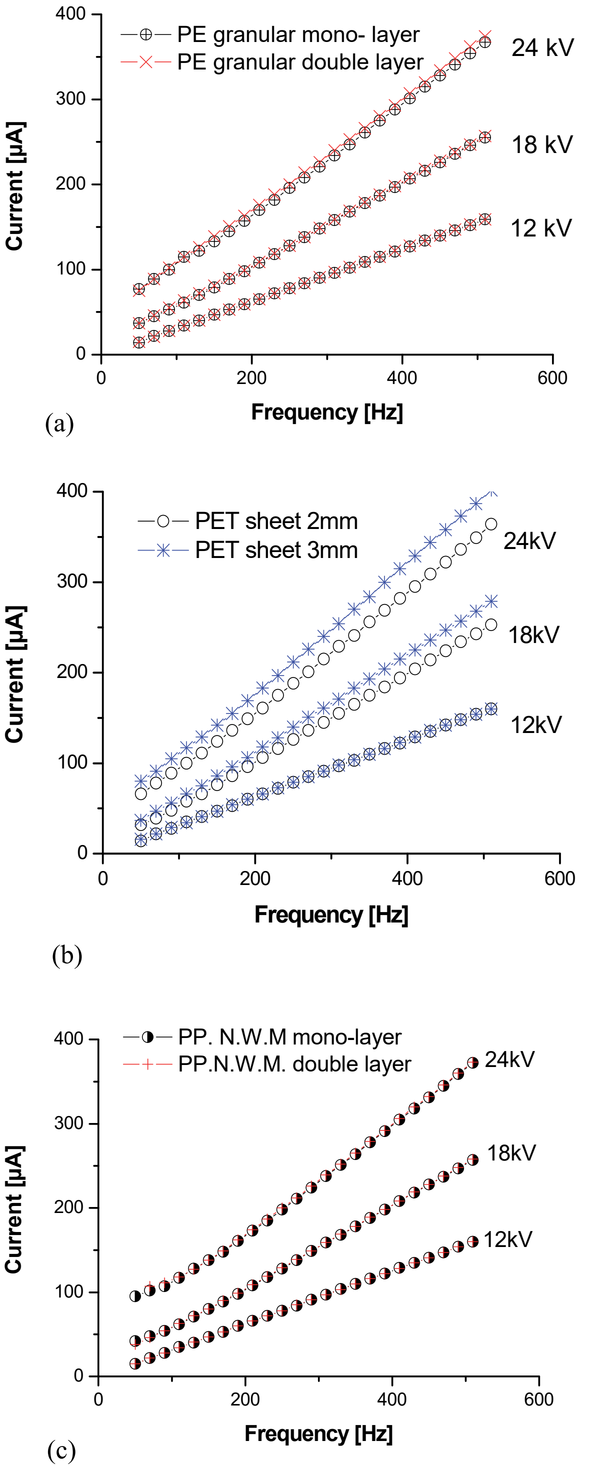
$$i_{tot}= i_{ionic}+ i_{disp} \tag{1}$$

The ionic component is mainly formed by the electric charges generated by the discharge mechanism and drifted towards the grounded electrode by the electric field (*E*). The ionic component is a non-sinusoidal function of time; it contains a fundamental and a sum of harmonics. However, as the harmonic signals are low as compared to the fundamental, the ionic current waveform can be considered to be quasi-sinusoidal and synchronized with the electric filed.

The displacement component is due to the time variation of the electric field:

$$i_{disp}= S.\varepsilon.\ dE/dt. \tag{2}$$

where S is the surface of the grounded electrode and ε the equivalent permittivity of the inter-electrode space.



(a)

(b)

(c)

Figure 3. Current (R.M.S)–frequency characteristics at three voltage levels 12 kV, 18 kV and 24 kV for: (a) PE granular material, (b) PET sheets and (c) PP. non-woven media.

