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The Effect of Temperature and Humidity on Electric Charge Amount of polypropylene Melt-Blown Nonwoven Fabric

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Abstract:*It's well known that the electret charge storage has a positive correlation with electret filters. However, in many cases, the charge storage performance of electret filters would be influenced by the surrounding environment, such as chemicals, solvents, oil mist, temperature, and humidity. In our current work, the electret charge storage of polypropylene melt-blown nonwoven fabrics were evaluated under different temperature (25℃, 50℃, 75℃, 100℃) and humidity (60%, 80%, and 95%)at different time interval by SIMCO FMX-004 electrostatic fieldmeter. The results showed that the crystallinity and grain size changed when nonwoven fabrics treated under high temperature, the charge storage performance increased when the electret filters exposed to an elevated temperature condition, and thecharge storage performance decreased when the electret filters exposed to higher humidity.*

Keywords: *Polypropylene, Melt-blown Fabrics, Electret, Temperature, Humidity, Electric charge amount*

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I. Introduction

Fine particulate matter (PM) pollution has attracted overall attention because of its danger to the atmosphere, biological systems, and general wellbeing[1, 2]. The melt-blown polypropylene (PP) electret nonwoven fabricsbroadly utilized as air filter media as a result of its high filtration efficiency, low-pressure drop, and extraordinary electrostatic attraction[3]. Its brilliant electrostatic attraction relies upon the electret charge in the nonwoven fabrics [4]. Pengcheng Li [5] inquired about the electret technology of the melt-blown polypropylene fabrics and showed that the temperature treatment has a specific improvement for the charging effect of fabrics. De-Qiang Chang et al. [6] built up a two-layer charged composite filter and discovered it had a high figure of merit and a better holding limit concerning PM2.5. Nevertheless, few investigations have done on the joining of corona charging with temperature. Zhang et al. [7] examined the electromechanical demonstration of cell polypropylene electrets charged at a high temperature. Zhong-Bao et al.[8] contemplated the charge stockpiling and its soundness of corona-charged polypropylene nonwoven fabric treated with high temperature, and the outcomes demonstrated that charge stockpiling and its steadiness were improved. Also, the relative humidityaffects the charge amount of the PP electret melt-blown nonwoven fabric. As it decreases the charge amount of the surface of the fabric, so the filtration efficiency goes down as well [9].Solid aerosol particles are responsible for obstructing the pores of the electret filter, and the deposited aerosol is playing a vital role in reducing the surface charge.[10] Regardless, little attentionpaid with the effect of electret temperature and the relative humidity. In this work, the impact of temperature and humidity on charge amount attenuation of PP melt-blown electret nonwoven fabricinvestigated. Notably, the charge amount change of PP melt-blown electret nonwoven fabrics at a temperature of 25℃, 50℃, 75℃, and 100℃, and humidity of 60%, 80%, and 95%elaborated. Besides, the crystallinity and grain size of fibers also tested.

II. Materials and Methods

2.1 Materials

The melt-blown PP electret nonwoven fabrics produced inTongxiangJianmin Filter Materials Co. Ltd.Specifically, the PP chips together with electret additives were melted and extruded through a spinneret, and then the melted polymer was drafted into fibers under compressed air; the fibers were randomly collected on a running belt and formed the melt-blown PP electret nonwoven fabrics; at last, the nonwoven fabrics treated by corona discharge. Therefore, the electric chargestored in nonwoven fabrics.

The PP electret nonwoven fabrics were charged by the method of corona discharging system with an adaptable electric field[11].Correctly, advantages of PP electret melt blow fabric are, it can hold a plentiful amount of charges on the surface of it, so the efficiency of air filtration will be identical [12, 13].

