Factors that Influence the Decay Rate of the Potential at the Surface of Non-woven Fabrics after Negative Corona Discharge Deposition

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Abstract— **Surface potential decay (SPD) measurements are considered as the most appropriate technique for the investigation of the corona charging of dielectric surfaces. The aim of the experiments reported in the present paper was to point out the peculiarities of SPD in the case of non-homogeneous dielectrics, such as the non-woven fabrics employed for heat, ventilation and air conditioning. This study reports experimental data collected on two types of polypropylene (PP) media, characterized by different fiber diameters. The experiments were performed on 60 mm x 50 mm samples of non-weaved sheets of PP (sheet thickness: 300 µm; average fiber diameter: 20 µm), in ambient air (temperature: 18°C to 22°C; relative humidity: 25% to 60%). The samples were charged for 10 s by exposing them to the negative corona discharge, using a triode-type electrode arrangement, energized from a DC high-voltage supply. Their surface potential was then measured with an electrostatic voltmeter. The measured data indicate that the charge of the filter is limited by the local discharges that occur inside the fibrous dielectric.**

Index Terms— **electric charge, corona discharge, dielectric materials, surface potential decay**

I. INTRODUCTION

SURFACE potential decay (SPD) measurements [1-4] have been extensively employed for the investigation of the corona charging of dielectric surfaces, due to their reliability and low cost [5-8]. The development of this field of research has been stimulated by industry demand related to adjustment of Xerox-photography processes, development of electrets, assessment of cable insulation, evaluation of electrostatic risks or monitoring of aged insulators [9-12].

Most of the literature on SPD deals with homogenous dielectrics, such as insulating films or plates. Several mechanisms are involved in surface potential evolution of such materials: atmospheric neutralization, surface conduction, polarization, intrinsic conduction, piezoelectricity, interfacial charge injection, and so on [13].

The peculiarities of SPD in the case of non-homogeneous dielectrics, such as the non-woven fabrics employed for heat, ventilation and air conditioning, were the object of relatively fewer studies [14, 15]. Most of them aimed at identifying the factors that affect the collection efficiency of these materials when employed as air filters, as the electrostatic forces acting on charged particles might trap them on the charged fabrics.

Thus, Oda and Ochiai [16] reported several interesting observations regarding the corona-charging characteristics of a non-woven poly-propylene (PP) sheet air filter: (1) the surface potential of the filter media is limited by the local discharges that occur inside the porous sheet; (2) the surface potential profile becomes rougher with the increase of the voltage applied to the corona-charging electrode system; (3) the relative humidity of ambient air accelerated the SPD. Horenstein [17], as well as Kacprzyk and W. Mista [18] confirmed the limitation of the surface potential that can be attained by high-resistivity corona-charged fabrics.

Walsh and Stenhouse [19], as well as F.J. Rornay et al [20] pointed out the effect of using mixed fibers of various layouts on the efficiency collection of the electret filters. However, it is important to relate the operating characteristics of the filters to their charging state. A good filter is the one that is capable to preserve as long a time as possible a high level of charge, and hence a high collection efficiency.

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In two previous papers [21, 22], the authors studied the positive corona-charging of a PP non-woven media. They pointed out that a triode-type electrode arrangement may improve uniformity of corona-charging, though it does not significantly increase the charge imparted to the samples. For this polarity, the surface charge density seems to be limited at 8 $\mu C/m^2$ when the samples are in contact with a grounded electrode and exposed to uncontrolled ambient conditions.

The aim of the experiments reported hereafter was to expend that study to the case of negative corona-charging, in order to facilitate a more in depth analysis of charge decay phenomena, as influenced by the ambient conditions and by the fibrous structure of the tested media.

II. MATERIALS AND METHODS

The experiments were performed on 60 mm x 50 mm samples of two non-woven polypropylene (PP) media, designated as M1 and M2 (Fig. 1), in ambient air (temperature: 18°C to 22°C; relative humidity: 25% to 60%). The thickness is the same for both medias: 400 μm. M1 is entirely made of 2.8 dtex PP fibers (average fiber diameter: 20 μm), while M2 is a mixture of 85% of 2.8 dtex PP fibers and 15% of 0.1 dtex PP fibers (average fiber diameter: 4 μm).