Hence, this component is proportional to the media permittivity (considered independent of time [24]) and the dynamic of electric field. Since the applied electric field is sinusoidal, the displacement component is shifted of π/2 in advance to the applied voltage. The total current is therefore formed by the sum of two perpendicular phasors and, consequently, its amplitude is:

$$I_{tot} = \sqrt{I_{ion}^2 + I_{disp}^2} \qquad (3)$$

With consideration of obtained results (Figures 3 and 4), the current-frequency relation is quasi linear even in the presence of a dielectric layer on the surface of the grounded electrode. However, the slopes of the current-frequency characteristics are different. For high voltage and frequency values (beyond 200 Hz), the current measured for the 3-mm-thick PET sheet is higher than for the other materials (Figure 4b and Figure 4c). This can be attributed to the amount of trapped [25] charge at the surface of the samples. Indeed, since the electric field across the PET sheets is weak, the deposited charges cannot be injected in the bulk [26]. At the same time, it would take a lot of time for the charges to move along the surface, because of the large dimensions of the samples [27]. As a consequence, the charges are blocked on the surface. Therefore, the highly charged material facing the AC corona electrode enhances the electric field in the air gap and hence the discharge current is increased.

Based on equation (2) and in accordance to the obtained results (Figure 3 and Figure 4), the R.M.S value of the displacement current may be expressed as a function proportional to the voltage and frequency:

$$I_{cap} = k.\,f.\,\mathrm{U} \qquad (4)$$

The proportionality coefficients, *k*, can be deduced from the total current before the establishment of the discharge such as:

$$k = (dI_{tot}/df)/U \qquad (5)$$

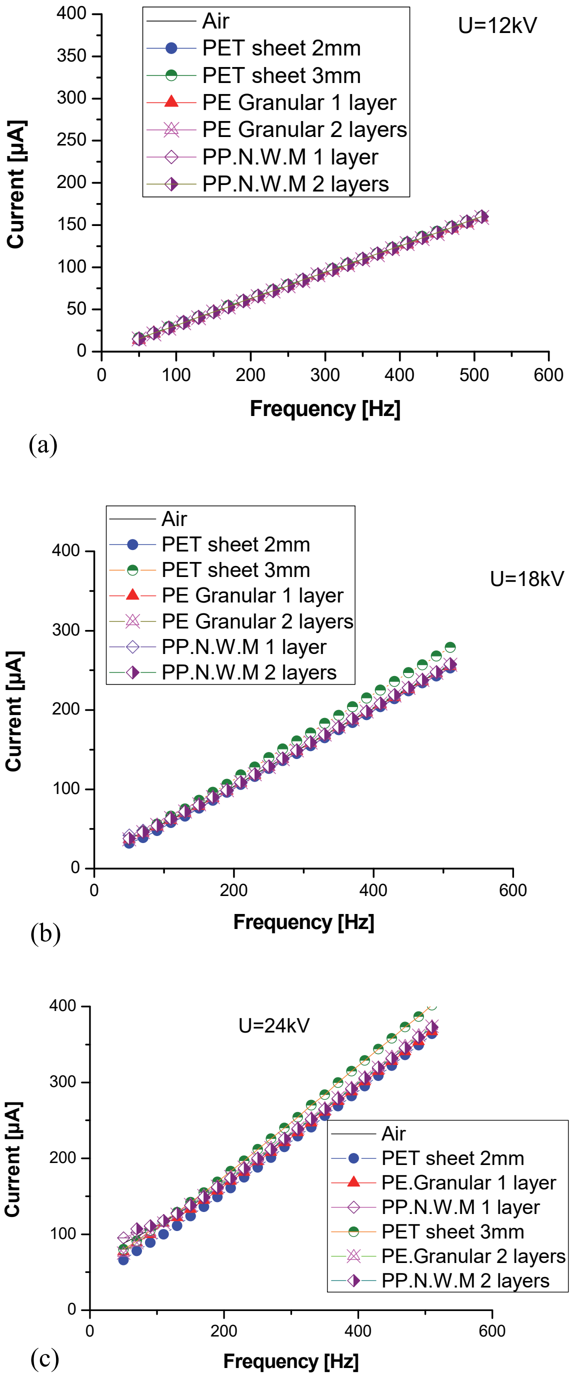
This allows the determination of the ionic current from equation (3) for applied voltage levels exceeding the discharge onset.

In this paper, the "*k*" coefficient is calculated for the lowest voltage value (12 kV), where current is almost capacitive, since the ionization process is weak and the ionic component can be neglected (Table 1).

Table 1. The calculated values of "*k*" coefficient.

Material	k $(A.s.V^{-1})$
Air PE Granules PP.N.W.M PET sheet	$2.6268\ 10^{-5}$ $2.6268\ 10^{-5}$ $2.6268\ 10^{-5}$ $2.6449\ 10^{-5}$

Figure 5 shows the capacitive and the ionic components estimated from the total measured current using equations (3), (4) and (5). As indicated in Table 1, the coefficient "*k*" is the same for all the cases, except for PET sheets where it is slightly higher. This means that the current varies in the same way as function of the frequency, and that the capacitive current is almost the same for all materials (Figure 5a). However, the capacitive current is expected to be most important in case of PET sheet, than the other materials, based on values of "*k*" coefficient (Table 1).