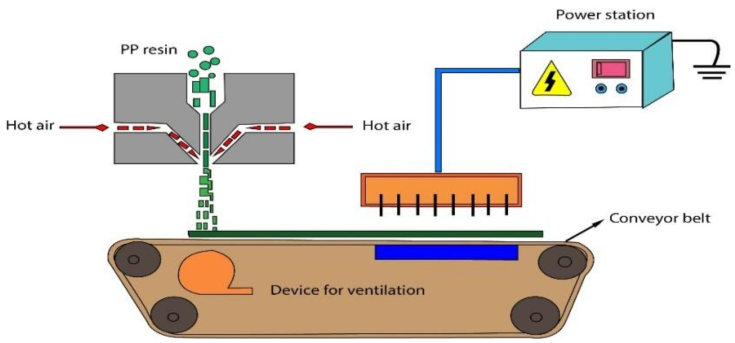


Figure 1. Schematic illustration of the fabrication procedure of the PP melt blown nonwovens and the corona charging technology

2.2 Methods

The morphology of the fabric observed utilizing a scanning electron microscope (Model JSM-5610LV Japan), and a specific number of SEM pictures gathered. The fiber diameter estimated using Image J and the mean of 100 fiber diameters were determined.

The pore and size appropriation of the texture was estimated utilizing Capillary FlowPorometer (Model CFP-1100-A1 USA). The samples cut into small circular sizes and set in a round glass dish with a proper measure of permeate liquidin which surface pressure is 20.1 dynes/cm. At that point began the test when the samples consistently penetrated.

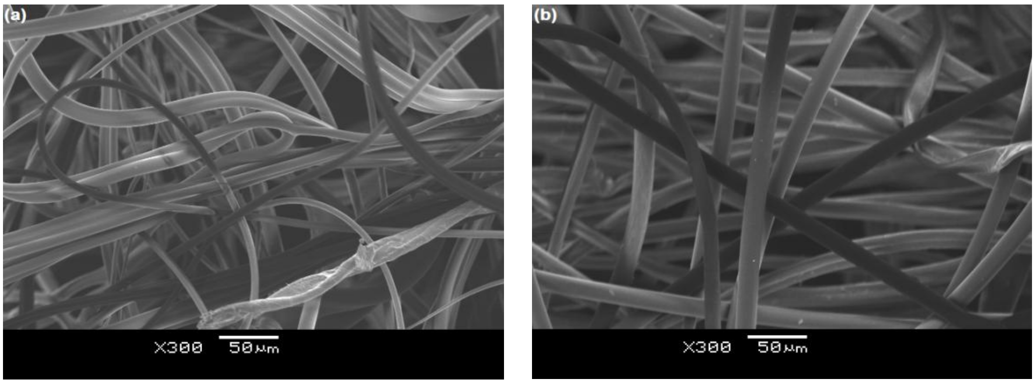
The crystallinity and grain size of PP fiberanalyzed by XRD and the sample size is 1 x 1cm2; the test condition is 40kv 40mA, Scan range: 10-80°, Scan speed: 5°/min.

Humidity chamberuse for given relative humidity to the sample . each sample got 3 hours of humidity every day, and after that charge amount collected bySimco-ion handy Digital electrostatic field meter(model: FMX-004, made in Japan). The relative humidity amount is 60%,80%,95% chronologically.

Constant temperature oven (model: SFNXIN-DGG-9240B) use for giving the temperature to the sample. Each sample got 6 hours of temperature every day. The temperature is 25℃, 50℃, 75℃, 100℃ successively. After that charge amount collected by Simco-ion handy Digital electrostatic field meter(model: FMX-004, made in Japan).

III. Results and Discussions

In the SEM picture (a) we can see that the fiber is quite smooth; there is no harsh surface of the fiber. Here fiber diameter is 10.83±2.71nm, and pore size distribution is 82.03 nm. This result is for sample 1. In the SEM picture (b) we observe that the morphology of the fabric shows the fiber is very nicely attached, and the fiber diameter calculated is 1.96±1.07nm, pore size distribution is 8.44nm. This result is for sample 2. Picture (c) refers to sample 3. Here we can notice there are some rough surfaces of the fiber, but it nicely attached. The fiber diameter for the sample number 3 is 16.04±2.03nm, and the pore size distribution is 49.49nm. Picture (d) alludes to sample 4. Here the fibers are different in size and have some rough surface. The fiber diameter of the sample is 1.91±0.69nm, and the pore size distribution of the sample is 9.70nm. Those are the basic structure of the nonwoven electret fabrics.



