Surface potential decay measurements of corona-charged non-woven fabrics for air filtration

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1 Summary / Abstract:

The aim of this paper is to discuss the possibility of using the surface potential decay (SPD) curves for predicting the particle collection efficiency of corona-charged non-woven air filtering materials. The slower the SPD, the longer the charge is retained by these materials and the better the particles are captured by the air filter which mainly consists of non-woven fabrics made of thermally pressed polymeric fibers. The experiments were performed on two types of non-woven polypropylene (PP) samples, which are typically employed in the construction of air filters for the air conditioning industry. The fabrics where corona charged using the triode arrangement, which consists of a wire-to-plane electrode system, a metallic grid and a grounded aluminum plate which is in contact with the samples. After charging the samples with negative electric charges, the variation of the electric charges, on the the surface of the samples, was evaluated using the SPD technique. Thermally pre-conditioning 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. The deposition of Teflon nano-particles on the surface of the fibers improved the SPD characteristics of the materials.

2 Introduction

Filter media are porous or spongy materials that retain impurities (solid particles) found in suspension in a fluid [1]. They are composed of different types of fibers, either synthetic (polypropylene, polyethylene, polyester, etc.), or natural (cotton, wool, etc.). The media made of pressed polymeric fibers have recently gained a substantial place on the market.

The filtering proprieties of these media are improved when they are electrically charged, as an optimal balance is achieved between filtration efficiency and pressure loss during service [2]. In such filters, the particle collection takes place mechanically (by blocking the passage of solid particles between the polymer fibers) and electrostatically (due to the interaction between the charged particles and the electric field in the media). This electric field, often inhomogeneous, is generated by the presence of space charge in the structure of the filter media.

The present paper addresses the major limitation of these filters: the stability of charge. Charge decay is accompanied by the reduction of particle collection efficiency.

The scientific investigation of the surface charge decay of dielectric materials [3] has been stimulated by industry demand related to adjustment of Xerox-photography processes, development of electrets, and assessment of polyethylene films [4, 5]. The most convenient way to evaluate the charge is to measure the potential at the surface of the respective materials. Indeed, the potential V_s measured at the surface of the media is proportional to the deposited electric charge q :

$$V_s = (q \cdot g_s) / (\varepsilon \cdot A) \quad (1)$$

where ε is the absolute permittivity of the filter media, g_s – the thickness of the sample and A – area of the sample. Because of their reliability and low cost, the surface potential decay (SPD) measurement techniques have been performed as part of research protocols aiming at evaluation of electrostatic risks or monitoring of aged insulators [6].

According to the few papers published on the electrostatic characterization of filter media, the SPD on such materials depend on a series of factors: air humidity, surface resistivity, fiber permittivity, charge injection [7].