The triode-type electrode arrangement employed for the experiments is shown in Fig. 2 (a). The electrode system is energized from a negative DC high-voltage sypply (model SL 300 Spellman, Hauppauge, NY). The corona discharge is generated between a wire-type dual electrode [23] and a metallic grid electrode, shown in Fig. 2 (b). In all the experiments, the samples were charged for 10 s (a duration beyond which no significant increase of the initial surface potential was noticed), at various grid potentials

The dual electrode consists of a tungsten wire (diameter 0.2 mm) supported by a metallic cylinder (diameter 26 mm), distanced at 34 mm from its axis, and energized from the same high-voltage supply. Unless otherwise specified, the distance between the wire and the plate electrode is 30 mm.

The grid is connected to the ground through a series of callibrated resistors having a total resistance R. In this way, for the constant current I = 100 μA delievered by the power supply, a well-defined potential $V_g = RI$ is imposed between the grid electrode and the grounded plate on which the samples are placed. Part of the charge carriers generated by the corona electrode pass through the grid and are driven by this potential to the surface of the non-woven media, which retains them. The potential at the surface of the media V_m due to the accumulation of these charges is limited by either the potential of the grid V_g or by the partial discharge voltage of the sample V_b. Indeed, when $V_m = V_g$ the electric field in the air gap between the grid and the sample is zero, the charge carriers are no longer attracted by the surface of the media, and no more charge can be deposited on the fabric. The potential at the surface of the media V_m can be increased by increasing the potential of the grid electrode V_g. However, as soon as $V_g > V_b$, partial discharges occur in the media, so that the potential V_m that is measured at the surface of the samples can never exceed V_b.

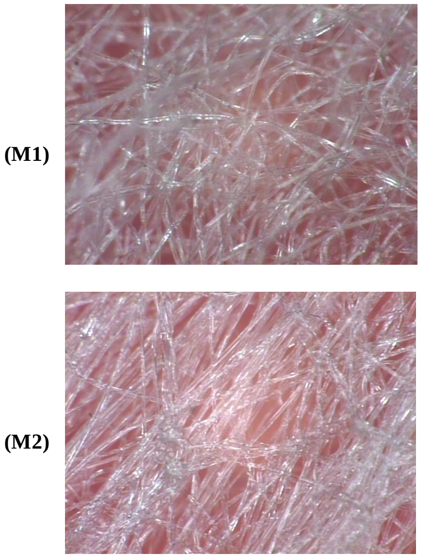
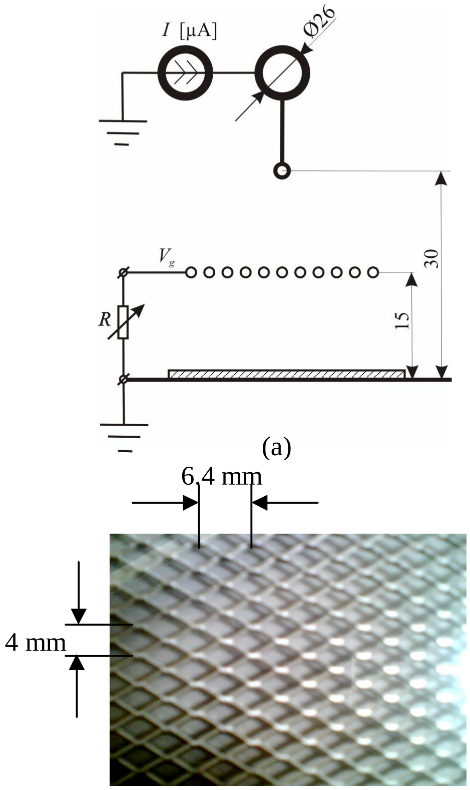


Fig. 1. Photograph of the non-woven polypropylene media.



(a)

(b)

Fig. 2. Electrode systems employed for the corona-charging of non-woven media (all dimensions are in milimeters); (a) wire-type dual electrode facing a grounded plate; (b) triode-type arrangement; (c) aspect of the grid electrode (grid wire diameter: 1.18 mm).

The surface potential of the samples is measured with an electrostatic voltmeter (model 341B, equiped with an electrostatic probe model 3450, Trek Inc., Medina, NY) and monitored via an electrometer (model 6514, Keitheley Instruments, Cleveland, OH), connected to a personal computer (Fig. 3). The processing of the data is performed using a virtual instrument, in LabView environment.

