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Different electrostatic methods for making electret filters

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Abstract

Three charging techniques (viz., corona charging, tribocharging, and electrostatic fiber spinning) were used to charge fibers or fabrics of different polymer types. Corona charging is suitable for charging monopolymer fiber or fiber blend, or fabrics. Tribocharging is only appropriate for charging fibers with dissimilar electronegativity. Electrostatic fiber spinning combines the charging of polymer and the spinning of the fibers as a one-step process. It was observed that two dissimilar fibers following tribocharging had higher filtration efficiency than the corona-charged polypropylene fibers. An electrostatic spinning process produced nanofibers exhibiting extremely high efficiency by mechanical filtration mechanisms. Little charge was retained in electrospun polyethylene oxide fibers; however, polycarbonate and polyurethane retained a great amount of charge. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Fibrous materials used for filter media provide advantages of high filtration efficiency (FE) and low air resistance. Electrostatic charging of the media improves their FE by the electrostatic attraction of particles without the increase of pressure drop [1]. Three techniques (viz., electrostatic spinning (ES) [2], corona charging [3] and tribocharging [4]) are used to make and/or to charge the fibers or the fabrics. This paper compares the FE and the surface charge potential of these three

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techniques. The processes for making the media are addressed and the media properties presented.

2. Experimental design

Meltblown (MB) fabrics of basis weights 17, 25, 70 and 100 g/m^2, and spunbond (SB) of 35 g/m^2, received corona charging. Two types of needle-punched felts having basis weights ranging from 60 to 160 g/m^2 were supplied by Texel, Canada. One was three denier 100% polypropylene (PP) which was corona charged using TANTRET Tech-I and T-II [5]. The other one contained two dissimilar electrical properties of fibers, PP and specialty fibers, and was charged by triboelectrification during the textile carding process. Three polymer solutions (viz., polyethylene oxide (PEO), polycarbonate (PC) and polyurethane (PU)) were used to make ES fibers. PEO solution was prepared by dissolving 10% PEO in 80% isopropyl alcohol (IPA) and 10% water. PC solution was made by dissolving in dimethylformamide (DMF) and tetrahydrofuran (THF) at a ratio of 1 : 1 for a concentration of 20% by weight. PU was dissolved in DMF for a concentration of 10%. Fabric weight from 3–10 g/m^2 were electrospun for this study.

Fig. 1 presents the electrospinning process onto a stationary flat collector for this paper. The ES process consists of a pipette for the reservoir of the polymer solution as well as for the spinning nozzle, a grounded surface for collecting the fibers to make nonwoven web, and a SIMCO high-voltage DC power supply having maximum voltage of 50 kV and amperage of 2 mA to generate electrostatic charges. The

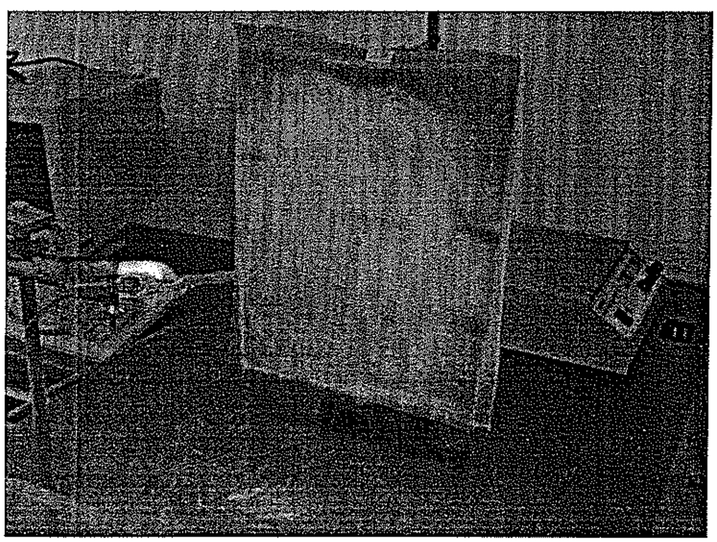

Fig. 1. An electrospinning process onto stationary flat collector, collector scale 1 : 6.

high-voltage electrode is directly introduced into the solution from the top end of the pipette. The distance between the bottom end of the pipette to the collector is 30 cm. Fiber production rate from a single orifice is typically in the range of 10–100 mg fiber per min.

