

Corona Charging of Composite Non-Woven Media for Air Filtration

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Abstract— The surface potential decay (SPD) measurement is a commonly-used method for monitoring the charge state of non-woven dielectric media for air filtration applications. The aim of this paper is to evaluate the factors that influence the SPD rate of a specific class of filtering media: “M1” consisting in two layers of non-woven polypropylene (PP) attached to a grid of same material and “M2” which has an additional layer of active carbon in between the two PP layers. The samples were charged by exposing them to corona discharges produced by a wire electrode facing a metallic grid parallel to a grounded plate. After charging, SPD was measured in a central point of each sample, for various grid potentials (between $V_g = 3$ kV and 10 kV) and conditioning temperatures ($T_e = 21^\circ\text{C}$ and 75°C). The experimental results show that the surface potential decreases faster for the material with the carbon layer and is higher for the samples exposed to elevated ambient temperatures or grid potentials.

I. INTRODUCTION

Standard air filters are composed of fibrous materials, which remove solid particles such as dust, pollen, mold and bacteria [1, 2]. In response to the specific requirements of each application, a wide variety of filter media are presently on the market. They are essentially made of either synthetic (polypropylene, polyethylene, polyester, polystyrene) or natural (cotton, wool) fibers [3, 4].

Non-woven polymeric filter media are widely employed for heat, ventilation and air conditioning [5, 6]. The particle collection efficiency of these filters is known to be enhanced by the static charging of the fibers [7, 8]. Indeed, the fine charged particles that would otherwise go through the air filter might be trapped on the charged fabrics due to the electrostatic forces acting on them. Walsh and Stenhouse [9], as well as F.J. Rornay et al [10] pointed out the effect of using mixed fibers of various layouts on the efficiency collection of 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..

Oda and Ochiai [11], Horenstein [12], as well as Kacprzyk and W. Mista [13] have thoroughly studied the corona-charged non-woven filter media, using the surface potential decay measurement techniques previously employed for the characterization of dielectric films, the adjustment of Xerox-photography processes, development of electrets, assessment of cable insulation [14-17]. Recently, the authors made use of the same technique for the study of positive and negative corona-charging of a polypropylene (PP) non-woven media [18-20]. They pointed out that the ionic species generated by the negative polarity corona (C03-, 02-) seem to be more effective for charging this type of media. Thermal pre-conditioning of the materials may enhance the external charge injection, while maintaining a low relative humidity of the ambient air may reduce the superficial moisture and favor the retention of the charge.

In some applications, such as the cabin air filters that are placed in the outside-air intake of the vehicle's passenger, a layer of activated carbon is placed between the non-woven dielectric media [21, 22]. Due to the large surface area of carbon granules, they are excellent at trapping odors and other volatile organic compounds. How does the presence of activated carbon modify the electric charging characteristics of filter media?

The aim of the present paper is to find an answer to the above question, by comparing the SPD measurements performed on two types of PP filters, with and without activated carbon. A special attention is given to the investigation of ambient temperature and relative humidity effects on the capacity of filter media to retain the electric charge and preserve their particle collection efficiency.

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", in ambient air (temperature: 18°C to 22°C; relative humidity: 25% to 60%). M1 is made of two layers of 2.8 dtex PP fibers (average fiber diameter: 20 µm; layer thickness: 400 µm), attached on both sides of a PP grid. "M2" is similar to "M1", but has an additional carbon layer between the grid and one of the PP non-woven fabrics (Fig. 1).

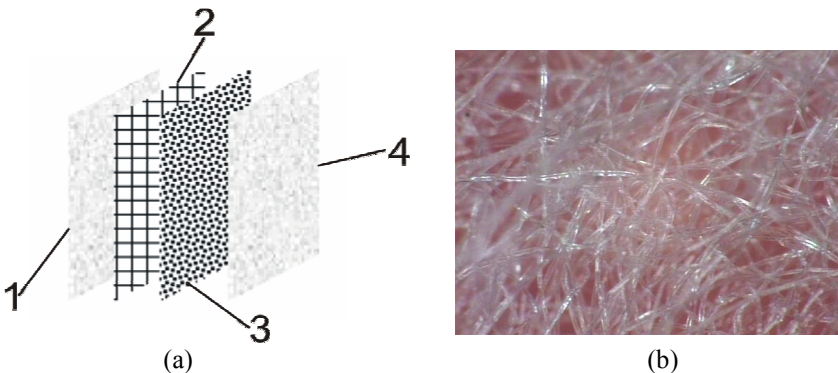


Fig. 1. (a) Composition of the composite media "M2"; (b) Microscopic view of the non-woven PP media. (1 – non – woven layer; 2 – polypropylene grid; 3 – carbon layer; 4 – non – woven layer).