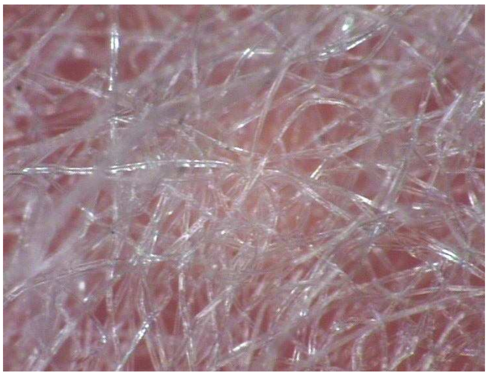

Fig. 1: Non-woven PP fabric

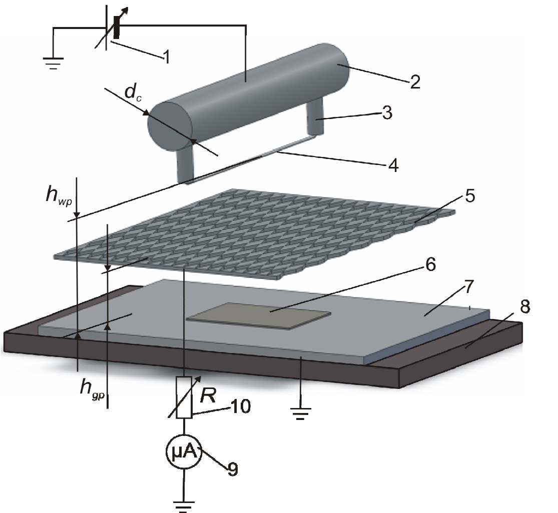

Fig. 2: Triode corona electrode charging system: 1 – high voltage supply, 2 – metallic cylinder, 3 – metallic rod, 4 – tungsten wire, 5 – aluminum grid, 6 – non – woven sample, 7 – PP grid, 8 – PVC support, 9 – micro-ammeter, 10 – variable resistor, 11 – grounded aluminum plate, 12 – PVC element for sustaining the PP grid, d_c – cylinder diameter, h_{wp} – distance between the tungsten wire and the grounded plate, h_{gp} – distance between the metallic grid and the grounded plate, h_{sp} – distance between the sample and the grounded plate

In a previous paper [8], the authors studied the positive corona-charging of non – woven polypropylene samples. They pointed out that the electrode system, consisting of wire-to-plane electrode and metallic grid, improves the uniformity of corona-charging. However, the surface charge density for the positive polarity was limited at 8 µC/m^2, when the samples were in contact with a grounded aluminum plate and exposed to uncontrolled ambient conditions.

In another paper [9], the authors demonstrated that the relative humidity seriously affects the stability of the electric charge deposed on the surface of the samples.

The present paper investigates the effects of three other factors that might affect the SPD characteristics of non-woven filter media: thermal pre-conditioning; maintaining a low relative humidity of the ambient air; deposition of Teflon nano-particles on fiber surface.

3 Materials and Methods

The experiments were carried on two types of samples, designated S1 and S2 with the dimensions 60 mm x 40 mm. The S1 samples (Fig. 1) were plain non-woven pressed PP fabrics, while the S2 samples contain an additional active nano-particle layer deposited on the surface of the sample.

The thickness of the two samples was measured using a plate-to-plate micrometer. The measurements were carried out in 5 different points of each sample type and the average of the measurements was calculated. It was found that the average thickness of the samples was about 200 µm.

The corona charging of the samples was performed with an electrode system known as triode corona electrode charging system [8]. It consisted of a wire-type “dual” corona electrode [9], a grounded aluminum plate and an aluminum grid (Fig. 2). The active element of the electrode was a tungsten wire (diameter d_w = 0.2 mm) suspended to a metallic cylinder (diameter d_c = 26 mm) by two metallic rods.

The wire was distanced at h_{wc} = 34 mm from the supporting cylinder and at h_{wp} = 30 mm from the grounded plate electrode. In view to obtain a uniform charge of the sample, an aluminum grid (Fig. 3) supplied with a controlled voltage was placed between the corona wire and the grounded plate.

The electrode system is energized from a continuous high voltage power supply (100 kV, 3 mA, SPELLMAN SL300 Hauppauge, NY) (Fig. 4). The metallic grid is connected to ground using a variable resistor R and a micro-ammeter. In this way, the electric current I through this resistor establishes the potential V_g between the grid and the plate electrode at a value $V_g = R \cdot I$ that can be calculated using the electric current values measured with micro-ammeter and the resistance R connected in series with it.

When the sample’s surface potential V_s becomes equal with the grid potential 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.

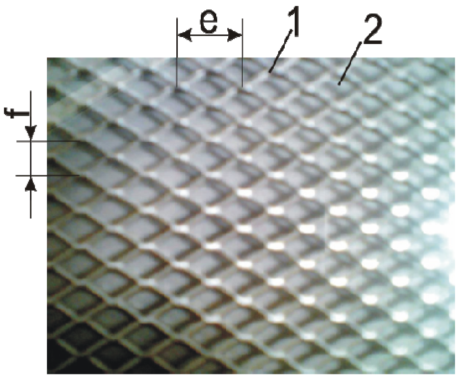

Fig. 3: Grid electrode (1 – wire, 2 – loop, *e* – big axis, *f* – small axis)