Surface-charge potential of the fabrics was measured by the scanning system [1] developed at the University of Tennessee. Generally, the surface-charge potential of a charged media either by corona charging or by triboelectrification, before or after heat treatment, has a high coefficient of variation (CV), about 50%. Therefore, 400 scans (20×20 for x- and y-axis), 2.54 cm apart between scans, were measured. Arithmetic and absolute averages as well as the CV were computed from the 400 scanned data. Absolute average is the arithmetic average of the absolute values. It is important to correlate FE and absolute average of surface-charge potential if the media has a randomly distributed positive and negative charges because they both contribute to FE and their arithmetic average cancels them out.

An automatic filtration tester, TSI 8110, that generated NaCl aerosol having a number mean particle size of 0.1 μm and geometric standard deviation of 1.9 at a face velocity of 5.3 cm/s was used to test the media FE. Aerosol of dioctyl phthalate (DOP) at a velocity of 9.1 cm/s was also used to load the ES fabrics for charge-retention testing. DOP had a number mean particle size of 0.2 μm and a geometric standard deviation of 1.6. FE decay of the media was accelerated by heating to 60°C, 90°C and 120°C for needled felts and 110°C, 120°C and 130°C for MB fabrics using a Werner Mathis AG through-air laboratory oven. The fiber diameter of MB fabrics is around 2 μm and of needled felts is 25 μm. Higher temperature treatment is needed for MB fabrics in order to observe their FE decay because they have better charge-retention ability. The CV of the media FE is around 5%. Therefore, six FE tests were measured for each sample and the average was calculated.

3. Results and discussion

Basis weight and FE of the needled felt media charged by corona and triboelectrification are summarized in Table 1. These three corona-charged felts

Table 1
Basis weight and filtration efficiency of corona-charged and triboelectrified needled felts

Sample		B. weight (g/m^2)	FE (%)	ΔP (mm H_2O)	FE normalized to 100 g/m^2
Corona	1	100	75.7	0.18	75.7
	2	70 (15SB + 55 felt)	64.5	0.2	77.2
	3	160	87.5	0.9	72.7
Tribo	4	130	97.8	0.55	94.7
	5	120	97.3	0.8	95.1
	6	60	83	0.4	94.8

had an average FE of 75% after being normalized to $100\,g/m^2$ while the three triboelectrified had an average FE of 95%. Please note that Sample 5 had a lower basis weight but exhibited a higher pressure drop (Δp) than Sample 4 because it was made denser for application purpose. A dense needled fabric increases its mechanical strength but not really FE as shown in the table. Triboelectrified media had 1.27 times higher FE than that of corona-charged. However, triboelectrified materials contain two dissimilar fibers of different electronegative properties, usually PP and modacrylics. Modacrylics is expensive and both fibers need to be highly cleaned in order to generate triboelectrification effect. The static charges produced by triboelectrification also increase the difficulty in the carding process. Fibers for corona-charged felts are usually PP produced from a fiber spinning process containing spin finish that eliminates charge retention on the media. However, the charge retention problem can be resolved if spin finish with little antistatic agent is carefully chosen.

Fig. 2 compares the FE decay rates of Samples 1 and 4 in Table 1 as a function of the duration of heat treatment time at temperatures of 60°C, 90°C and 120°C. The percentage of the FE decay in terms of filtration index after 60-min heat treatment, indicated on each series, showed that corona-charged fabrics had a higher decay rates than those triboelectrified (viz., 31.2% vs. 24.1%, etc.) Filtration index is defined as

$$\mu = \frac{\ln(1/p)}{\Delta p}, \quad (1)$$

where μ is the filtration index, p the penetration, Δp the pressure drop.

It is essential to use filtration index to compare the FE decay rather than the FE percentage, e.g., the decay of the FE from 99% to 90% is 9.1% in FE but 50% in filtration index. An FE of 90% is equivalent to the FE of 50% of the weight of a 99% FE media.

