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Electrospun Nanofibrous Membrane for Air Filtration

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***Abstract* — Nanofibers have a large potential in air filtration applications, so this paper explores the performance of electrospun nanofiber membrane compared to traditional filtration fabrics. Poly (ethylene oxide) (PEO) and Polyvinyl Alcohol (PVA) were electrospun into nanofibrous membranes and analyzed their filtration attributes. Experimentation revealed that nanofibrous membranes have higher filtration efficiency than traditional filtration fabrics, such as meltblown and needle filtration material. In addition, Nanofibrous membranes under the same electrospinning process but with different materials had similar high filtration efficiency, while their permeability had obvious difference. We suggest that different structure in the nanofiber membrane should cause this difference. Our work proves that there is a large potential for nanofiber membranes to utilize in air filtration area.**

Keywords —Electrospinning; Nanofibers; Membranes; Filtration; PEO; PVA

I. INTRODUCTION

Electrospinning has gained much attention in the last decade not only due to its versatility in spinning a wide variety of polymeric fibers but also due to its consistency in producing fibers in the submicron range[1]. To date, a large number of polymers have been successfully electrospun [1] and immense research has been carried out to gain in depth understanding of the process for better control of fiber formation [2–6]. Now, more and more potential applications of electrospun fibers have also been realized such as, protective textiles [7-8], high-performance air filters [9], advanced composites [10-12], sensors [13,14], wound dressing [15,16] and as scaffolds in tissue engineering [17-21] and more recently as membranes in affinity separation [22].

In a lot of commercial air filtration applications, polymeric nanofiber has a large of potential value, because small fibers in the submicron range, compared with large ones, are well known to provide better filter efficiency at the same pressure drop in the interception and inertial impaction regimes [23]. Thus electrospun nanofibrous membranes possess several attractive attributes of separation, such as high porosity, pore sizes ranging from tens of nanometer to several micrometers, interconnected open pore structure, high permeability for gases and high surface area per unit volume. In particular, they have been highly successful in developing high-performance air filters. In fact, it was in air filters that electrospinning saw its first commercialized application [24, 25, and 26].

In this paper, PVA and PEO will be used to electrospinning and form membrane for air filtration applications. We try to compare the nanofibrous membranes with traditional filtration material and find their advantages. At the same time, we will compare performances of different nanofiber membranes and discuss the effect of nanofiber configuration for filtration performances.

II. EXPERIMENTS

A. Materials and Process

PEO (Tianjin, Da Di Fine chemical Engineering Co., 300,000g/mol) was mixed with water and ethanol (V/V: 50%/50%) and its concentration was 19 wt%. The solution was prepared by stirring at room temperature for 25 minutes. A syringe pump was utilized to supply a constant flow of 100μl/h polymer solution during electrospinning. The distance between needle and collector was 8cm. The voltage of 8 kV was applied to draw the nanofibers from the prepared solution.

Figure 1 and Figure 2 show such process and related machines. Now, scanning electron micrographs (SEMS) are generally used to characterize electrospun nanofibers, so the configuration of PEO nanofibrous membrane can be seen with it as in figure 3. At the same time, we can get some important information of PEO nanofibrous membrane from Table Ⅰ. The average fiber diameter of PVA nanofibrous membrane is 200nm, and picture statistic calculation shows the detected pore size is 1~10μm. The membrane thickness is 350μm.

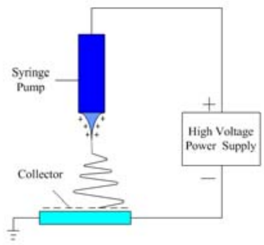

Figure 1. Electrospinning process and related machines.

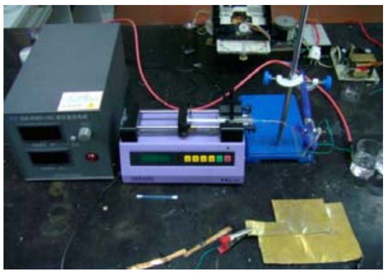

Figure 2. Electrospinning process and related machines

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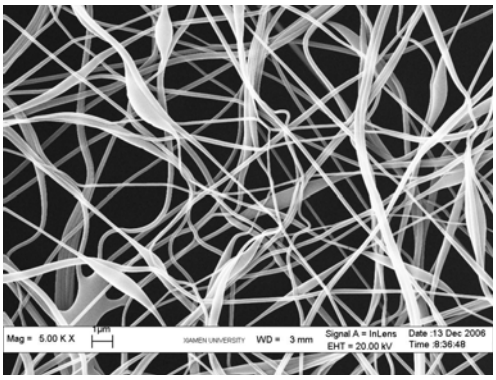

Figure 3. Configuration of PEO nanofibrous membrane

TABLE I. PROCESS CONDITIONS AND PEO MEMBRANE PROPERTIES

Conditions		Membrane properties	
Polymer concentration	19wt%	Average fiber diameter	200nm
Spinneret inside diameter	232μm	Membrane thickness	350μm
Tip-collector distance	8 cm	Detected pore size	1-10μm
Air pressure	101.3 kPa		
Flow-rate	100μl/h		
Humidity	75%		