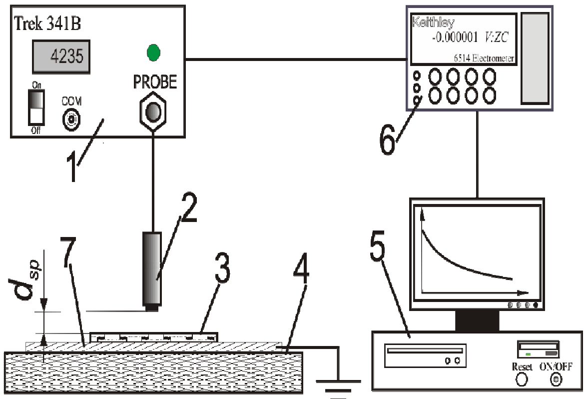

Fig. 4: Experimental set-up for SPD measurement: 1 – TREK 341B electrostatic voltmeter, 2 – TREK 3450 voltmeter probe, 3 – sample, 4 – PVC Support, 5 – computer for data acquisition, 6 – Keithley 6514 electrometer, 7 - grounded plate, d_p – distance between the sample and the voltmeters' probe

In all the experiments, the S1 and S2 samples were electrically charged at a grid potential V_g = 1 kV. The charging time was t_i = 10 s. Unless otherwise specified, the relative humidity of the ambient air was RH_e = 32 % at a temperature T_e = 19 ^{o}C.

The surface potential was measured for 10 minutes, using an experimental set – up consisting in an electrostatic probe (TREK 3450), positioned at d_p = 3 mm ± 1 mm from the samples, an electrostatic voltmeter (TREK 341B, Medina NY), a electrometer (Keithley 6514) and a PC. The SPD measurement process started at less than 3 s from the end of the charging process, and lasted for t_m = 600 s. Acquisition and processing of the measured data was performed using a LabView virtual instrument.

For controlling the relative humidity *RH* and maintaining the ambient temperature T_e constant, the samples were introduced and preserved for 48 hours in a desiccator "Dry Keeper" (supplied by Sanplatec, Osaka, Japan).

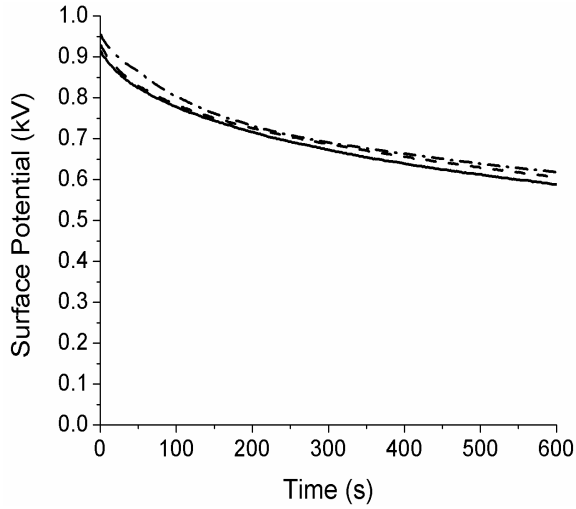

Fig. 5: Repeatability of SPD measurements, for three non-woven PP samples, thermally preconditioned at T_c = 70 ^{o}C and corona-charged at V_g = 1 kV (T_e = 19 ^{o}C, RH_e = 32 %)

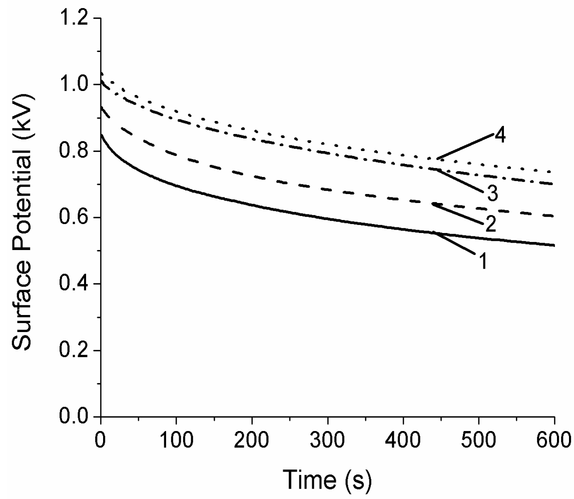

Fig. 6: SPD curves obtained for S1 samples, V_g = 1 kV (RH_e = 32 %) : 1 – T_e = 19 ^{o}C, 2 – T_c = 70 ^{o}C, 3 - T_c = 100 ^{o}C and 4 - T_c = 120 ^{o}C

4 Results and Discussion

The repeatability of SPD measurements can be judged from the curves represented in figure 5 for three non-woven PP samples. The maximum dispersion between the three measurements was 5%. In the following graphs, the curves $V_s(t)$ were obtained as the average of at least three measurements performed under rigorously similar experimental conditions.