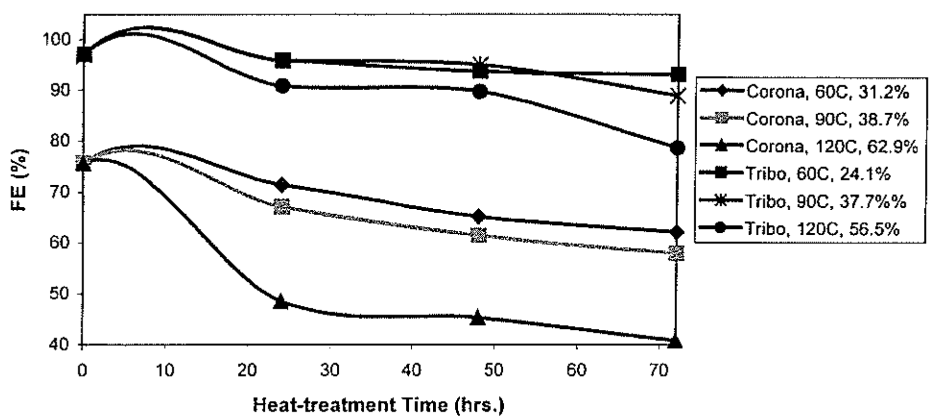

Fig. 2. FE decay rates of corona-charged and tribocharged felts as a function of the duration of heat treatment at different temperatures.

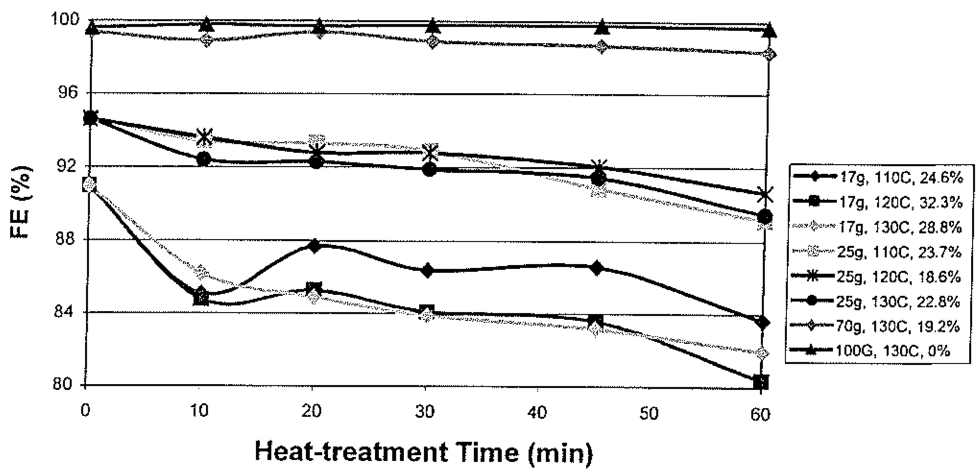

Fig. 3. FE decay rates of different weight meltblown fabrics as a function of the duration of heat treatment at different temperatures.

Table 2
Surface-charge potential measurements of corona-charged and triboelectrified felts

No.	Sample	Surface-charge measurements (V)					
		Face side			Back side		
		Arith. Avg.	Absolute Avg.	CV (%)	Arith. Avg.	Absolute Avg.	CV (%)
1	Sample 1, Table 1, T-I	304	357	89	−221	274	115
2	Sample 1, Table 1, T-II	1035	1121	52	−984	1012	58
3	Sample 4, Table 1	974	1000	43	−556	556	50
4	#3 recharged by T-II	1429	1442	36	−1386	1386	23
5	#3 normalized to 100 g/m^2	749	769	—	−428	428	—
6	#4 normalized to 100 g/m^2	1099	1109	—	−1066	1066	—

Fig. 3 shows the FE decay rates of corona-charged MB fabrics for four basis weights (viz., 17, 25, 70 and 100 g/m^2) as a function of the duration of heat treatment at three temperatures (viz., 110°C, 120°C and 130°C). These had much lower decay rates than those of corona-charged needled felts as indicated by the reduction of filtration index shown on each series in the chart. Higher basis weight of MB fabrics had a lower decay rate than lower basis weight. Furthermore, needled felts are much more porous than MB fabrics so their decay rate behaves like the MB fabrics of lower basis weight, which have higher decay rate.