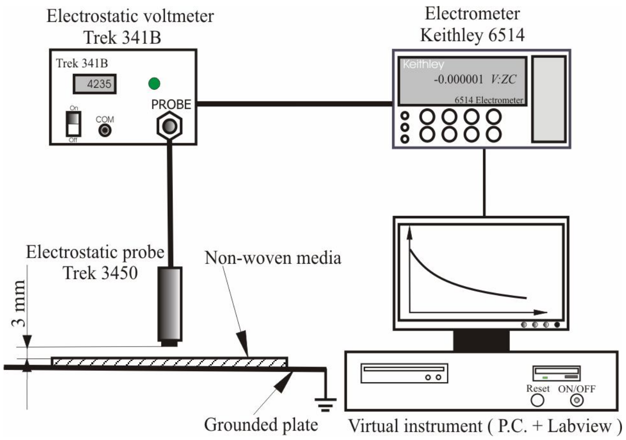


Fig. 3. Experimental set-up for the measurement of the surface potential

III. RESULTS AND DISCUSSION

The average surface potential decay curves recorded for media M1 corona charged using several values of the potential V_g of the grid electrode are displayed in Figs. 4 and 5. The initial value V_{mo} of the potential V_m measured at the surface of the media increased progressively with the voltage applied to the grid, as long as $|V_g| < 1.5$ kV (Fig. 4). At $|V_g| > 1.5$ kV (Fig. 5), the initial surface potential remains pratically the same as the one obtained for $V_g = - 1.22$ kV, that is: $V_{mo}^{(max)} = 0.9$ kV. It is sure that at the moment when the high-voltage supply is turned off the potential V_s at the surface of the media is closer to V_g, but it decays rather fast. Therefore, the potential $V_{mo}^{(max)}$, which is measured 3 s after the high-voltage turn-off, is only roughly 0.75 V_g.

At higher voltages applied to the grid electrode, the so-called cross-over phenomena occurred (Fig. 5): the initial surface voltage is higher, but the decay is faster, due to a physical mechanism explained by several researchers [1-4]. Thus, at 15 min after high-voltage turn-off (Fig. 6), the potential at the surface of the media is $V_{m(15\ min)} = 730$ V, for $V_g = 3.09$ kV, which is lower than $V_{m(15\ min)} = 800$ V, and $V_{m(15\ min)} = 850$ V, recorded respectively for $V_g = 2.05$ kV and $V_g = 1.22$ kV. Thus, the best charging effect is obtained for a grid voltage $V_g = - 1.22$ kV, as can also been seen in Fig. 7, which was obtained by processing the experimental data using the SURF function of Matlab.

Heating the samples prior to corona-charging may change the aspect of surface potential decay curves (Fig. 8), due to two competing physical mechanisms: (i) the increase of the volume conductivity with the increase of the temperature; (ii) the decrease of the surface conductivity with the evaporation of part of the adsorbed water. The former mechanism is responsible for the fast decay of the surface potential during the first three minutes after corona-charge deposition. As the temperature decreases with time, this effect vanishes and the surface potential decay slows down.

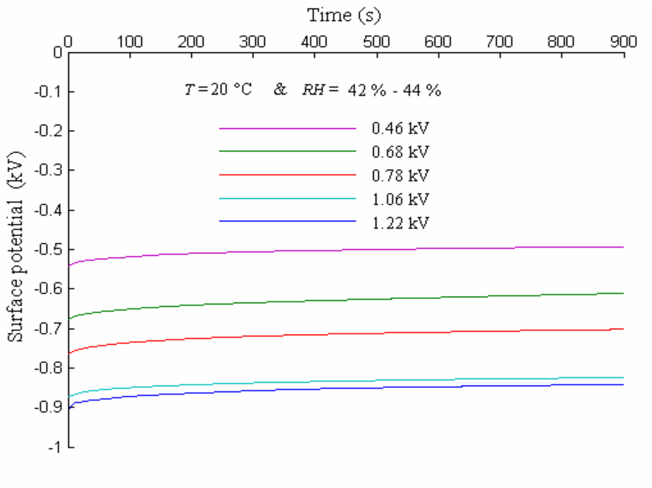


Fig. 4. Typical surface potential decay curves obtained for media M1 at various potentials of the grid electrode $V_g < 1.5$ kV.

