Measurement of the electric potential at the surface of non-uniformly charged polypropylene nonwoven media

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Abstract. The aim of this paper is to establish the conditions in which the vibrating capacitive probe of an electrostatic voltmeter could be employed for mapping the electric potential at the surface of non-uniformly charged insulating bodies. A first set of experiments are performed on polypropylene non-woven media (thickness: 0.4 mm; fiber diameter: 20 µm) in ambient air. In a second set of experiments the non-uniformity of charge is simulated using five copper strips (width: 2 mm or 3 mm; distance between strips: 2 mm). All the strips are connected to a high-voltage supply (Vₛ = 1000 V). The sample carrier is attached to a computer-controlled positioning system that transfers it under the capacitive probe (TREK, model 3451) of an electrostatic voltmeter (TREK, model 1341B). The measurements are performed at various relative speeds Vₚ between the sample and the probe, and for various sample rates Fₑ. A first set of experiments point out that the electric potential displayed by the electrostatic voltmeter depends on the spacing h between the sample and the probe. The diameter D of the spot “seen” by the probe is approximately D ≈ 8h/3. From the second set of experiments performed with the test plate, it can be concluded that the surface potential can be measured with the media in motion, but the accuracy is limited by the spatial resolution defined by k = Vₛ/Fₑ.

1. Introduction

Electrostatic charging enhances the collection efficiency of nonwoven fibrous media employed as air filters [1]. Surface potential decay measurement [2] - [4] is a standard technique for the characterization of such media with respect to their ability to preserve the electric charge [5], [6]. Electric potential measurements have also been used for characterizing the distribution of the electric charge at the surface of non-woven media for air filtration [7] - [9]. Some of the peculiarities of non-contact techniques employed for the measurement of the electric potential at the surface of insulating bodies have been pointed out in [10] and [11].

In a recent paper [12], the authors have analyzed the correlation between the value displayed by the instrument and the distribution of the potential across the surface examined by the probe. In order to reduce the errors due to potential decay in time, all measurements need to be done as fast as possible, ideally with the sample moving at constant speed in front of the probe. The question is: “To what extent the relative speed between the sample and the probe affects the accuracy of the measurement?” The aim of the present paper is to answer this question, taking also into consideration the effect of the sample-rate at which the acquisition of the date is performed.
2. Experimental set-up and material

In the corona-charging experiments, carried out under stable ambient conditions (temperature 20 – 25°C; relative humidity 30 – 48%), a triode-type electrode system (figure 1) is used to corona-charge PP nonwoven samples (surface: 95 mm x 95 mm; thickness: 0.4 mm; fiber diameter: 20 μm), the aspect of which can be examined in figure 2. The ionizing electrode consists in a tungsten wire (diameter 0.2 mm) supported by a metallic cylinder (diameter 26 mm) and distanced at 34 mm from its axis. The wire and the cylinder are energized from the same high-voltage amplifier 30 kV, 20 mA (model 30/20A, Trek Inc., Medina, NY). The amplitude $V_s$ of the high-voltage is adjusted using a synthesized function generator (model FG300, Yokogawa, Japan).

The grid of the triode-type electrode system is connected to the ground through a resistance $R$. For an intensity $I$, a potential $V_g = RI$ is imposed to the grid. Part of the charge carriers generated by the ionizing electrode pass through the grid and are driven by this potential to the surface of the sample laid on the grounded plate electrode. The deposition of the charge stops when the electric potential at the surface of the sample is equal to that of the grid. In all the experiments the samples are exposed for 10 s to the corona generated at an applied high voltage $V_s = 11$ kV and the grid potential $V_g = 1$ kV.

![Figure 1](image1.png)

**Figure 1.** Experimental setup for the corona-charging of PP non-woven fabrics and the measurement of the electric surface potential.

The probe-characterization experiments (figure 2) are performed using two test plates fabricated of a PCB. One plate has a central strip 20-mm-wide, 80-mm-long, connected to high potential (1 kV or 0.5 kV), the rest of its surface being grounded (figure 3, a). The other plate has five strips 80 mm - wide, distanced at $d = 2$ mm (figure 3, b). Each strip can be connected at a different electric potential, to simulate the non-uniformity of charge distribution at the surface of a sample. The four 2-mm-wide and one 3-mm-wide strips are separated from the rest of the copper layer at the surface of the PCB by 0.1 mm - wide insulating strips. In these experiments all the copper strips are connected to a high potential $V_s = 1$ kV, and the rest of the plate is grounded.