Table 2 lists the surface-charge potential measurements on both sides of the media of Samples 1 and 4 in Table 1. After normalizing to 100 g/m^2, triboelectrified felts had a higher surface-charge potential than that of corona-charged by T-I but lower potential than corona-charged by T-II. When the charges on the triboelectrified felts were neutralized by washing using IPA and corona-recharged using Tech-II, they showed higher surface-charge potential but lower FE than the original triboelectrified felts. Tech-II charged media to a higher surface-charge potential but lower FE for lower basis weight media as observed by our previous research [1]. Both corona-charged and triboelectrified felts had a similar amount of surface-charge potential but opposite polarities on both sides of the media. This means that they both behave like bipolar materials. This is a typical result of charged materials and this property is believed to increase the FE of neutral aerosols because the bipolar electric field polarizes the neutral aerosols, and to increase the media charge-retention ability because the positive and negative charges attract each other. Fig. 4 illustrates the FE of triboelectrified felt of Sample 4 in Table 1 before and after IPA washing, and corona-recharged after washing. Felts made of dissimilar fibers can be well triboelectrified. Therefore, their FE were greatly improved. When these felts were corona-charged, the FE was lower than the original triboelectrified media.

Fig. 5 presents SEM photomicrographs of ES fibers made from PC, PU and PEO, showing similar and uniform fiber diameter in the range of 0.1–0.5 μm. Fig. 6 shows the penetration, a value of FE subtracted from 100%, of these three media by loading with DOP. Please note that penetration curve is commonly preferred to describe the FE decay with the particle loading. Both PC and PU had a higher initial FE, then decreased after DOP loading because they retained the charge from ES and the charge was neutralized by DOP. In contrast, PEO did not have the FE decay characteristic because it did not retain the charge. This why it did not have higher initial FE.

PEO had a lower basis weight ($3\,g/m^2$) than PC and PU. Therefore, its FE was lower as was its pressure drop (Fig. 7). PU had a sharp increase in pressure drop by DOP loading because the fibers were swelled by DOP adsorption. The swollen fibers occupied the pores between the fibers.

The FE of PEO web is purely mechanical. However, the NaCl FE (78%) of the $3\,g/m^2$ PEO is equivalent to that of $100\,g/m^2$ of uncharged MB and to $1000\,g/m^2$ of uncharged spunbond (SB) fabric. Table 3 compares the FE of uncharged SB and MB

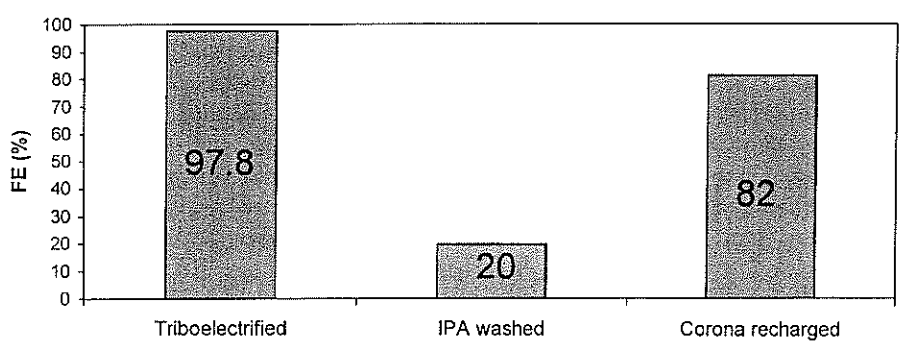

Fig. 4. Filtration efficiency of triboelectrified needled felt, charge neutralized by IPA and then corona-recharged.

