Implementation and interpretation of surface potential decay measurements on corona-charged non-woven fabrics

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Abstract. The aim of this paper is to discuss the peculiarities of the surface potential decay (SPD) curves obtained for certain non-woven media. The experiments were performed on samples of non-woven poly-propylene (PP) sheets, which are typically employed in the construction of air filters for heat, ventilation and air conditioning. The samples were in contact with a grounded plane, in order to: (1) ensure better charging and measurement reproducibility; (2) simulate the worst situation of practical interest. They were charged using either a high-voltage wire-type dual electrode or a triode-type electrode arrangement. The aspect of the SPD curves depends on the electrode configuration. When the electric field is strong enough, it can activate charge injection at the insulator-metal interface and extrinsic conduction.

1. Introduction
Electret filters consist of non-woven fabrics made of dielectric materials that have a quasi-permanent electrical charge. Electric charging of the media improves their particle collection efficiency by the electrostatic particle capture mechanism that enhances the conventional mechanical filtration without causing an increase of the pressure drop [1]. Thus, the efficiency of an air filter is related to the initial level and the persistence of its electric charge [2, 3].

Surface potential decay (SPD) measurement techniques are widely used for the investigation of the electric charge on dielectric surfaces in a wide range of industry applications [4-9] Several interesting observations on the corona-charging characteristics of a non-woven poly-propylene (PP) sheet air filter are reported in [10]; the surface potential of the filter media is limited by the local discharges that occur inside the porous sheet and the relative humidity of the ambient air accelerates the charge decay. More recent studies [11, 12] confirmed the limitation of the surface potential attained by high-resistivity corona-charged fabrics when placed on conducting surfaces.

In two previous papers [13, 14], the authors employed the SPD technique to evaluate some factors that influence the corona charging of fibrous dielectrics. The critical issue concerning surface potential decay measurements is the interpretation of the curves, since these physical processes can lead to similar responses [4, 15, 16]. The rate of the potential decay $dV/dt$ is often considered as a better observable than the potential decay itself. The product of the derivative by the absolute time in seconds ($tdV/dt$) versus ($log t$) characteristic can be used for data analysis in order to separate phenomena with different characteristic times and amplitudes [17, 18]. The aim of this paper is to analyse the peculiarities of this mathematical transformation in the case of non-homogeneous dielectrics, such as the nonwoven fabrics.
2. Materials and method

The experiments were performed on 100 mm × 85 mm samples of nonwoven sheets of PP (sheet thickness of 300 µm and average fiber diameter of 20 µm, as shown in Fig. 1) in ambient air (temperature of 18 °C–22 °C and relative humidity of 30%–50%). The PP fibres represent roughly 15% of the volume of the media.

![Figure 1. Photograph of the nonwoven PP media.](image)

The samples were charged using the positive corona discharge generated by a high-voltage wire-type dual electrode [13], facing a grounded plate electrode (aluminium, 120 mm × 90 mm), as shown in Fig. 2(a). The high-voltage electrode consisted of 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 (model SL 300, SPELLMAN; rated voltage: 50 kV; rated current: 6 mA). Unless otherwise specified, the distance between the wire and the surface of the plate electrode was 30 mm. In some experiments, a grid electrode was interposed between the wire and the plate, to obtain a triode type electrode arrangement [14].

![Figure 2. Electrode systems employed for the corona-charging of nonwoven media (all dimensions are in millimeters). (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).](image)

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) by exposing them to the corona discharge, at various values of the high voltage applied to the dual electrode or at various grid potentials, in the case of the triode system. The samples were placed in contact to the grounded place so that to: (1) ensure better charging and measurement reproducibility; (2) evaluate the charge decay in the worst possible conditions. As soon as the high-voltage supply of the corona charger was turned-off, the conveyor belt transferred the samples from Position 1 to Position 2 (Fig. 3), where the surface potential was measured with an electrostatic voltmeter (TREK, model 341B, equipped with a probe model 3450, accuracy: ±0.1% of full scale, drift with temperature 200 ppm/°C), calibrated before each set of measurements. The measured potential was monitored via an electrometer (Keithley, model 6514) connected to a personal computer (Figure 3). The processing of the data was performed using a virtual instrument in the LabView environment.
3. Results and discussion

The results of the SPD experiments carried out with the wire-type dual electrode system for different values of applied high voltage and with the triode-type electrode arrangement for different values of grid voltage are shown in figure 4. The main feature of these curves is a slow decay for low surface potential values. At higher surface potentials, the slope of the curves becomes steeper, leading to the so-called “cross-over phenomenon” [4], which is mainly due to charge injection. According to the models described in the literature [18], the crossover can be explained by the proportionality of the initial SPD rate to the square of the charge deposited on the surface the media.

The representation \( \frac{dV}{dt} = f(\log t) \) of SPD measurements for corona-charged non-woven fabrics are shown in figure 5 for both electrode arrangements. In the case of the triode electrode system, the basic response curve is obtained for grid voltages of 0.6 kV and 0.9 kV. This intrinsic response of the media occurs in conditions of moderate temperature and electric field, which are factors of injection activation. The response amplitude increases with the grid voltage, and this corresponds to the occurrence of broad peaks on the 1.5 kV, 4 kV, and 6 kV curves (figure 5, b). At relatively high voltages, this broad peak – which is caused by charge injection from the grounded electrode [18] - is centred at about \( 10^{16} \) s, and is superimposed on the baseline response.
This type of injection, which occurs beyond a threshold voltage, is due to the increased electric field strength at the insulator-metal interface [4], so that the charge carriers can cross the potential barrier between the ground electrode and the surface states states of polypropylene fibers, to pass into the conduction band of the dielectric.

In the absence of the grid (figure 5, a), at applied voltages 12 kV and 18 kV, a broad peak replaces the basic response curve. The characteristic feature for this type of corona-charging is the steep peak with a long descent that occures for an applied voltage equal to 24 kV, at around $10^{0.65}$ s. This can be explained by the intensity of the electric field and the non-uniformity of the charge deposit. When the electric field is strong enough, it can activate the injection of charges and extrinsic conduction [4]. At the same time, the fibrous and non-homogeneous structure of the media, associated with the non-homogeneity of the charge deposite due to the absence of the grid, can cause paths to the ground electrode that will accelerate charge decay at the surface of the samples.

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