Analysis of Electrospun Nylon 6 Nanofibrous Membrane as Filters

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Abstract: In this work, nylon 6 was firstly dissolved in 98% formic acid with the concentration of 13wt%, and then electrospun to obtain nanofibrous membranes. The morphology of the electrospun nylon 6 nanofibrous membranes was observed by scanning electron microscopy (SEM), the filtration efficiency and the mechanical properties were also examined. The results show that the average diameter of electrospun nylon 6 fiber was 217 nm, the surface average pore diameter was 234 nm, the thickness was 31 to 60 μm, the breaking tenacity was up to 8.06 Mpa and the elongation at break reached 52.8%; when the polyester fabric substrate was covered with the electrospun nylon 6 nanofiber membrane with the density of 1.25g/m^2, at the airflow speed of 2.83l/min, the separation for 1μm, 0.5μm 0.3μm particles was 92.16%, 89.66%, 87.38%, respectively. In comparison, the fabric substrate just gave 9.92% separation for 1μm particles and had no filtration effect for 0.5μm and 0.3μm particles. The separation efficiency was improved by using a thicker electrospun membrane with the density of 2.5g/m^2, the filtration efficiency could reach 97.03%, 96.23%, 95.65% for 1μm, 0.5μm 0.3μm particles repectively, but the permeability did not increase significantly. The excellent filtration performance, combined with a simple production process, suggested tremendous potential application as high-precision filter materials.

Keywords: Electrospinnin, nanofibers, mechanical properties, nylon 6, filtration performance.

1. Introduction

In recent years, filters which have characteristics of high efficiency and low resistance have drawn much attention. This is for the reason that they are widely used in biomedical and industrial fields. Few such areas include blood dialysis, respiratory protection, cleaning of test-tube baby 100-degree air, processing of nuclear and hazardous materials, particle collection in clean rooms and so on [1]. In particular, fibrous filters have been widely used to separate solid matter from the particulate laden air flow streams because of their simple structure and low material cost. Undoubtedly, it is the best for fibrous filters that have an extremely large surface area, relating to high dirt-loading capacity. The smaller the fibre diameter used in the filters, the greater the surface area for particle adsorption and the better the retention of small particles. Small fibres in the sub-micron range, in comparison with larger ones, are well known to provide higher filtration efficiency at the same pressure drop in the interception and inertial impaction stages of the filtration process.

Recently, a method to prepare ultrafine fibers, electrospinning, has received considerable attention. The electrospinning technique is a well-known process for making continuous sub-micron to nano-size fibers in the nonwoven mat form. Electrospun nanofibers have a variety of potential uses as sensors, tissue engineering scaffolds, wound dressings, high performance air filters, nano-filter materials, and as membranes due to their large specific surface area, high fiber aspect ratio and high degree of interconnection.

At present, the electrospun nanofibrous membrans have been used as air filters over the last 20 years. Ki MyoungYun prepared Polyacrylonitrile (PAN) fibers with mean diameters in 270-400 nm range by electrospinning for use as a filter media, and found electrospun filters had nanoparticle penetration values comparable to commercial filters [3]. Renuga Gopal dissolved PVDF in N,N-dimethylacetamide (DMAc)/ acetone mixture (1:1 v/v), and then electrospun into webs for liquid separation. They found that electrospun membranes were successful in rejecting more than 90% of the micro-particles from the solution. This work opens up the avenue of exploring the use of nanofibers for more mainstream application in the separation technology [4]. Additionally, they also prepared polysulfone nanofibrous membranes through electrospinning, whose bubble-point was 4.6 μm, was able to remove above 99% of 10, 8 and 7μm particles without any permanent fouling, could be used as pre-filters prior to ultra- or nano-filtration [5]. C. Shin produced polystyrene (PS) sub-μm fibers from recycled expanded polystyrene (EPS) through electrospinning. These fibers were mixed with micro glass fibers to modify the glass fiber filter media. They

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found that adding nanofibers to conventional micron sized fibrous filter media improved the separation efficiency of the filter media, the separation efficiency was improved from 61% to 91% [6]. Kang Weimin collected Poly (hexamethylene adipate) nanofibers whose diameter was in the range of 80~500nm on the electret melt-blowing nonwovens by electrospinning to form the nanofiber composite membranes. They found the filtration efficiency of nanofiber composite membrane reached 99.9％for the particles diameter of 0.3 μm [7].

