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A review on electrospinning for membrane fabrication: Challenges and applications

Farah Ejaz Ahmed, Boor Singh Lalia, Raed Hashaikeh *

Materials Science and Engineering Program, Masdar Institute of Science and Technology, P.O. Box 54224, Abu Dhabi, United Arab Emirates

HIGHLIGHTS

- Electrospinning as a membrane fabrication technique
- Optimization of electrospun membrane properties for water treatment applications
- Pre/post-treatments for electrospun membranes

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ABSTRACT

Fibrous structures with nanoscale diameters offer a multitude of fascinating features, such as excellent mechanical behavior and large surface area to volume ratio, making them attractive for many applications. Their large surface area also gives them high functionalization ability. Among the many techniques available for generating nanofibers, electrospinning is rapidly emerging as a simple process in which careful control of operating conditions and polymer solution properties enables the production of highly porous structures of smooth non-woven nanofibers. Compared to traditional phase inversion techniques for membrane fabrication, electrospinning allows the formation of interconnected pores with uniform pore size and porosities exceeding 90%. As a result, electrospun membranes are increasingly being applied to many water purification applications such as membrane distillation and pretreatment of feed prior to reverse osmosis or nanofiltration processes by the removal of divalent metal ions, grease and other contaminants. Although the use of electrospinning for membrane fabrication has previously been reviewed, the rapid increase in developments over recent years has necessitated the need for a review on the preparation and application of electrospun nanofiber membranes as the barrier layer for water treatment, with emphasis on the reinforcement and post-treatment of electrospun polymer membranes.

Contents

* Corresponding author. Tel.: +971 2 810 9152.
E-mail address: rhashaikeh@masdar.ac.ae (R. Hashaikeh).

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1. Introduction

Currently, about 11% of the world's population lacks access to drinking water. The World Health Organization anticipates that water shortages may affect up to 4 billion people by 2050 [1]. Although water constitutes more than 70% of the earth's surface, 97% of this is too salty for human use. Moreover, most of the remaining 3% is trapped underground or in glaciers and ice caps, leaving less than 1% of the world's water supply available to us [2]. With fresh water resources quickly running out, the need for more efficient and low cost water treatment methods is critical to help meet our ever growing water demands.

Membrane-based technologies have gained popularity over the last few decades due to their high separation efficiencies, relatively low costs and ease of operation. A membrane acts as a barrier between two phases that allows substances to be selectively transported from one side to the other [3]. Membranes are classified as porous or dense, depending on their structure [4]. Transport properties and selectivity of a membrane are strongly dependent on its pore structure. The two different transport mechanisms in porous and non-porous membranes are shown in Fig. 1.

1.1. Nano-porous membranes

Nano-porous membranes consist of a film in which molecules are transported via the solution-diffusion mechanism, i.e. dissolution in the membrane matrix accompanied by diffusion through the membrane thickness. Transport is driven by a pressure, concentration or potential gradient across the membrane [5]. Nano-porous membranes are typically used in desalination processes such as reverse osmosis (RO) and more recently, forward osmosis (FO). Nanofiltration (NF) membranes have very small pores (1–10 Å) and are also considered dense [6]. RO is increasingly being applied to desalination with very high salt rejection rates, although it is limited by very high pressure requirements. In FO desalination, the osmotic pressure difference provides the driving force for separation [7]. A draw solution with higher osmotic pressure than the feed is used on the other side of the membrane to allow water to flow in that direction, using the natural osmotic pressure gradient between the two solutions. Compared to RO and thermal desalination processes, FO does not require high hydraulic pressures or temperatures [8]. Nano-porous membranes are also used in pervaporation for separating organic mixtures and in gas separation due to their ability to separate very small molecules [9–14].

