

Effect of Electrospinning Material and Conditions Upon Residual Electrostatic Charge of Polymer Nanofibers

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Introduction

There are numerous applications of electrostatic charges in spraying systems such as electrostatic painting, electrostatic coating and electrostatic pesticide spraying [1]. Electrospinning (ES) is another application of electrostatic spraying systems. Not until recently has ES been used for producing filter media [2] and the possible application for protective materials [3] since the first patent was filed in 1934 [4]. Several investigations have been carried out in studying the ES mechanisms using single spinning nozzle [5]. More research has been conducted by Tsai, et al [6] to compare the filtration efficiencies (FE) of ES and other nonwoven, electrostatically- charged and uncharged, fabrics. In this project, four polymers, polyethylene oxide (PEO), polycaprolactone (PCL, a polyester), polycarbonate (PC), and polystyrene (PS), were evaluated for their charge induction and charge retention characteristics. Electrical properties for the resulting fibers from these polymers are described, including charge potential and the decay rate. The contribution of these charges on the possible applications of nanofiber webs as well as the comparison of the FE with other filter media, spunbond (SB), meltblown and needle punched (NP), are discussed.

Theoretical and Experimental

Fibers are spun from a melt or a solution in an ES process. Much coarser fibers, > 10 microns, are produced from an ES melt while nanofibers having fiber size in the range of 50 nm to 1 micron can be produced from solution. In order to produce nanofibers, solution ES was used in this study. The solutions were prepared by dissolving the polymers in different solvents, viz., 10% PEO in 10% water and 80% isopropyl alcohol (IPA), 15% PC, PCL and PS in 42.5% tetrahydrofuran (THF) and another 42.5% n,n-dimethyl formamide (DMF). The solutions were poured into the reservoir of a syringe and the syringe needle was used as the spinning nozzle. High voltage power up to 30kV was applied to the nozzle as depicted in Figure 1. When the polymer comes out the needle tip, if the electrostatic repelling force in the droplet overcomes the surface tension

of the solution, the repelling force forces the charges out of the droplet. When the charges leave the droplet, they drag a portion of the polymer solution to form fibers. The solvent evaporates as the fibers travel towards the collector and the fibers become smaller. At the same time, the fibers split due to higher repelling force from the smaller fibers and even finer fibers are formed. The final fiber diameter and the web properties such as bulkiness and uniformity are affected by the polymer type, solvent type, solution concentration, the distance between the nozzle and the collector (DCD), as well as the electrical field strength in the droplet (internal electrical field) and in the space between the nozzle and the collector (external electrical field). The fibers may dissipate or retain the charges depending on the electrical properties such as conductivity of the polymer, and the electrical polarity of the fibers is affected by the polarity of the applied voltage.

In this research, the fibers were collected on a metal plate to make a web. The charge potential was measured on the surface of the web using a capacitive probe having an aperture of 0.07" in diameter while the plate was grounded. The decay of the surface charge potential with time was recorded. The loading penetration of webs was conducted using dioctylphthalate (DOP) aerosol generated in a TSI 8110 automatic filtration tester to study the web electric charge property and their application for filter media. The DOP aerosol had a number average particle size of 0.2 microns and a geometric standard deviation of 1.6. The aerosol concentration was 101 mg/m^3 and the filtration velocity was 5.3 cm/s.

Results and Discussion

The ES fiber size made in this study was in the submicron range between 0.4 to 0.7 microns as shown in Figure 2 for PC and PEO. Fine fibers are excellent for aerosol filter media because they provide larger surface area. Table 1 shows the residual charge potential of the four polymers and the polarities of the applied voltage at the nozzle. Figure 3 illustrates the stability of the residual charge potential of PS web. Little residual charge potential was measured on PC and PEO. However, there is evidence that PC retained charges when filtration measurements were performed by DOP loading. As depicted in Figure 4, the penetration increased with loading time because the charges were neutralized by DOP. This indicates a drawback in the surface charge potential measuring system. One problem may be that the probe aperture is much larger than the size of the charges either in ion or electron form. The area that the probe detects can cover a large quantity of quasi- positive and negative charges. If this is the case, then the measured potential will be quasi-zero even if there exists a large quantity of charges. Another problem presented by the surface charge potential measurement is that the distance between the positive and negative charge can be much shorter than the gap between the web surface and the probe. In this case, the probe again detects quasi-zero charge potential for bipolar charges in the web.