The commercial PVA was purchased from Guang Zhou South Hua Bo Co., and the number of average molecular weight of PVA is 118000. PVA was mixed with water and stirred at 80℃ for 1h in order to get well-proportioned solution. Its concentration was 9wt%, and the flow rate of the solution is set as 200μl/h by means of syringe pump. The distance between needle tip and collector was 15cm, and the nanofiber was drawn from the prepared solution with a voltage of 15KV. We can see the configuration of PVA nanofibrous membrane from figure 4 and get related data from Table Ⅱ. The average fiber diameter of PVA nanofibrous membrane is 500nm, and the detected pore size is 0.5~8μm. The membrane thickness is 400μm.

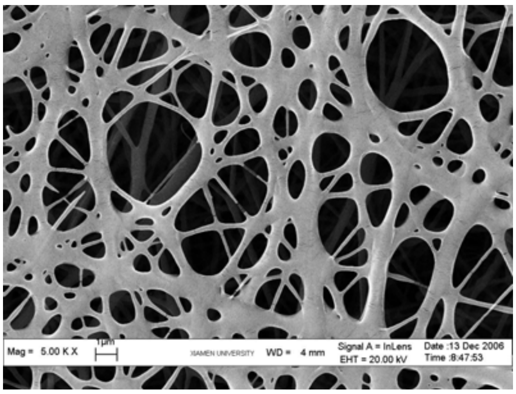

Figure 4. Configuration of PVA nanofibrous membrane

TABLE II. PROCESS CONDITIONS AND PVA MEMBRANE PROPERTIES

Conditions		Membrane properties	
Polymer concentration	9wt%	Average fiber diameter	500nm
Spinneret inside diameter	232μm	Membrane thickness	400μm
Tip-collector distance	15 cm	Detected pore size	0.5-8μm
Air pressure	101.3 KPa		
Flow-rate	200μl/h		
Humidity	75%		

B. Filtration Test

Here, a test system which is designed to compare the filtration performances of membranes as we can see from figure 5. The test system is composed of anterior air filter, vent-pipe, pressure test sensors, flow meter, system blower, air collector and analysis instrument. At first, nanofibrous membranes are weighted with high precise balance (Mettler-Toledo Co., AB-135S, 31g/0.01mg), then, mount the membrane with 10cm diameter into the test system. Secondly, the blower works, natural air is sucked into the test system, only the particle with diameter smaller than 10μm in the air can go through the PM10-100 particulate air filter, afterward natural air sample which has gone through air filter is collected and analyzed, and then air sample will penetrate the nanofibrous filtration membrane. After testing, nanofibrous membrane will be weighted by the high precise balance. Some changes will be found between twice weights. We can also analyze the changes of configuration with SEMS and get some particle sample for further study.

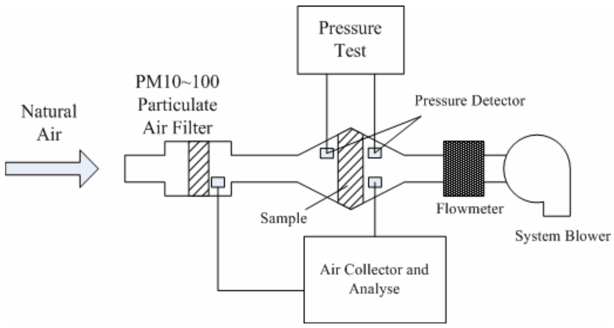

Figure 5. The schematic diagram of the test system setup

III. RESULTS AND DISCUSSIONS

The two filtration membrane samples of PEO and PVA are tested under the same condition. At that time, temperature was 14.1℃, and humidity was 50%. The particle concentration of the test air was 0.07mg/m3. Figure 8 shows particle size distribution of the test air. The diameter of test nanofibrous membranes was 10cm. Other related data can be seen from Table III. Figure 6 and Figure 7 show the tested nanofibrous membrane samples respectively.