Nylon 6 has good chemical stability and heat resistance, can be dissolved in formic acid and electrospun into nanofibers easily, which provide the application basis for the elecstrospun nylon-6 nanofibres. Pirjo Heikkila studied the effect of electrospinning parameters on the morphology of nylon-6 fibers[8]. Furthermore, Pan Zhijuan, who are from Suzhou university, made a profound study for the performance of elecstrospun nylon-6 fibres [9]. D. Aussawasathien electrospun nylon-6 nanofibrous webs with fiber diameters in the range of 30-110 nm which were employed as a membrane material for water filtration due to their excellent chemical and thermal resistance as well as high wet ability. They separated all particles with sizes from 1 to 10 μm, whereas approximately 90% separation was obtained for 0.5 μm particles. They found that the possibility of using membranes of electrospun nanofibers as pre-filters, prior to ultrafiltration or nanofiltration to increase the filtration efficiency and prolong the life of downstream membranes [10]. Ren Feng produced a novel sandwich structure nanofiber super cleaning material, and found that its filtration efficiency for yeast could reach 99.976% [11]. In this study, we dissolved nylon-6 in formic acid, produced electrospun nanofibers membranes, and then studied their morphology, mechanical property and filtration efficiency for the 0.3μm, 0.5μm, 1μm particles in air.

2. Materials and method

2.1 Electrospinning to develop Nylon-6 nanofibers

Nylon-6 (Sigma Aldrich Inc.) was dissolved in 98 wt % formic acid (Shanghai Chemical Reagent Co., Ltd) yielding a 13%(w/w) spinning solution. The electrospinning parameters are as follows: voltage 25kV, distance 13cm, the diameter of the needle tip 0.9 mm, flow rate 0.3 ml/h.

2.2 Characterization of morphology

The morphologies of the electrospun fibers were observed by a Hitachi S-570 SEM (scanning electron microscope). The average fiber diameters were calculated by analyzing the SEM images with a custom code image analysis program (Adobe Photoshop 7.0).

2.3 Mechanical property

The samples were balanced under constant temperature and humidity (T=23℃, RH=70%). After balancing for 24 h, the tensile testing was performed by using an Instron tester (Model 3365). The length of samples was 30 mm and the width was 6 mm. The cross-head speed was 20 mm/min, five samples in each group, 5 points was selected in each membrane to test the thickness by digital fabrics thickness instrument (Model YG(B)141D), and then calculated the average values. The mechanical property was characterized according to the following formula:

$$\text{Breaking tenacity} = \frac{\text{breaking strength}(N)}{\text{thickness}(\text{mm}) \times \text{width}(\text{mm})} \quad (1)$$

$$\text{Strain at break}\ (\%) = \left(\frac{L1 - L_0}{L_0}\right) \times 100 \quad (2)$$

Where L_0 was the length of sample, L1 was the length at break.

2.4 Filtration efficiency evaluation

The thickness of the polyester based fabric and the electrospun fibrous membranes were tested by digital fabrics thickness instrument (Model YG(B)141D, WenZhou Darong Textile Instrument Co., Ltd). The air permeability was measured by fabric permeability instrument (Model YG461, NingBo Textile Instrument Factory). The nylon-6 electrospun fibrous membranes were deposited on the surface of the polyester based fabric substrates. Then, the filtration efficiency of different diameter dust particles in air was evaluated by the Laser Particle Counter (Model CLG-03A, Suzhou Cleaning Technologies Research Institute), flow rate was 2.83L/min, air pressure was 101.3 kpa.