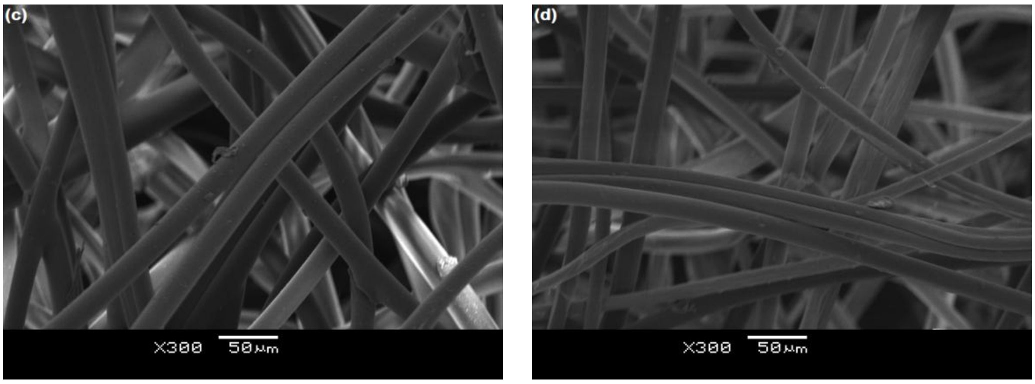


Figure 2: Morphology of PP melt blown nonwovens fabric

The crystallinity of fibers

In the picture of crystallinity, we can see that the percentage of crystallinity for the four samples. The crystallinity percentages of sample 1,2,3& 4 are 65.02%,73.66%,82.94% and 37.15% successively. The Grain sizesare 64nm,74 nm,83 nm,39 nm consecutively for the four samples. We know that bigger the crystallinity percentage and bigger grain size longer the electret charge. Furthermore, longer electret charge will give better and durable filtration for the electret air filter.

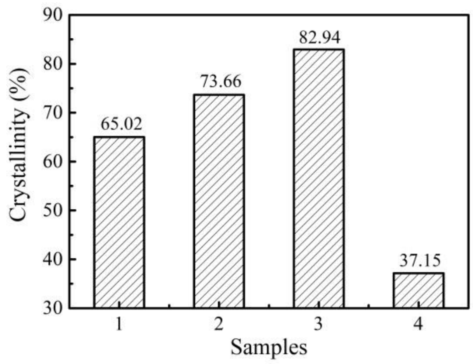


Figure 3:The crystallinity of PP nonwoven fabrics

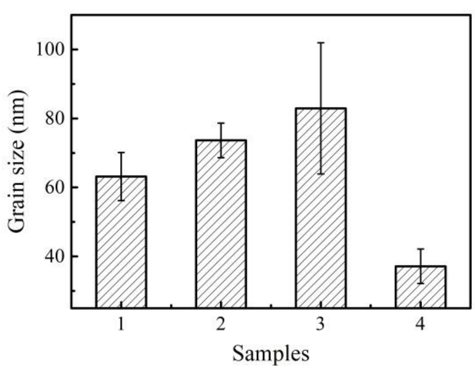


Figure 4:Grain size of PP nonwoven fabrics

Effect of temperature onelectric charge amount of nonwoven fabric

There were numerous endeavors made to think about the charge decay in electret air filters. The nature of charge decay in electret air filters was studied. The charge decay in electret air filters was seen as modeled by the following exponential relation:

$$\sigma\,(0, T) = \sigma\,(0, T)\exp\left(-\frac{t}{\tau}\right) \quad (1)$$

where σ (t, T) represents the effective charge density at time t and temperature T, σ (0, T) specifies the effective charge density at time 0 and temperature T, and τ is effective time constant of charge decay[14].