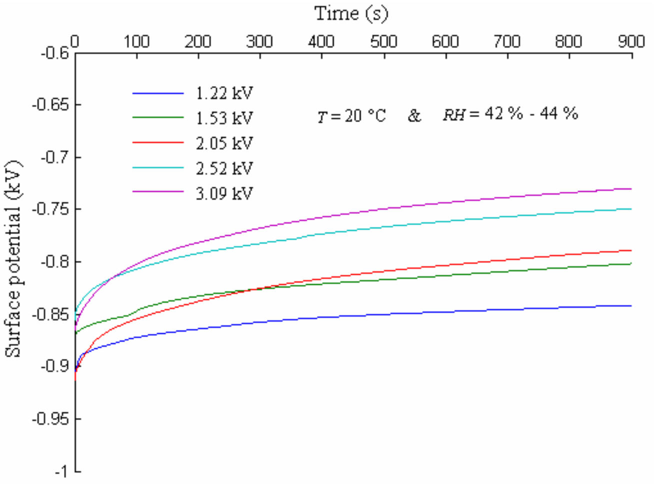


Fig. 5. Typical surface potential decay curves obtained for media M1 at various potentials of the grid electrode $V_g > 1$ kV.

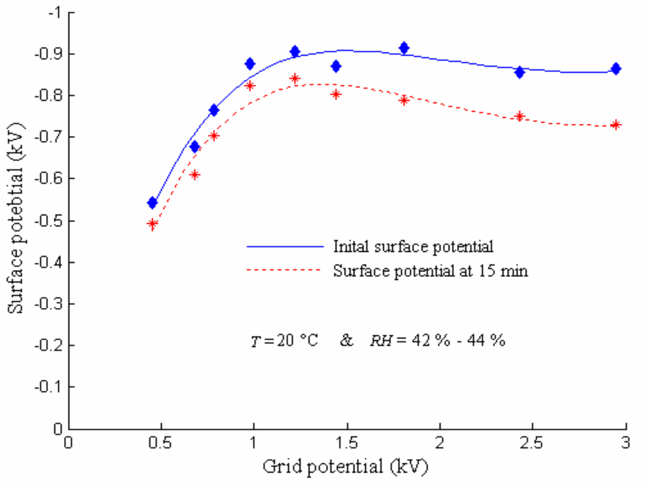


Fig. 6. Surface potential of media M1 measured at $t = 0$ s and $t = 15$ min as function grid potential V_g. Each point is the average of at least three measured values. The maximum dispersion range was 20%, for $V_g = 3$ kV.

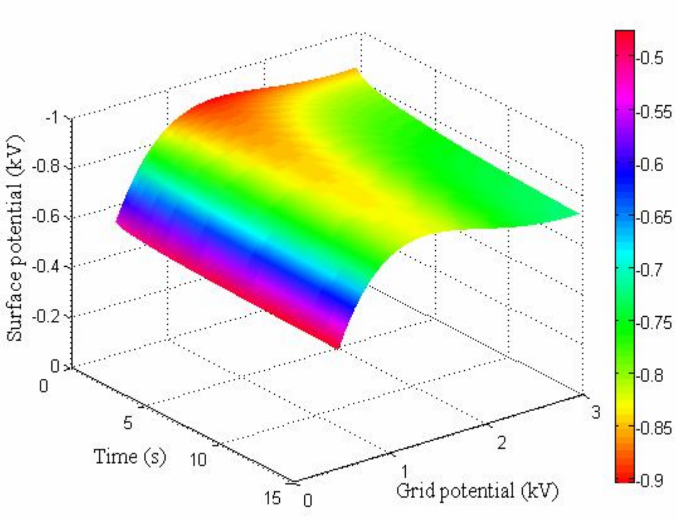


Fig. 7. Estimated average values of the surface potential of media M1 as function of time t and grid potentail V_g.