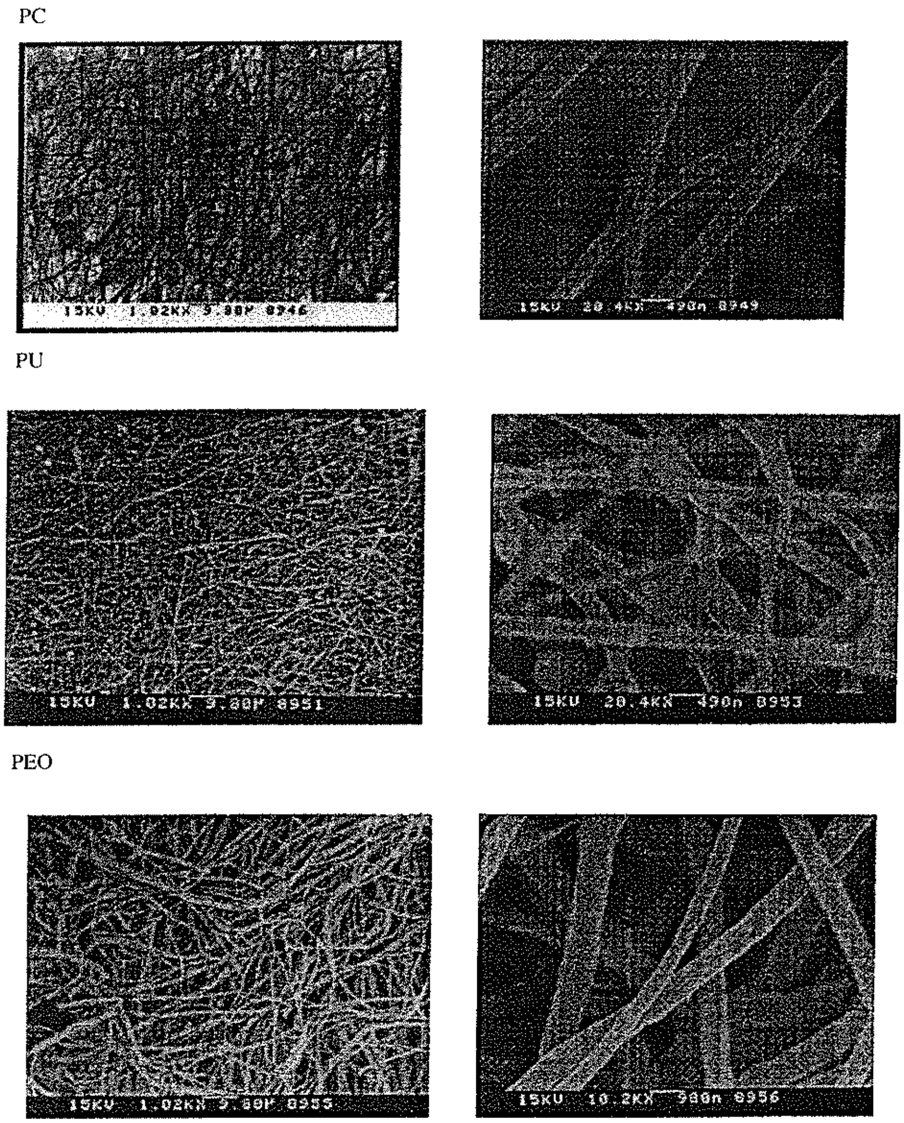

Fig. 5. SEM photomicrographs of three ES fiber samples.

fabrics, charged felts and electrospun PEO web at different basis weights and normalized to $10\,g/m^2$. It is interesting to note that a basis weight of $16.1\,g/m^2$ PEO electrospun web can achieve the FE of a HEPA (high efficiency particulate air) filter, i.e. 99.97%.