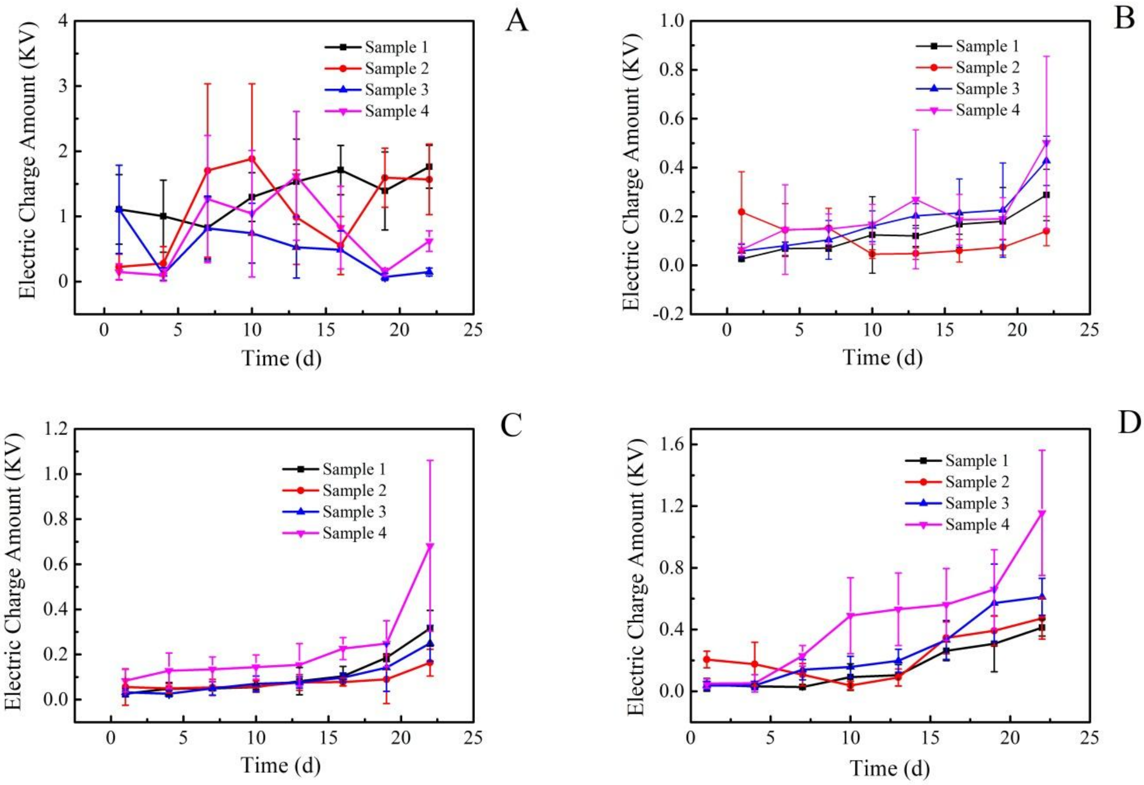


Figure 5: Effect of temperature on Electric charge amount of nonwoven fabrics
(A) 25℃, (B) 50℃, (C) 75℃, (D) 100℃

As we know that Figure A refersto 25℃, which considered as the room temperature. In the room temperature for 0-5 days time period, we can see the charge of sample 1slightly decreased, which is below 1kv. For sample2, itwas increasing, but the charge amount wasbelow 1kv.In sample3 and sample4, the charge amount was declining, and the charge amount goes near 0.1kv. In the time of 5-10 days, we observed the charge amount is rising for all the samples. The charge amount is near 1.5kv for sample1, 2kv for sample2, near 1kv for sample number 3, and over 1kv for sample number 4. After 10-15 days, the charge amount was growing for sample1,itwas near to 2kv, but for sample2,3 and 4, the chargeamount is below 1kv. 15-20 days period, the charge amount went down for sample1,3, and 4, but for sample 2, the charge amount is increasing. 20-22 days period charge amount was swelling for samples1,3, and 4, but for sample number 2 it was slightly falling.

Figure B refers to 50℃. Here we can see that in the 0-5days period, the charge amount wasrising for samples 1,3, and 4. The charge amount wasnear 1kv for samples 1 and 3. Again the charge amount wasnear 0.2kv for sample4. However, we see the charge amount waslessening for sample 2, and its near 0.1kv from 0.2kv.In 5-10 days period, the charge amount of sample 1,3,4was again rising, and the charge amount was slightly upper than 0.1kv, near to 0.2kv, closer to 0.2kv, respectively. Nevertheless, for sample 2, the charge amount was still decreasing, and its near 0kv. In the 10-15days period, we can see that the charge amount for all the samples was increasing except sample 4. the charge amount was near 0.2kv, 0.1kv, 0.2kv, and below 0.2kv, respectively. In the 15-20days period, the charge amount for all the samples is increasing, and the charge amount is near 0.1kv, 0.2kv, slightly upper than 0.2kv, near 0.2kv correspondingly. In 20-22 days period, we can observe that the charge amount for all the sampleswas swelling, and the charge amount wasnear 0.3kv, higher than 0.1kv, upper than 0.4, and very close to 0.5kv, respectively.