The penetration of electrostatically-charged MB fabrics increased sharply with the DOP loading as illustrated in Figure 5. Therefore, the media is not appropriate for the application in an oily environment. In contrast, PEO had good oil-resistant ability as

shown in the same figure over the full range of DOP loading time because it did not retain charge. However, the FE of PEO is much superior when compared with other charged media, SB, MB and needle-punched as observed in Table 2, due to the high surface area of the ES PEO. These media had even much lower FE when without being charged as shown in the same table.

The electric field conditions in the ES processing of the polymers that are unable to retain the residual charges can still affect the formation of the resulting fabric. By controlling the internal and external electric fields, unusual fiber collection characteristics can be achieved, due to the fact that these polymers still can carry charges before the fibers are collected on the collector. The fluffy PEO fabric shown in Figure 1 was produced by the repelling force in the fibers, even though no residual charge was measured on the resulting fabric.

Conclusions

ES can produce nanofibers that can provide high FE. The FE will not decay in oily environment if the web does not retain the charge. Some polymers can retain residual charge that can enhance the FE by electrostatic attraction. The web charge polarity can be controlled by the polarity of the applied voltage. The web formation in the ES process can be controlled by the control of the external electric field.

References

1. Cooper, S. C. and Law, S. E., "Novel Applications of Electrostatic Spraying Technology," Proceedings ESA Annual Meeting, 2000, Brock University, Niagara Falls, Ontario, June 18 – 21, 2000, PP. 23 – 32.
2. Simm, W. L., "Apparatus for the Production of Filters by Electrostatic Fiber Spinning," US Patent 3,994,258, 1976.
3. Schreuder-Gibson, H., Gibson, P., Senecal, K. and Tsai, P., "Protective Materials Based on Electrospun Nanofibers," 39th International Man-made Congress, Dornbirn/Austria, Sept. 13 – 15, 2000.
4. Formhals, A., "Process and Apparatus for Preparing Artificial Threads," US Patent 1,975,504, 1934.
5. Reneker, D. H., Yarin, A. L., et al., "Bending Instability of Electrical Charged Liquid Jets of Polymer Solutions in Electrospinning," J. Appl. Physics, Vol. 9, Part I, 87, 2000.
6. Tsai, P., Schreuder-Gibson, H., and Gibson, P., "Different Electrostatic Methods for Making Electret Filters," Journal of Electrostatics, in press.

Table 1. Applied nozzle voltage and web charge potential.

Ploymers	Nozzle Volt (KV)	Web Charge (V)	Nozzle Volt (KV)	Web Charge (V)
PEO	12	0	-10	0
PC	12	0	-10	0
PCL	12	188	-12	-212
PS	10	251	-10	-230

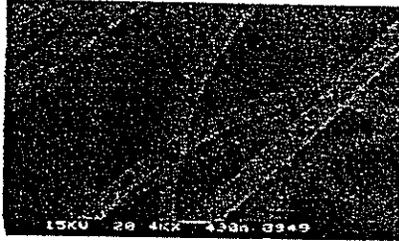
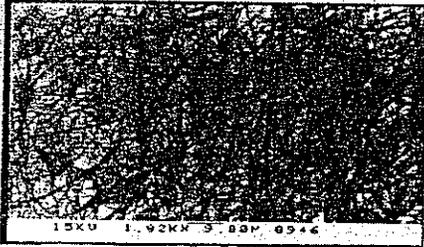
Table 2. FE of charged and uncharged media produced by ES and other nonwoven processes.