Fibers having different diameters ranging from nanometers to micrometers can be produced from numerous polymers by the electrospinning process [6,7]. The charge-

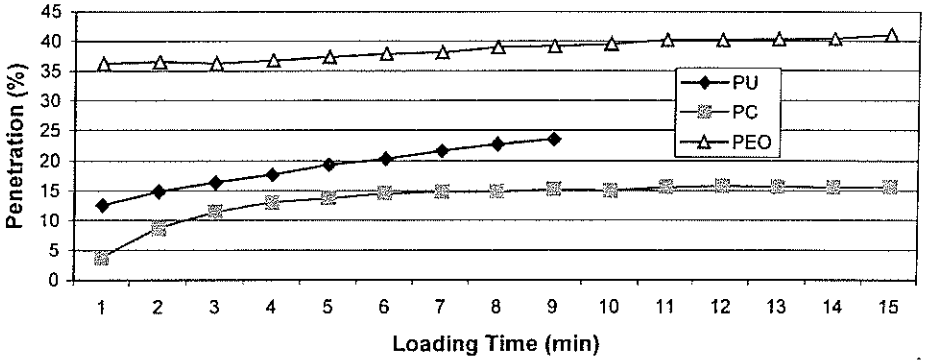

Fig. 6. Penetration of three ES samples with DOP loading as a function of time.

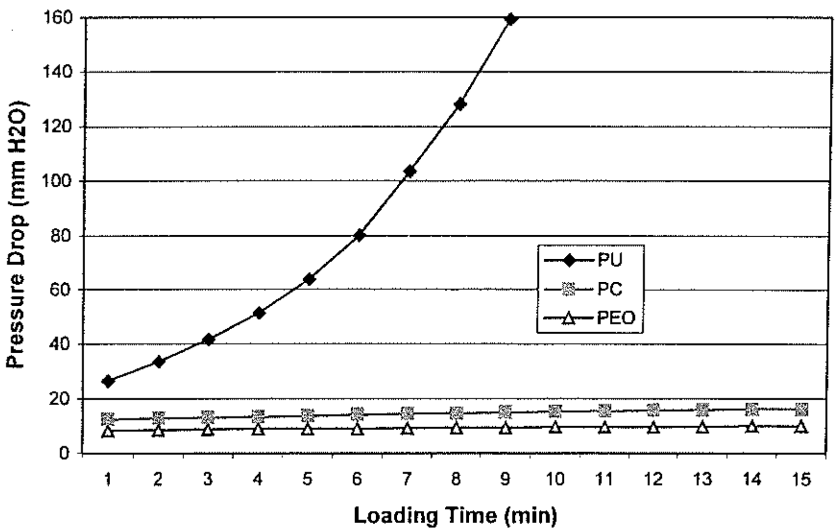

Fig. 7. Pressure drop of the three ES samples in Fig. 6 loading with DOP as a function of time.

Table 3
Comparison of FE for different nonwoven-making processes

Sample	FE (%)	FE (%) normalized to $10\,g/m^2$
SB ($35\,g/m^2$), corona-charged, T-I	37.2	9.5
MB ($35\,g/m^2$), corona-charged, T-I	98.6	70.5
Triboelectrified felt ($130\,g/m^2$)	97.8	25.4
Corona-charged felt ($100\,g/m^2$), T-II	75.7	13.2
Electrospun PEO ($3\,g/m^2$), uncharged	78	99.4

retention ability by this process as well as by other electrostatic charging processes such as corona charging and triboelectrification depends on the electrical properties such as conductivity and dielectric constant of the polymers rather than on the charging techniques [8]. Fibers produced from ES polycarbonate have good charge retention and have been commercially used for vehicle cabin-air filters [9].

4. Conclusions

Corona charging, triboelectrification and electrostatic spinning are three techniques for making charged media for filters. FE depends on the charging techniques while charge retention is independent of but depends on the electrical properties of the polymers as well as the fiber diameter and the media structure. Charged media produced by triboelectrification has a higher charge density and FE but charging can only be achieved in the carding process and it requires two dissimilar electronegative properties of the fibers. Both corona charging and triboelectrification are able to produce bipolar materials. Corona charging can also greatly improve the FE on the uncharged materials for triboelectrification but not so significant as by triboelectrification. Corona charging is applicable to both fibers and fabrics but it is superior to charge higher density fabrics than lower density ones. Fibers are charged in electrospinning process and this process can produce very fine fibers but the production speed per spinning nozzle is slow.

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