In Figure C we can see that here 75℃ temperature given to the samples consistently. In the 0-5days period, we can see that the charge amount of the samples was growing up. Furthermore, the charge amount for samples 1,2, and 3 was near 0.1kv, and the charge amount for sample 4 was slightly upper than 0.1kv. Next 5-10 days periods, the charge amount for sample number 1,2,3wasgoing very close to 0.1kv, and the charge amount for sample number 4 wasalmost 0.2kv. We can observe that in the next 10-15 days period the charge amount was still increasing, but the increasing trend was deficient. The charge amount for sample number 1,2,3 is very close to 0.1kv, and the charge amount for sample number 4 was slightly upper than 0.2kv. In 15-20days period the charge amount for sample 1,2,3 and 4was 0.2kv,0.1kv, upper than 0.1kv and near 0.4kv respectively. In the 20-22days period, we can still observe that the charge amount wasgrowing up. The charge amount for sample number 1,2,3 and 4 was 0.3kv, upper than 0.1kv, 0.2kv and 0.7kv sequentially.

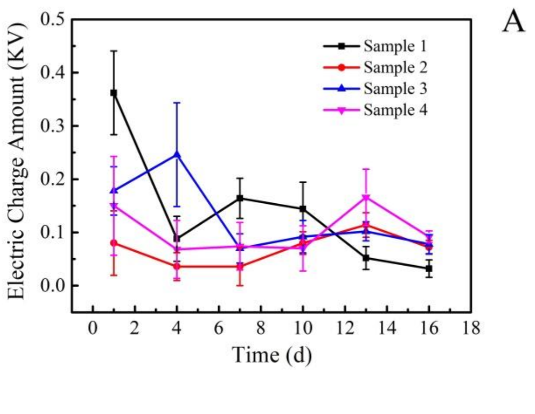
In Figure D here, we can observe that all the samples got 100℃ temperature continually. In the 0-5days period, we can see that high temperature increased the charge amount of the samples. The charge amount of samples 1,3, and 4 was below 0.1kv, and the charge amount of sample 4 was near 0.1kv. We see that the charge amount of sample 4 was lessening. In the next 5-10 days period, we observed the charge amount for the sample number 1,2,3 and 4 is 1kv, almost 0kv, near 0.2kv and 0.5kv consecutively. In the 10-15days period, we can notice that the charge amount for all the four samples is near 0.2kv, slightly upper than 0.2kv,0.3kv, near 0.6kv chronologically. In the next 15-20 days, we can identify that the charge amount for the four samples wasswelling.The charge amount for 4 samples was near 0.3kv,0.4kv,0.6kv, and upper that 0.8kv serially. In the 20-22days period lastly, we can see that the charge amount for four samples was 0.4kv,close to 0.5kv, 0.6kv, and near to 1.2kv successively. We can clarify that temperature effects will increase the charge amount of electret fabric as we know that it can increase the crystallinity of the fabric as well [15-16].

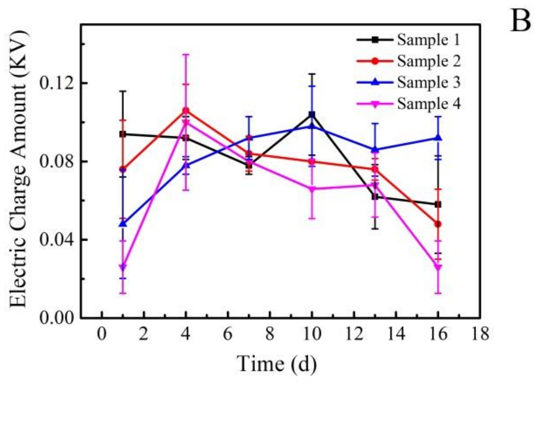
Effect of humidity onelectric charge amount of nonwoven fabric