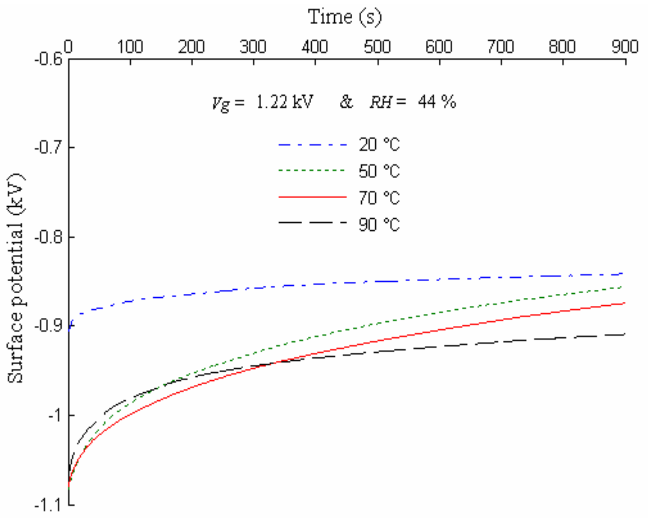


Fig. 8. Typical surface potential decay curves obtained for media M1 corona-charged using a grid electrode potential V_g = 1.22 kV, after being heated to various temperatures: θ = 20°C, 50°C, 70°C and 90°C.

The comparison between the surface potential decay curves obtained for heated and non-heated samples is in the favor of the former. The dried samples preserved better the charge than those that were not thermally conditionned.

The influence of the superficial moisture on the surface potential decay characteristics is confirmed by the results displayed in Figs. 9 and 10, which were obtained for samples that had been maintained for more than 24 h in a relatively dry atmosphere (RH < 25%). For these samples, the surface potential had a higher initial value V_{so} and decayed at a slower pace. The curves in Fig. 11 clearly show that the potential V_m at the surface of the non-woven media M1 was at any time and for any grid potential V_g higher in the experiments performed with samples maintained at lower ambiant humidity.

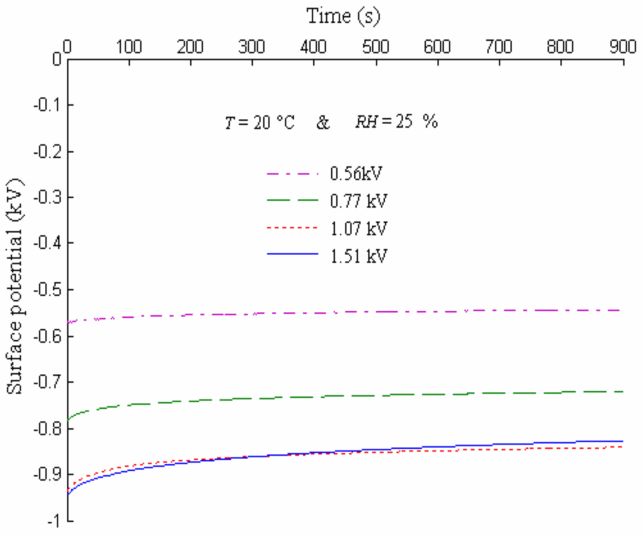


Fig. 9. Typical surface potential decay curves obtained for media M1 at various potentials of the grid electrode V_g < 1.5 kV, at low ambient humidity.

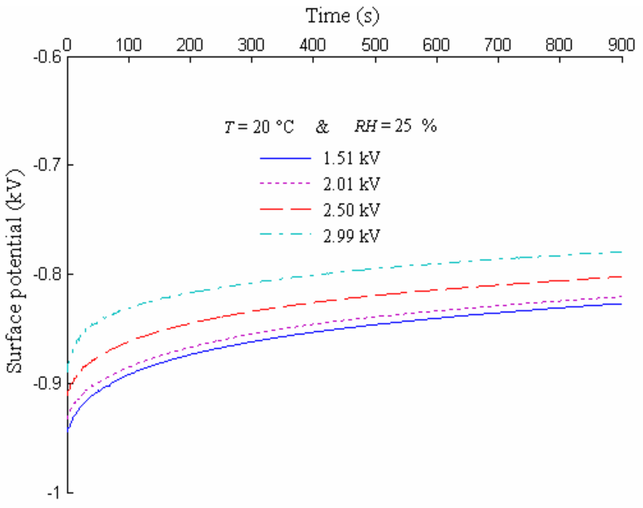


Fig. 10. Typical surface potential decay curves obtained for media M1 at various potentials of the grid electrode V_g > 1 kV, at low ambient humidity.

The surface potential decay curves obtained in all these negative-corona charging experiments have a different aspect than those previously recorded at positive polarity of the high-voltage supply that energizes the electrode system [21, 22]. The initial surface potential measured for the positive corona was higher than for negative corona, but the dispersion of the measured values was larger. On the other hand, the surface potential at 15 min was always higher for the negative polarity.