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 supply (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). The former consists of a 0.2 mm tungsten wire supported by a metallic cylinder (diameter 26 mm), distanced at 34 mm from its axis, and energized from the same HV supply. Unless otherwise specified, the distance between the wire and the plate electrode is 30 mm. 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 grid is connected to the ground through a series of calibrated resistors having a total resistance R . In this way, for the constant current $I = 100 \mu\text{A}$ delivered by the power supply, a well-defined potential $V_g = RI$ is imposed between the grid electrode and the grounded plate. 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 media surface 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 .

The surface potential of the samples is measured with an electrostatic voltmeter (model 341B, equipped with an electrostatic probe model 3450, Trek Inc., Medina, NY) and monitored via an electrometer (model 6514, Keithley Instruments, Cleveland, OH), connected to a personal computer (Fig. 3). The processing of the data is performed using a virtual instrument, in LabView environment [19].

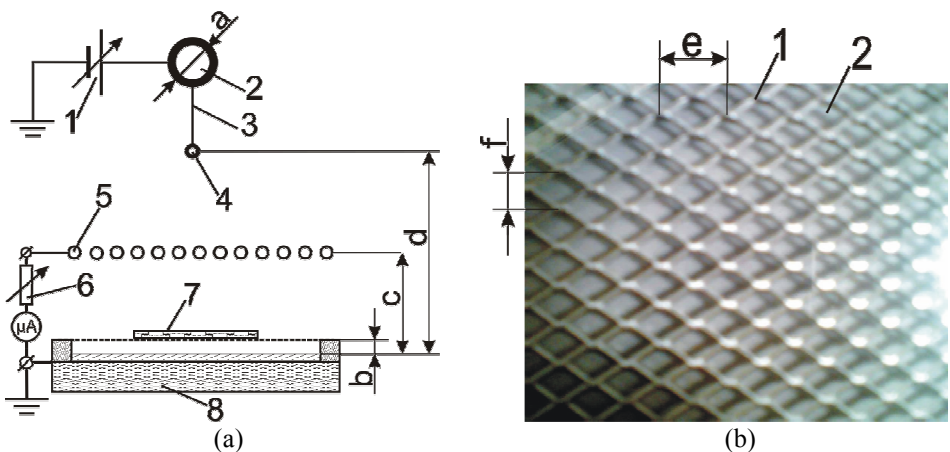


Fig. 2. Electrode systems employed for the corona-charging of non-woven media (all dimensions are in millimeters): (a) triode-type arrangement (1 – high voltage source, 2 – metallic cylinder, 3 – metallic rod, 4 – tungsten wire, 5 – metallic grid, 6 – resistive box, 7 – non-woven sample, 8 – P.V.C. support, a – 26 mm, b – 4.6 mm, c – 15 mm, d – 30 mm); (b) aspect of the grid electrode (1 – wire, 2 – loop, e – 6.4 mm, f – 4 mm).

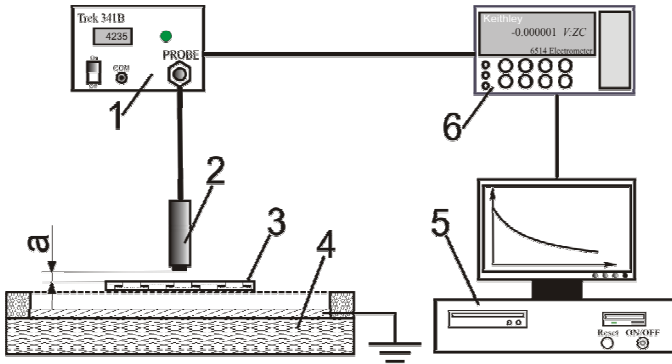


Fig. 3. Experimental set-up for measurement of the surface potential. (1 – electrostatic voltmeter TREK 341B, 2 – voltmeter probe 3450, 3 – non – woven sample, 4 – P. V. C. Support, 5 – computer for data acquisition, 6 – electrometer Keithley, a – 3 mm).