![Figure 2](image2.png)

**Figure 2.** Experimental set-up for the surface-potential-probe-characterization experiments.

The sample carrier is attached to a computer-controlled positioning system (minimum resolution: 10 μm; minimum speed: 1.5 mm.s⁻¹; maximum speed: 30 mm.s⁻¹). As soon as the corona discharge is turned off in the corona-charging experiments or the bands are energized from an appropriate power supply in the probe-characterization experiments, the sample carrier is moved under the electrostatic probe (model 3450, Trek Inc., Medina, NY), of an electrostatic voltmeter (± 20 kV; model 341B, Trek Inc., Medina, NY). The translational speed of the sample-carrier relative to the probe can be adjusted at various values. The measured values of the electric potential are transferred to a computer via an acquisition card (model NI USB 6009), and processed by an ad-hoc virtual instrument, developed in LabView. The sample rate is limited to 5 kHz. Different sample rates (1 to 64Hz) and various scanning speeds (1.5 to 24 mm.s⁻¹) are compared in the present study.
3. Results and discussion

The electric potential values displayed in figure 4 are obtained as averages of 10 measurements, at constant sample rate \( F_e = 10 \) Hz in “static mode” (i.e., every 2 s, the electrode carrier is moved 0.1 mm along the \( x \) axis and the data are recorded point by point), for different values of \( h \) and \( V_s \). The probe “sees” the potential in a circular area (spot) of diameter \( D \) on the surface of the test plate facing it. The spot diameter \( D \) can be estimated from the curves in figure 5 as the difference between the first position \( x_{\text{max}} \) where the voltmeter displays the potential \( V = V_s \) and the last position \( x_0 \) where \( V = 0 \). The diameter \( D \) does not depend on \( V_s \), but is affected by the probe-sample spacing \( h \): \( D \approx \frac{8}{3} h \).

In figure 5, the data recorded point-by-point for the five-strips test plate are compared to the results recorded in the “dynamic mode” for different values of the sample rate \( F_e = 1 \) to 64 Hz, at constant scanning speed: \( V_b = 24 \) mm.s\(^{-1}\). Similarly, in figure 6, the “static mode” data are compared to the results of the measurements performed at various scanning speeds \( V_b = 1.5 \) to 24 mm.s\(^{-1}\), and constant sample rate: \( F_e = 1 \) Hz. In neither modes, the 0 V zones between two adjacent strips cannot be detected, as their width (2 mm) is smaller than the spot diameter (\( D = 8 \) mm, for \( h = 3 \) mm).

The spatial resolution is better for the lower values of \( k = V_b/F_e \). For \( k < D/20 \), the values of electric potential measured in the “dynamic mode” are close to those obtained in “static mode”.

**Figure 3.** Schematic representation of the test plates for spot diameter study (a) and for non-uniformity simulation (b).

**Figure 4.** Repartition of the potential along the \( x \)-axis in function of relative position between the probe and the copper strip center, for two values of spacing \( h \) and source potential \( V_s \).

**Figure 5.** Repartition of the potential along the \( x \)-axis of the five-strip test plate, for different sample rates (\( F_e = 1 \) to 64 Hz); \( V_b = 24 \) mm.s\(^{-1}\).

**Figure 6.** Repartition of the potential along the \( x \)-axis of the five-strip test plate, for different speeds (\( V_b = 1.5 \) to 24 mm.s\(^{-1}\)); \( F_e = 1 \) Hz.
The results of an experiment performed with a corona-charged non-woven PP sample are represented on figure 7. They have been obtained with the maximum scanning speed of the sample-positioning system ($V_b = 30$ mm.s$^{-1}$). The comparison between the curves corresponding to three different values of $F_e$ show that the capacitive probe is able to accurately detect the variations of the potential at the surface of a sample in motion, provided that $k < D/20$.

4. Conclusion

(i) In the case of non-uniformly charged media, the values recorded by an electrostatic voltmeter can follow the rapid variations of the actual potential at the surface of a moving sample, if the spatial resolution is $k < D/20$, where $D$ the diameter of the circular area “seen” by the capacitive probe.

(ii) At high scanning speeds, the increase of the sample rate is able to significantly improve the accuracy of the electric potential measured by the electrostatic voltmeter, but the recorded values must be filtered to reduce the noise.

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