Desalination 344 (2014) 266–273

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Effect of oriented fiber membrane fabricated via needleless melt electrospinning on water filtration efficiency

Xiaohu Li, Youchen Zhang *, Haoyi Li, Hongbo Chen, Yumei Ding, Weimin Yang **

College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029, China

HIGHLIGHTS

- A new needleless melt electrospinning device was introduced.
- Determined an optimum condition to fabricate oriented fibers guided by an simulation.
- Oriented membranes showed higher retention rate than the native membranes.
- Uniform angle of adjacent oriented membranes improved the filtration efficiency.

ARTICLE INFO

Article history:
Received 22 December 2013
Received in revised form 29 March 2014
Accepted 3 April 2014
Available online xxxx

Keywords:
Needleless melt electrospinning
Oriented fibers
Membrane
Interval angle
Filtration efficiency

ABSTRACT

The oriented polypropylene fibers in this article were fabricated via the needleless melt electrospinning technique, and the influence of arrangement for oriented fiber membranes on the filtration efficiency was studied using it, guided by an electric field simulation with the software ANSYS, then combined with an experimental study to investigate the influence of the nozzle-to-electrode distance and the electrical field strength on fiber diameter. An appropriate distance to electrospun oriented fibers in the range of 5–10 cm was determined, and it was shown that the fiber diameter significantly became thinner with the increasing cylinder speed. Characterizations revealed that the mean pore size of the electrospun oriented membranes was much smaller than the electrospun random membranes, and the mean pore size of oriented membranes and random membranes was 18.96 μm and 27.29 μm, respectively. Experimental results demonstrated that electrospun oriented membranes showed higher efficiency in rejecting the 0.5 μm particles with a diameter of 2.49 ± 0.418 μm and still maintained nearly the same permeate flux as that of the native membrane. The interval angle of adjacent membranes was more uniform, and the water flux and rejection ratio would be greater.

1. Introduction

As we all know, since Formhals [1] invented the electrospinning technique in 1934, electrospun fibers have been attracting a lot of interest due to their high specific surface area and good mechanical properties. They have a broad application prospect in many areas such as biomedical filtering material, medical tissue engineering scaffolds, and composite material [2–6]. The basic electrospinning setup mainly includes a high voltage power supply, a spinning nozzle connected to high voltage static electricity, and a counter-electrode collector. The basic process of electrospinning is as follows: a polymer solution or melt in a high-voltage electrostatic field of thousands to tens of thousands volts overcomes the surface tension giving rising to a charged jet, and the solution or melt jet is then solidified during the injection process and ultimately rests on the receiving electrode in fiber form [7].

Needless to say, with increasingly serious water pollution, more and more researchers are paying attention to the study of filter membranes. Microfiltration (MF) as one of the most widely used on water treatment plays an irreplaceable role, including pretreatment of waste water, clarification of beer and wine, and removal of bacteria, algae or protozoans from surface water or contaminated water [8,9]. In many application fields, the electrospun fibers function as a filter medium that is relatively mature because of its high flux and low resistance during filtering [10–12]. Current studies on electrospun fiber membrane filtration mainly include the research on the mechanism of the filtration [13], simulation of fiber membrane filtration [14–16], and actual filtration performance [17,18]. Representatively, Hosseini [14,15] built 2-D and 3-D models of particle filtration in electrospun nanofibrous filters. Kaur investigated the influence of hot pressing on electrospun

* Corresponding author. Tel./fax: +86 10 64436737.
** Corresponding author at: Beijing University of Chemical Technology, Beijing 100029, China. Tel./fax: +86 10 64434734.
E-mail addresses: zhangyc@mail.buct.edu.cn (Y. Zhang), yangwm@mail.buct.edu.cn (W. Yang).

http://dx.doi.org/10.1016/j.desal.2014.04.003
0011-9164/

nanofibrous membrane (ENM) properties. The results showed that hot pressing influenced the pore size distribution of the substrate membranes and subsequently their filtration efficiency [17]. Benjamin developed a high-flux poly(vinyl alcohol) (PVA) microfiltration filters based on electrospinning and explored the influence of film thickness on the water flux. As the thickness changed from 20 μm to 40 μm, the pure water flux of the electrospun PVA membrane was decreased. Nevertheless, when the thickness was increased to 40–100 μm, the pure water flux was kept fairly constant [18].