III. RESULTS AND DISCUSSION

The average SPD curves recorded for media M1 and M2 after corona-charging using several values of the grid potential V_g are displayed in Fig. 4. The initial value V_{mo} of the potential V_m measured at the surface of the media increased progressively with the grid voltage. In the case of M1, $V_{mo} \cong V_g$ (Fig. 4,a), and V_m decays faster for higher values of V_g . The SPD is steeper in the case of the combined media M2. As the potential V_{mo} is measured 3 s after corona-charging voltage turn-off, its value is $V_{mo} \geq V_g$ (Fig. 4,b).

At higher voltages applied to the grid electrode, the so-called “cross-over” phenomena [24, 25] occurred (Fig. 4,b): the higher is initial surface voltage, but the faster is the decay. This is mainly due to the charge injection mechanism, as explained in [26–28]. Thus, at 15 min after corona-charging turn-off, the potential at the surface of the media is $V_{m(10\text{ min})} = 4.1$ kV, for $V_g = 10$ kV, which is lower than $V_{m(10\text{ min})} = 5.3$ kV, for $V_g = 8$ kV. The presence of activated carbon accelerates all charge relaxation mechanisms, including the charge injection, which explains the “cross-over” phenomena.

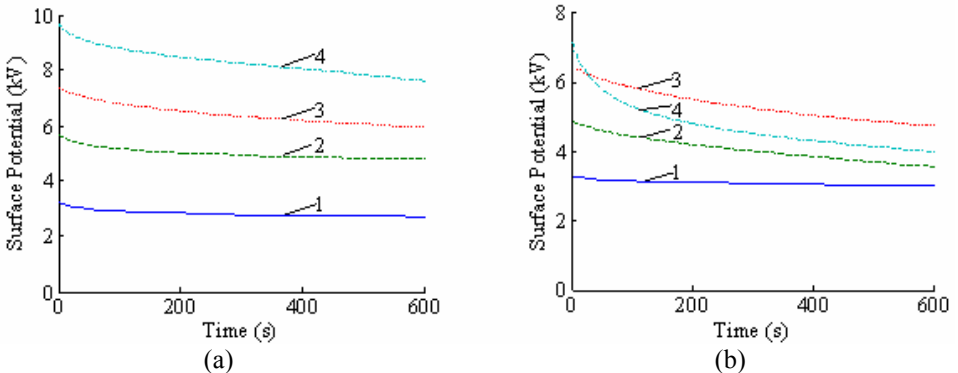


Fig. 4. Surface potential decay curves obtained for (a) „M1” and (b) „M2” samples at: 1– $V_g = 3.5$ kV, 2– $V_g = 6$ kV, 3– $V_g = 8$ kV, 4– $V_g = 10$ kV ($T_e = 21^\circ\text{C}$ and $RH = 35\%$).

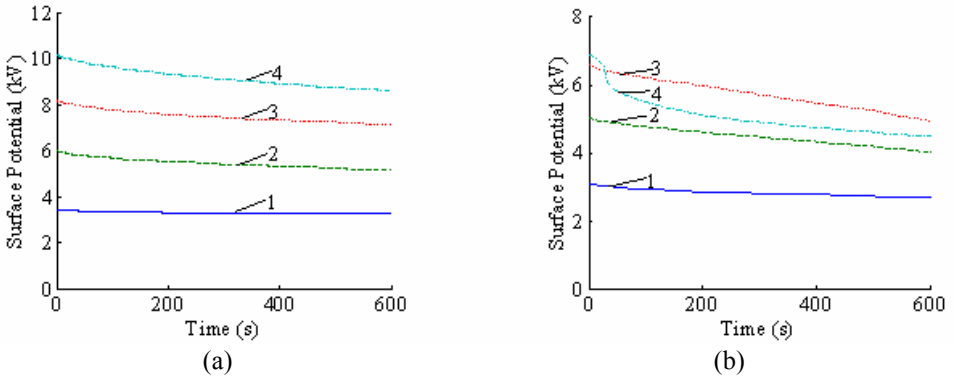


Fig. 5. Surface potential decay curves obtained for (a) „M1” and (b) „M2” samples at: 1- $V_g = 3.5$ kV, 2- $V_g = 6$ kV, 3- $V_g = 8$ kV, 4- $V_g = 10$ kV ($T_e = 75^\circ\text{C}$ and $RH = 35\%$).