The comparison between these curves point out that the nature of the ionic species generated by the negative corona favors the retention of the charge by the non-woven PP. In spite of the fact that negative corona is accompanied by the generation of a larger quantity of ozone, this polarity is recommended for the development of an industrial corona-charging process for this type of filter media.

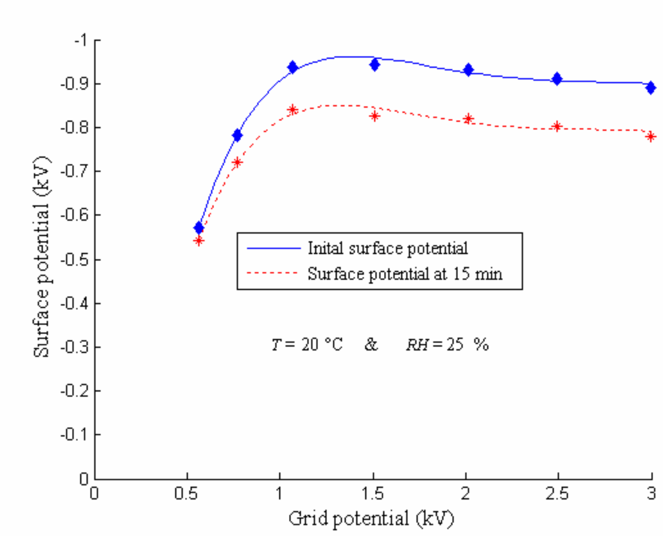


Fig. 11. Surface potential of media M1 measured in low humidity ambient air, at $t = 0$ s and $t = 15$ min as function grid potential V_g. Each point is the average of at least three measured values. The maximum dispersion range was 15%, for $V_g = 3$ kV.

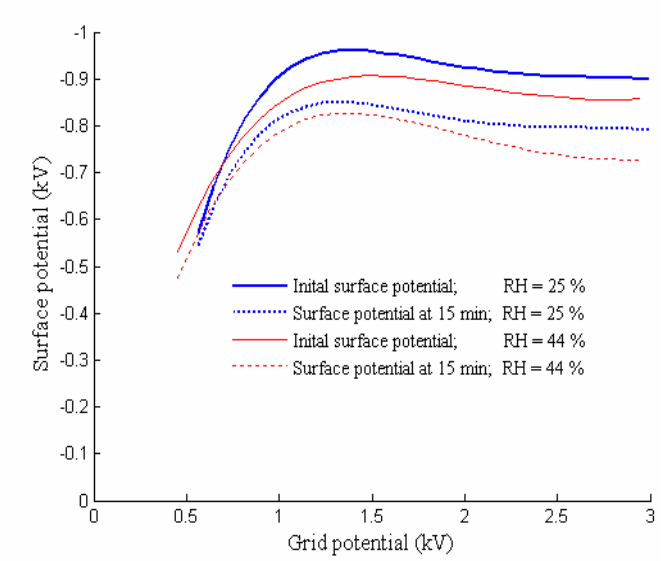


Fig. 12. Comparison between the surface potential of media M1, at two values of the relative humidity of ambient air, at $t = 0$ s and $t = 15$ min, as function grid potential V_g.

The experiments on media 2 were done at low relative humidity of the ambient air: *RH* = 25%. The average surface potential decay curves recorded for this media when corona charged using several values of the potential V_g of the grid electrode are displayed in Figs. 13 and 14. Similar to media M1, the initial value V_{mo} of the potential V_m measured at the surface of the media M2 increased progressively with the voltage applied to the grid, as long as $|V_g| < 1.5$ kV (Fig. 13).

At $|V_g| > 1.5$ kV (Fig. 14), the so-called "cross-over" phenomena occurred, but the surface potential values measured right after and 15 min after high-voltage turn-off (Fig. 15) remained pratically the same as the one obtained for $V_g = -1.08$ kV, that is: $V_{mo}^{(max)} = -1$ kV and $V_{m(15\ min)} = -0.9$ kV.