Electrospun fibers are randomly arranged, because the jet whipping caused polymer jet trajectory bending during the process of electrospinning. Unfortunately, fiber configuration has a great influence on the membrane pore structure. At present, preparation of oriented fibers is carried out in several ways: using a cylinder collector with high rotating speed, an auxiliary electrode field, a thin wheel with sharp edge, a frame collector and so on [19]. Some researchers have contributed to the development of the oriented fiber membrane filtration performance. Dipayan Das [20] used virtual fiber models by varying the degree of orientation to simulate the influence to aerosol particle capture behavior. It was observed that a fiber membrane with a higher frequency of fibers oriented along the vertical direction of the membrane exhibited lower particle capture efficiency. Huang [21] observed that parallel filter always performed worse than orthogonal filters through experiment. Only when particles are smaller than the most penetrating size and are under high face velocity does the parallel filter perform better. Therefore, it has a great significance to study the influence of fiber orientation on the filtering performance. However, experimental studies of the oriented fiber membranes are very limited. It is therefore necessary to study how the fiber orientation affects the filtration efficiency of fiber filter media systematically.

Currently, solution electrospinning has achieved industrialized application, and the melt electrospinning is still in the laboratory stage. However, because it is difficult to overcome the problems of the fiber holes and environmental pollution caused by solvent volatilization for the solution electrospinning, its industrial application is therefore limited. This paper introduces a new melt electrospinning device used for the preparation of fibers and then studies the filtration performance of fiber membranes when the arrangement of oriented fibers changes.

2. Experimental

2.1. Material

Polypropylene (PP) with a melt flow rate of 2000 g/10 min was purchased from Shanghai Expert Co. (China). Then the purchased PP was used to fabricate fibers via needleless melt electrospinning as received.

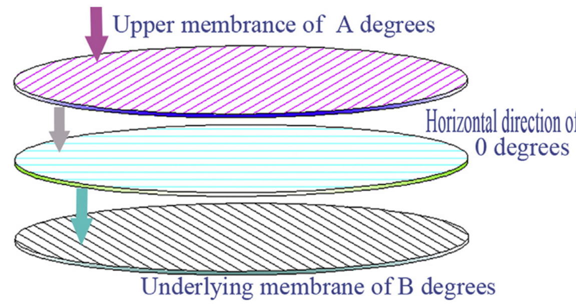

Fig. 2. Schematic diagram of samples under different azimuthal angles.

2.2. Preparation of PP filter membrane by electrospinning

2.2.1. Melt electrospun oriented PP fibers

As shown in Fig. 1, this study introduces a new needleless melt electrospinning apparatus which consists of variable high voltage power supply, a needleless inner-cone nozzle, a heating device and a cylinder collector. It possesses two attractive advantages; (1) we connect the high voltage to the plate electrode and make the nozzle grounded; thus the feeding device can get rid of disturbance of high voltage. Furthermore, a direct heating way like the heating coil can be used; (2) it breaks through the limitation of capillary electrospinning, brings forth the new idea of melt differential and uses a needleless inner-cone nozzle, which can not only eliminate the defect of low capillary production and easy blocking, but also make fiber diameter refinement.

The relationship between fiber diameter and operating parameters of melt electrospinning was investigated after a lot of explorative experiments. We also preliminarily determined the optimal operating parameters of single-electrode and dual-electrode. Elecrospinning was carried out in a humidity of 25% at 24 °C, and the nozzle temperature was set at 240 °C. The polymer melt was electrospun at the condition of single-electrode with a feed rate of 15 g/h controlled by an adjustable pump; a cylinder collector (diameter: 10 cm, maximum rotating speed: 1400 rpm) was used to get the oriented fibers and was placed 26 cm off the nozzle.

2.2.2. Preparation of PP filter membrane

As shown in Fig. 2, oriented PP fiber membranes were stacked under different azimuthal angles based on the horizontal datum of 0 degrees

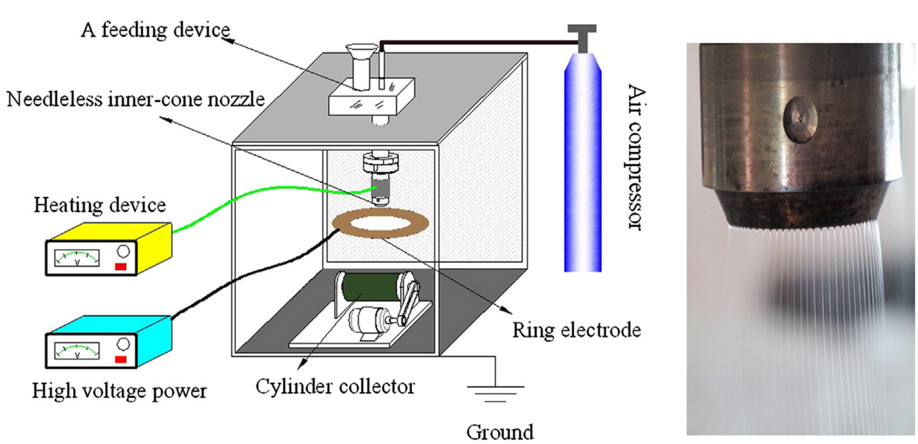

Fig. 1. Schematic diagram of the melt electrospinning apparatus and the image of the melt jet.