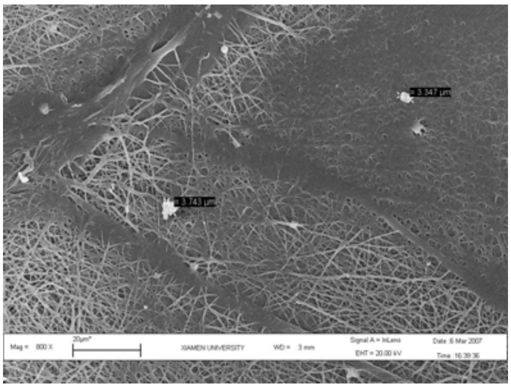

Figure 6. The tested PEO nanofibrous membrane

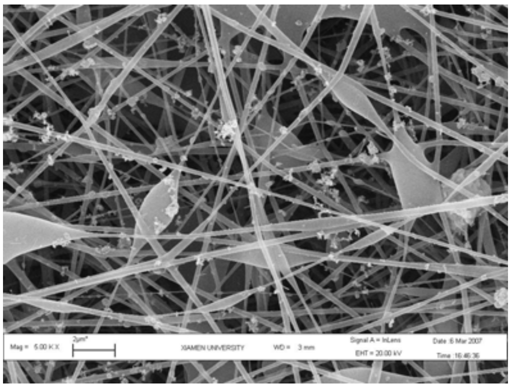

Figure 7. The tested PVA nanofibrous membrane

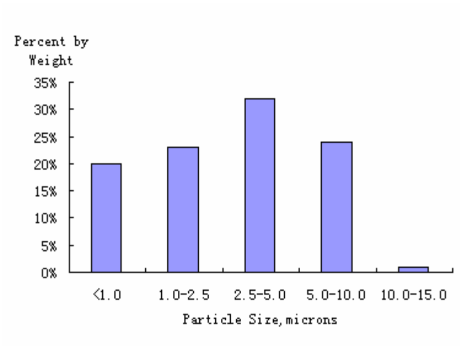

Figure 8. Particle size distribution

From Tab 3 we can see, the thickness of two samples is similar. The thickness of PEO membrane is 350μm, and PVA membrane is 400μm. Through analyzing statistics data of detected pore size and related calculation, we find that the distribution of the detected pore size of PEO membrane is 1~10μm, and that of PVA membrane is 0.5~8μm.

With Eq. (1), the efficiency of sample can be calculated.

$$FE = \left(\frac{W_{total} - W_{permeate}}{W_{total}} \right) \times 100\%$$

$$= \left(\frac{\Delta W_{sample}}{W_{total}} \right) \times 100\% \qquad 1$$

W_{total} is the total weight of particles of test air, and $W_{permeate}$ is the weight of particles which can permeate filtration membrane. Then ΔW_{sample} is the change between twice weight of filtration membrane. Through calculating, we know, the efficiency of PEO nanofibrous membrane is 92.8%, while the efficiency of PVA nanofibrous membrane is 97.6%. But, compared with nanofibrous membranes, when particles in the air, including PM10, PM2.5 and PM1.0, are used as testing sample, filtration efficiency of needle cellulose filtration fabrics is only between 20% and 40%, while the filtration efficiency of meltblown filtration fabrics between 50% and 80%, and the pressure drop grows quickly with the increasing of the wind speed[27]. The causes of this phenomenon maybe: firstly, the detected pore size of filtration materials has obvious difference. we can know, usually, the average pore size of traditional cellulose filtration material is bigger than electrospun nanofibrous membranes, so separation capability of nanofibrous membrane precedes traditional filtration material for smaller particle in air; secondly, the diameter of electrospun nanofiber is smaller than the diameter of traditional fiber; therefore, the direct interception effect and inertial impact effect of nanofiber are more evident than traditional fiber.

TABLE III. RELATED DATE OF EXPERIMENT

Membrane / Key data	PEO	PVA
Membrane thickness	350μm	400μm
Detected pore size	1-10μm	0.5-8μm
Average fiber diameter	200nm	500nm
Air flux	100 L/min	100 L/min
Test time	60 min	60 min
Average pressure drop	800 Pa	1100 Pa
Filtration efficiency	92.8%	97.6%
Humidity	50%	50%

In addition, two kinds of nanofibrous membranes are compared with each other. At the same testing conditions, the pressure drop of PEO nanofibrous membrane is 800 Pa, while the pressure drop of PVA nanofibrous membrane is 1100 Pa, thus it shows PEO nanofibrous membrane has higher permeability. Because the average pore size of PVA nanofiber membrane is smaller than PEO nanofibrous membrane, we think it maybe cause the permeability difference of nanofibrous membranes.

Both of the nanofibrous membranes have similar thickness, PVA nanofibrous membrane has better filtration efficiency, but the difference of their filtration efficiency isn't obvious.

Probably, the difference of their nanofibrous configurations causes it. The diameter of PVA nanofiber is bigger than that of PEO nanofiber, the centrifugal impact effect of PVA nanofibrous membrane is stronger than PEO nanofibrous membrane, and the average pore size of PVA nanofibrous membrane is smaller than PEO nanofibrous membrane, so it enhances the filtration capability of PVA nanofibrous membrane.

IV. CONCLUSIONS

Experiment results show that, compared with traditional air filtration material, electrospun nanofiber has better filtration capability, so it has a large potential to utilize as cheaper and more efficient civil microfiltration membranes to remove air particle. In succession, we study the effect of fabrications and configurations of nanofibrous membranes for filtration performances through comparing two samples, and we find PVA membrane has higher filtration efficiency because of its smaller fiber diameter, but its average pore size is smaller than PEO nanofibrous membrane, so it has lower permeability. It is worth for us to make further research to find the relations between nanofibrous configurations and filtration attributes for the sake of extending the filtration applications of electrospun nanofibrous membranes.

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