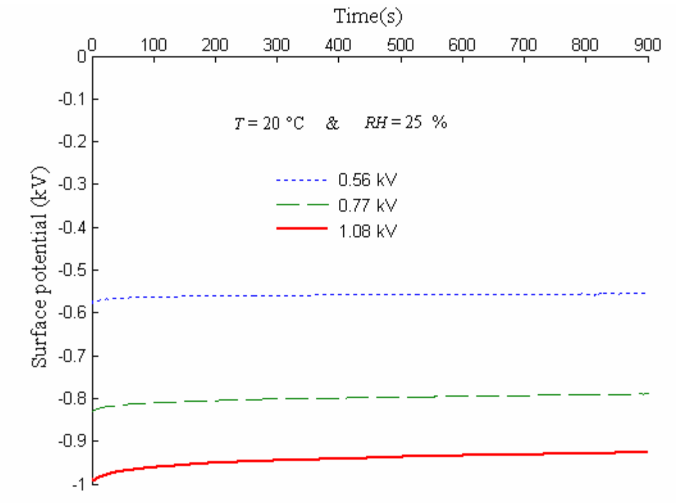


Fig. 13. Typical surface potential decay curves obtained for media M2 at various potentials of the grid electrode $V_g < 1.5$ kV.

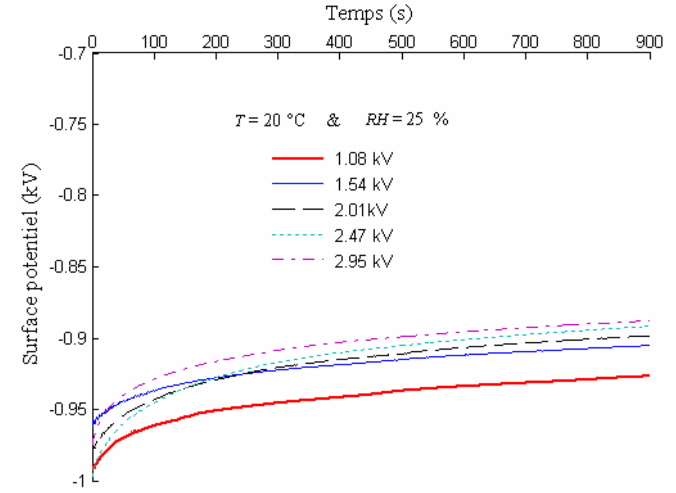


Fig. 14. Typical surface potential decay curves obtained for media M2 at various potentials of the grid electrode $V_g > 1$ kV.

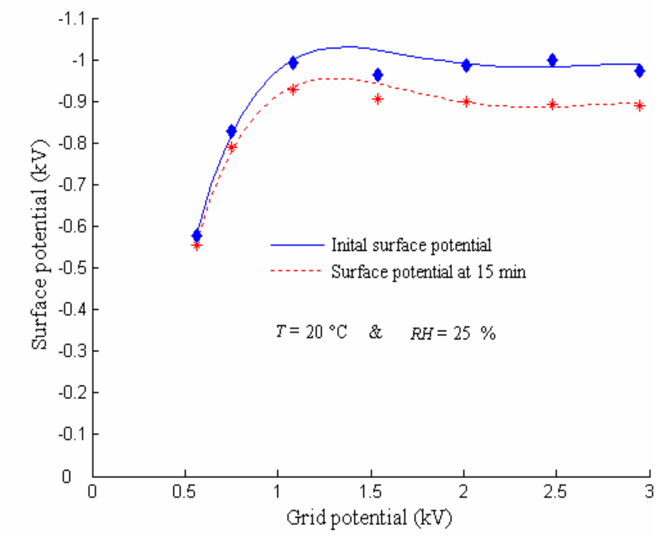


Fig. 15. Surface potential of media M2 measured at $t = 0$ s and $t = 15$ min as function grid potential V_g. Each point is the average of at least three measured values. The maximum dispersion range was 12%, for $V_g = 3$ kV.

The surface potential of media M2 at 15 min after high-voltage turn-off, is higher than that of media M1. The larger total surface of the fibers composing the media M2, which contains 15% of 0.1 dtex fibers, may explain their ability to better preserve the charge acquired by corona discharge. Further investigations are needed to confirm the positive effect of such combined textures on the charging and discharging characteristics of non-woven media.

CONCLUSION

Negative polarity seems to be more effective for the corona-charging of PP non-woven media. Thermal pre-conditioning of the materials and maintaining a low relative humidity of the ambient air may reduce the superficial moisture and favor the retention of the charge. The use of finer fibers is likely to improve the charging characteristics of these materials.

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