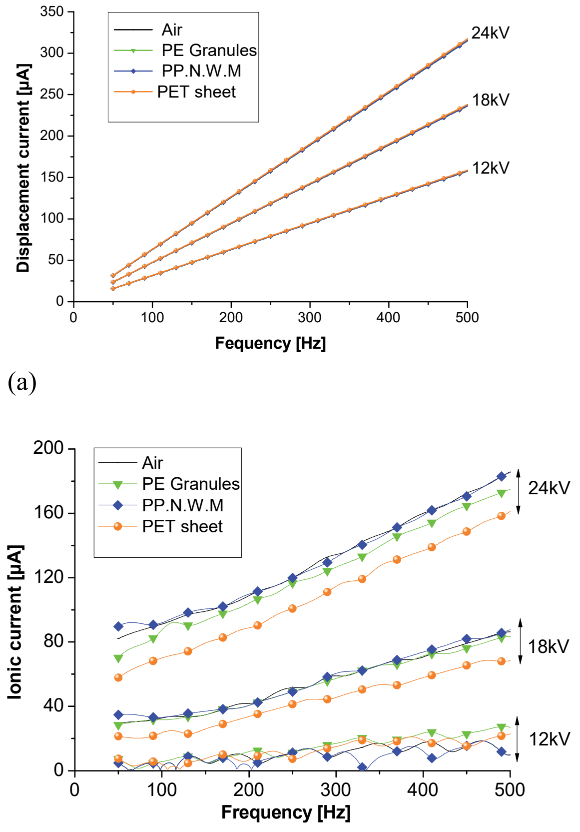
(a)

(b)

(c)

Figure 4. Current (R.M.S) - frequency characteristics: effect of the material (a) 12 kV, (b) 18 kVand (c) 24 kV.

The ionic current is in turn function of frequency and voltage amplitude. Unlike the capacitive current, the ionic current is dependent on the dielectric material type. The ionic current for the PP. N.W.M is practically equal to the ionic current in the absence of any dielectric layer on the surface of the grounded electrode. This is also true for the PE granules for 18 kV, but at 24 kV, the current is lower than in the reference case (air). As for PET sheet, the ionic current is clearly lower than in the other cases. The porous or granular materials allow more ionic current flow to the ground. Conversely, the PET sheets acts as a barrier and reduces thereby the ion flow. However, the total current is higher in the case of PET, as its capacitive component is higher than that estimated for the PE granules and the PP non-woven media. The capacitive component increases rapidly with the frequency and can be several times larger than the ionic current at higher frequencies, depending on material and voltage amplitude.



(a)

(b)

Figure 5. Discharge current components calculated for three voltage levels (12kV, 18kV, 24kV):(a) displacement component, (b) ionic component.

For the same voltages, the comparison between Figure 5b and Figure 2, presenting discharge characteristics under DC voltage, shows a close values of the order of magnitude of ionic current and total DC current. However, there should be a difference since in AC voltage the ionic current must be smaller because of voltage duration and variation between positive and negative values.

4 CONCLUSIONS

In this paper, the corona discharge generated from a high-voltage wire electrode facing a grounded plate in the presence of dielectric materials has been characterized. The main results of this experimental study are as follows:

(1) I–V characteristics in DC corona discharge are dependent on the dielectric material: onset voltage is higher in the case of thick and uniform sheets. The current increases quite steep with the applied voltage in the case of non-uniform materials, such as granular layers and non-woven media.

(2) The discharge current is proportional to the frequency; the relationship is almost a straight line the gradient of which depends on the material permittivity and especially voltage amplitude. Current-frequency characteristics of PET sheets, PE granular material and PP non-woven media are almost the same in the considered frequency range. However, at high frequency and for higher voltages, the PET sheets allow slightly higher discharge currents when compared with PE granules and PP media.

(3) The ionic component is a function of the voltage amplitude and frequency. The material under discharge can affect the ionic current. The capacitive component forms the most part of the discharge current but the ionic current plays an important role in processes like charge neutralization using AC corona discharge.

Further investigations are planned to understand the mechanisms behind the ionic current component inside a dielectric material deposited on the grounded electrode in the case of AC corona discharge.

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