Sample	Charging	mat'l	B. Wt. (g/m ²)	FE (%)	ΔP (mmH ₂ O)	FE normalized to 10 g/m ²
SB1	unchgd	PP	34	3.5	0.1	1.1
SB2	corona	PP	34	26	0.1	8.5
MB1	unchgd	PP	34	32	2.9	10.7
MB2	corona	PP	34	84	2.9	41.7
NP1	unchgd	PP	100	7.8	0.2	0.8
NP2	corona	PP	100	48.1	0.2	6.3
NP3	unchgd	P+acry	100	8.3	0.3	0.9
NP4	tribo	P+acry	100	66.3	0.3	10.3
ES	unchgd	PEO	10	97.2	4.1	97.2



Figure 1. High voltage is applied to the needle of a syringe in the ES process.

PC



PEO

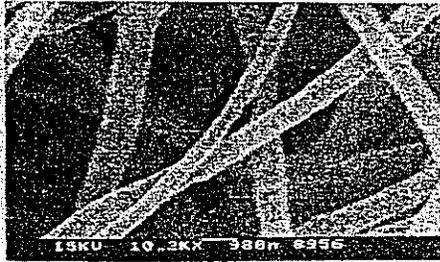
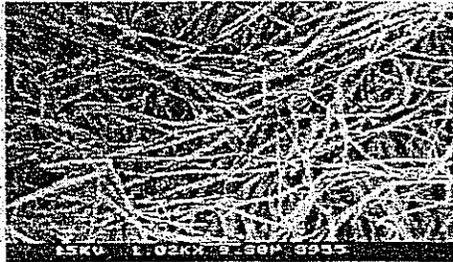


Figure 2. The SEM photomicrograph of PC and PEO.

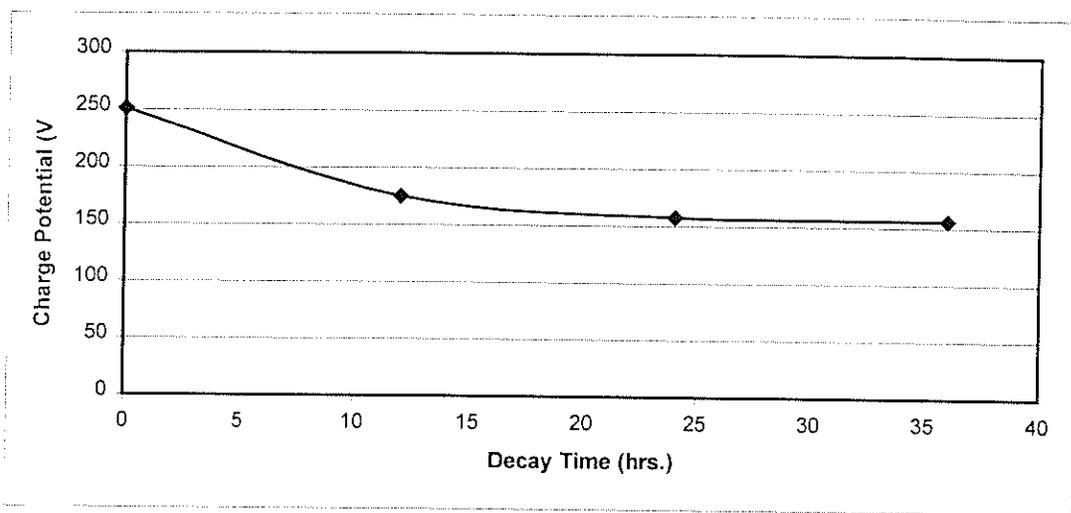


Figure 3. Residual charge stability on ES PS web.