Heating the samples prior to corona-charging may change the aspect of surface potential decay curves (Fig. 5). The decrease of PP fibers surface conductivity with the evaporation of part of the adsorbed water may explain, at least in part, the slow down of surface potential decay in both “M1” and “M2” media. At the same time, with the charges trapped deeper in the samples heated at higher temperature, the potential measured at the surface is more stable in time (Fig. 6).

The higher conductivity of activated carbon, which facilitates the redistribution of the electric charge in the volume of the non-woven media, may explain the faster decay of the potential at the surface of the composite media “M2”, at least during the first 10 min after the corona-charging of the samples (Fig. 7). This process seems to be limited in time, but the volume of data available for longer surface potential decay durations do not allows a firm conclusion on this issue. Further experiments should be conducted, under rigorously controlled environmental conditions, as the relative humidity of ambient air significantly influence the surface potential decay (Fig. 8).

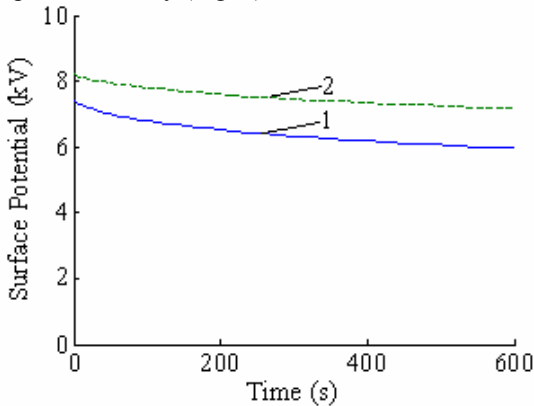


Fig. 6. Comparison between two surface potential decay curves for “M1” samples at $V_g = 8$ kV, for two temperatures: 1 - $T_e = 21^\circ\text{C}$ and 2 - $T_e = 75^\circ\text{C}$ ($RH = 21\%$).

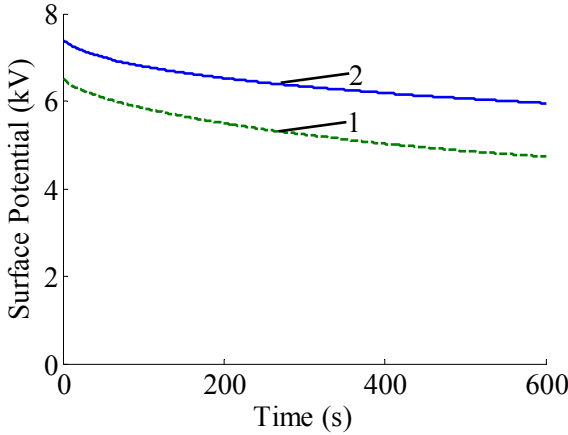


Fig. 7. Surface potential decay curves for: 1 – “M1” ; 2 – “M2”, at $V_g = 8$ kV ($T_e = 21^\circ\text{C}$ and $RH = 21\%$).

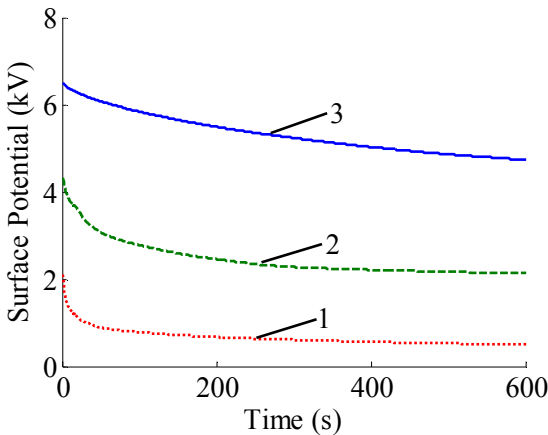


Fig. 8. Comparison between two surface potential decay curves for “M2” samples, at $V_g = 8$ kV, for three different humidities: 1 – $RH = 80\%$, 2 – $RH = 50\%$, 3 – $RH = 21\%$. The ambient temperature was $T_a = 21^\circ\text{C}$

IV. CONCLUSIONS

- (1) The decay of the electric potential at the surface of combined non-woven media is accelerated when the design of the air filter includes an activated carbon layer.
- (2) Thermal conditioning of the samples and operation at lower RH of the ambient air may help the media preserve their static electric charges.
- (3) Further researches should be performed in order to dissociate the two mechanisms involved in the surface potential decay, namely the redistribution of the charges in the volume of the media and their neutralization by the ions in ambient air.

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