The effect of thermal preconditioning can be examined in figure 6. By increasing the temperature, the initial value detected by the electrostatic probe is higher and the SPD process slows down.

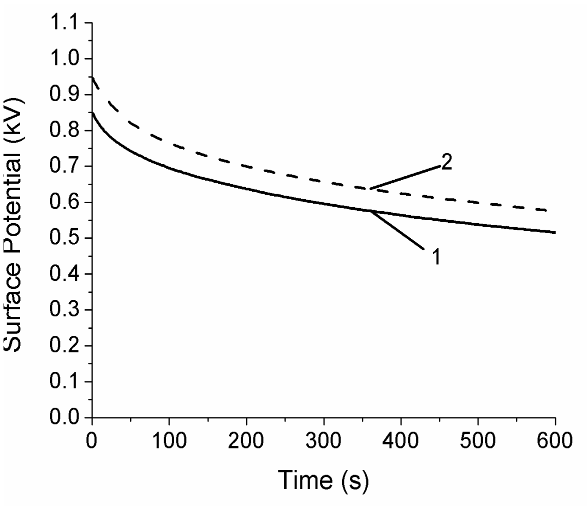

Fig. 7: SPD curves obtained for S1 samples: 1 – RH_e = 32%, 2 – RH = 15 % (T_e = 19 ^oC)

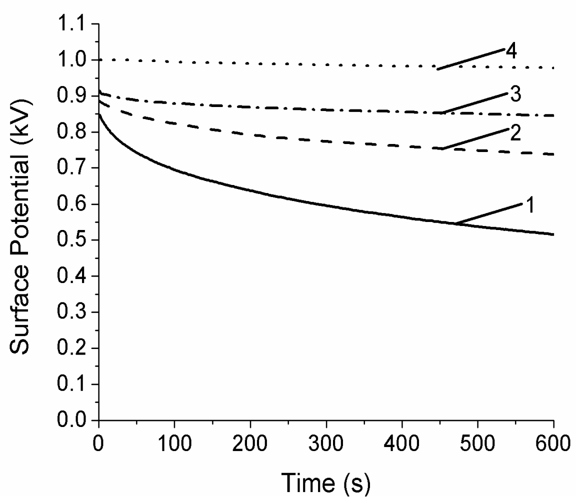

Fig. 8: SPD curves obtained at V_g = 1 kV: 1 – S1 samples and 2, 3, 4 – various S2 samples (T_e = 19 ^oC, RH_e = 32 %)

This can be explained, at least in part, by the decrease in surface conductivity of the hydrophobic PP fibers [9] with the evaporation of part of the adsorbed water. To verify this, the mas of S1 samples was measured before and after being thermally conditionned at 70 ℃ for 5 min. The 0.2% mass reduction can be explained by the evaporation of superficial water.

The curves obtained in the figure 7 highlight the effect of ambient humidity on the surface potential of the samples. Due to the fact that the water is a highly polar liquid (dielectric constant ε_r= 81), the water molecules condense onto the surface of the non-polar PP fibers. Maintaining the samples for 48 h in air at room temperature (19℃) but at lower relative humidity (15%) the charge decay mechanisms related to the presence of superficial water were inhibited.

Deposition of Teflon nano-particles on the fibers at the surface of the samples modified the aspect of the SPD curves (Fig. 8). This can be explained by the different dielectric and hydrophobic characteristics of this material.

5 Conclusion

Thermal pre-conditioning, rigorous control of ambient humidity, and deposition of Teflon nano-particles at the surface of the fibers may improve the charge decay characteristics of non-woven PP media, and hence increase the particle collection efficiency of the air filters.

6 Acknowledgment

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7 Literature

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