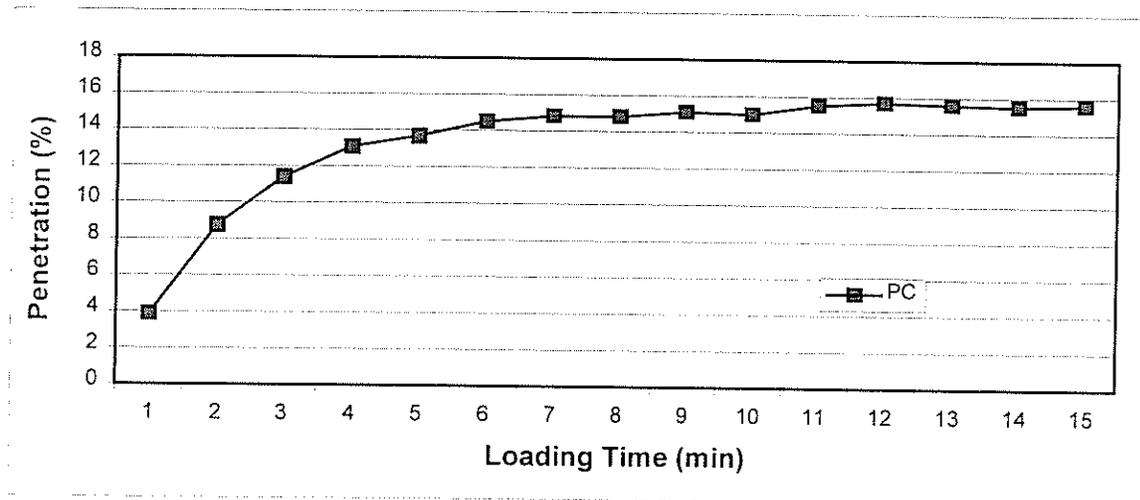


Figure 4. The increase of penetration with DOP loading shows the charge retention on PC.

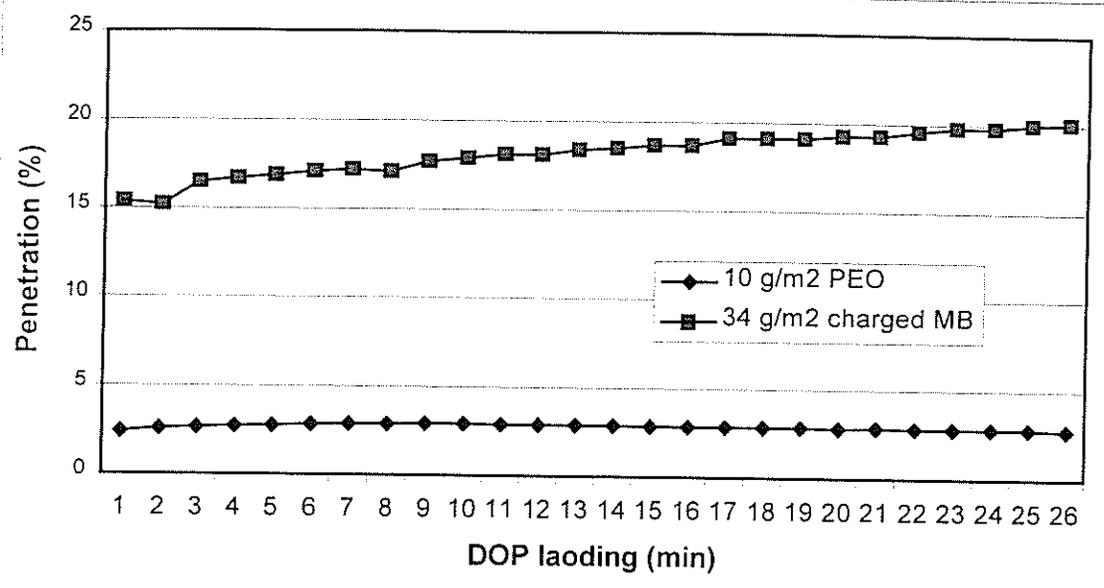


Figure 5. DOP loading of charged MB and ES PEO webs.