As we can know that in figure A, all the samples got 60% relative humidity, andin the 0-4days period, the charge amount for four samples went down except sample 3. The charge amount for all the samples are below 0.1kv, under 0.05kv, 0.25kv, slightly upper than 0.05kv chronologically. In the 4-8days period, we can observe that for the four samples still, the charge amount was decreasing except sample 1. The charge amount for the four samples was0.15kv, below 0.05, slightly upper than 0.05 and faintly upper than 0.05kv consecutively. In the next 8-12days period, the charge amount for the four samples, near 0.1kv,0.1kv,0.1kv, and very close to 0.15kv successively. In the 12-16days period, we can see that all the sample's charge amount was decreasing, and the charge amount for the four samples were lower than 0.05kv, close to 0.1kv, near to 0.1kv, and 0.1kv consecutively.

In figure B we can see that here, all the samples got 80% relative humidity. Firstly in the 0-4days period, we can see that all the sample's charge amount was increasing a bit. The charge amount for four samples was near 0.10kv, very close to 0.11kv, adjacent to 0.08kv and 0.10kv successively.Secondly, in the 4-8days period, we can observe that the charge amount for the four samples was decreasing except sample number 3, and the charge amount was 0.09kv, close to 0.09kv, near to 0.10kv, adjacent to 0.08kv chronologically. Thirdly in the 8-12days period, we can see here the charge amount for all the four samples is close to 0.08kv, near to 0.08kv,0.09kv, and 0.07kv sequentially. In the last 12-16days period, we observe that all the sample's charge amount was going downwards. The charge amount for all the four samples was 0.06kv,0.05kv,close to 0.10kv and near0.03kv consecutively.

In figure C we can see that all the samples got 95% relative humidity.In 0-4days the charge amount for the four samples was slightly upper that 0.07kv,0.10kv,0.09kv and 0.08kv respectively. Next 4-8days period, we can observe here the charge amount for all for samples is very close to 0.06kv,0.06kv, adjacent to 0.10kv, near to 0.08kv successively. In 8-12days period, the charge amount for four samples was close to 0.05kv, adjacent to 0.04kv, near to 0.05kv,0.05kv chronologically. The last 12-16days period, the charge amount for all the four samples was 0.04kv,0.02kv,0.02kv and adjacent to 0.04kv consecutively. The overall scenario of the figures indicatedthat humidity affected the chare amount of the samples. It reduced the charge amount of the sample very quickly. It affects the durability of the electret nonwoven fabric [9,17].





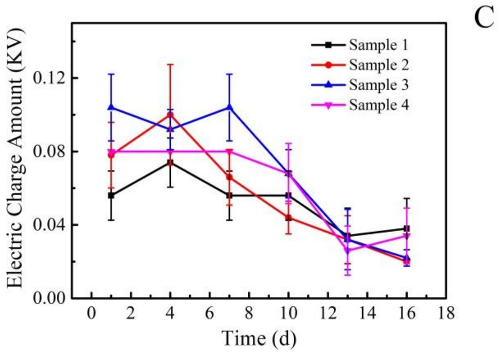


Figure 6: Effect of humidity on Electric charge amount of nonwoven fabrics
(A) 60% humidity, (B) 80% humidity, (C) 95% humidity

IV. Conclusions

In this work, we described a proper investigation on effects of temperature and humidity on electric charge amount of polypropylene melt-blown nonwoven fabric. Conclusions are as follows:

Firstly, we try to analyze the sample structure through different experiments such as SEM, XRD, pore size distribution, the fiber diameter estimated using Image J and the mean of 100 fiber diameters were determined. Secondly, we give the temperature by the constant oven, start from 25℃ and then 50℃, 75℃, 100℃ successively in the periods of 1-20days for the each sample. After that, we observed the charge amount by Simco-ion Digital electrostatic field meter, and we came to know that high temperature enhanced the charge amount of the samples. Thirdly, we again give the relative humidity with the help of the humidity chamber, starts from 60% and after that 80%, 95% consecutively in the periods of 1-20days for the each sample when the temperature being constant 25℃. After that, we detected the charge amount by Simco-ion Digital electrostatic field meter, and we saw that higher humidity decreased the charge amount of the samples.

However, if there is a controlled environment, there temperature and humidity level can be precise, then the charge amount of the electret fabric can be durable so the filtration performance can be developed as well.

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