In order to achieve sufficiently high fluxes, the dense layer is fabricated to only a few hundred nanometers in thickness. A porous supporting layer is therefore necessary for mechanical integrity especially in high-pressure applications such as NF and RO [6,15]. This support layer should exhibit mechanical, thermal and chemical stability [16]. Most thin film composite (TFC) membranes are based on an asymmetric porous support prepared by phase inversion [17]. However, electrospun scaffolds are now replacing conventional support systems

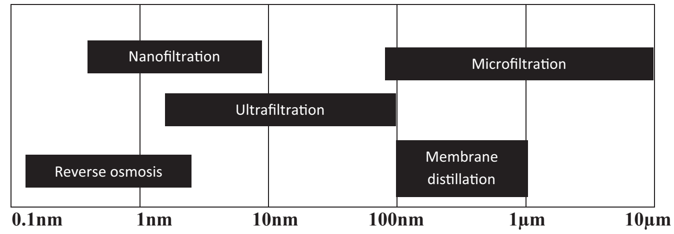

Fig. 2. Size of particles rejected in different membrane processes [35].

in TFC membranes with improved performance due to the unique interaction between the barrier and support layers [16,18–26]. Commercial phase inversion support layers cannot be easily extended to FO as their thickness causes resistance to diffusion, eventually leading to poor membrane performance. Transport properties of TFC membranes can be enhanced to better suit FO by controlling the structure of the support layer without compromising its mechanical integrity and suitability as a substrate for interfacial polymerization [27]. Electrospun membranes are a promising choice for developing high flux FO membranes as their interconnected pore structure permits a shorter path for diffusion of molecules, allowing higher flux to be obtained [28–32]. Another advantage of using electrospun membranes is that they can be made thin, while retaining good mechanical properties. Recently, some studies have reported the use of electrospun nanofibers for high performance pervaporation membranes [33,34].

1.2. Micro-porous membranes

Micro-porous membranes are used for other pressure-driven processes such as microfiltration (MF) and ultrafiltration (UF). Selectivity is determined by the pore size and pore size distribution across the membrane such that only particles smaller than the pore size are allowed to pass through. MF membranes can separate particles between 0.1 and 10 μm, whereas UF can remove particles between 0.001 and 0.1 μm in size [35]. Fig. 2 shows the smallest particle rejected in different membrane processes. Control of pore size, pore size distribution as well as mechanical strength is necessary for efficient MF and UF membranes. Micro-porous membranes are also used in membrane distillation (MD). MD is a thermally driven desalination process in which the membrane retains water on one side and allows only vapor to pass through its pores. MD membranes should be hydrophobic, highly porous and mechanically stable with a narrow pore size distribution and high liquid entry pressure (LEP) [36–38]. Combined with the right choice of material, electrospinning offers control over these parameters, making electrospun membranes a suitable candidate for MD processes [36].

1.3. Electrospinning

Nanofibers are a unique class of nanomaterials with many interesting properties owing to their nanoscale diameters and large aspect

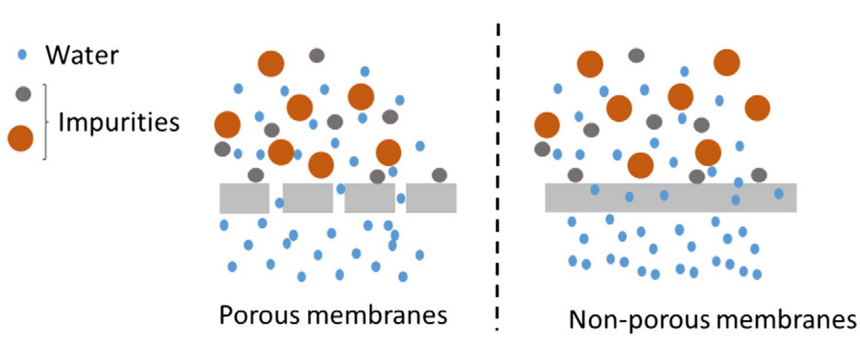

Fig. 1. Transport mechanisms in porous membrane (left) and non-porous membrane (right).