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A review on membrane fabrication: Structure, properties and performance relationship

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HIGHLIGHTS

- Membrane fabrication techniques
- Structure–property relationship of membranes
- Structure parameters affect the membrane performance.

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ABSTRACT

In this review, polymeric membrane fabrication techniques for pressure driven membrane processes and membrane distillation are discussed. The fabrication technique, properties of the fabricated membranes and performance in water desalination are related. Important parameters which affect the membrane performance such as crystallinity of the membrane based polymer, porous structure, hydrophobicity/hydrophilicity, membrane charge and surface roughness are analyzed. Despite the fact that extensive knowledge exist on how to 'tailor' membrane pore structure including its surface properties and cross-section morphology by selection of appropriate fabrication methods, there is still a challenge to produce reliable membranes with anti-fouling properties, chemical resistance, high mechanical strength with high flux and selectivity. To ensure progress in membrane performance, further improvements are needed of common membrane fabrication techniques such as phase inversion and interfacial polymerization. At the same time, the potential of novel fabrication techniques such as electrospinning and track-etching needs to be assessed. A comprehensive understanding between structure-surface properties and performance is a key for further development and progress in membrane technology for water desalination.

Contents

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1. Introduction

According to the world population clock, the population exceeds 7 billion and will reach 10 billion by 2050. Pure drinking water would be a major problem for the developing countries in the world. The improvement in the efficiency and cost of water treatment is a major challenge to overcome the scarcity of portable water. Different membrane methods have been used for water treatment, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO) and membrane distillation (MD) [1]. UF and MF are well-developed techniques used for water treatment, whereas RO is widely used for water desalination and purification. MD is a new developing technique and it has potential for desalinating highly saline water [2,3]. The membranes play a key role in membrane-based water treatment processes and determine the technological and economical efficiency of the aforementioned technologies; membrane improvement can greatly affect the performance of current technology. The material selection and pore size of the membranes depend on the application for which it would be used. Fig. 1 represents the average pore size requirement for membranes for different water treatment processes.

Different fabrication techniques and polymers used for the preparation of polymeric membranes are summarized in Table 1. Details of the fabrication techniques process and the material structural characteristics will be discussed in the subsequent sections.

In this article, the recent development of polymeric membrane materials and membrane preparation methods with focus on structure–property relationships for pressure-driven membrane processes and MD will be discussed. This review article will provide a reference to the researchers and manufacturers working on fabrication of membranes and materials for water treatment.

2. Membrane fabrication methods

The selection of a technique for polymer membrane fabrication depends on a choice of polymer and desired structure of the membrane. The most commonly used techniques for preparation of polymeric membranes include phase inversion, interfacial polymerization, stretching, track-etching and electrospinning.

2.1. Phase inversion

Phase inversion can be described as a demixing process whereby the initially homogeneous polymer solution is transformed in a controlled manner from a liquid to a solid state [4]. This transformation can be accomplished in several ways [5], namely:

(a) Immersion precipitation. The polymer solution is immersed in a non-solvent coagulation bath (typically water). Demixing and precipitation occur due to the exchange of solvent (from polymer solution) and non-solvent (from coagulation bath), that is, the solvent and non-solvent must be miscible.
(b) Thermally induced phase separation. This method is based on the phenomenon that the solvent quality usually decreases when the temperature is decreased. After demixing is induced, the solvent is removed by extraction, evaporation or freeze drying.
(c) Evaporation-induced phase separation. The polymer solution is made in a solvent or in a mixture of a volatile non-solvent, and the solvent is allowed to evaporate, leading to precipitation or demixing/precipitation. This technique is also known as a solution casting method.
(d) Vapor-induced phase separation. The polymer solution is exposed to an atmosphere containing a non-solvent (typically water); absorption of non-solvent causes demixing/precipitation.

However, among these techniques, immersion precipitation and thermally induced phase separation are the most commonly used method in the fabrication of polymeric membranes with various morphologies [6,7].

2.1.1. Immersion precipitation

Immersion precipitation is a process where a polymer solution is cast on a suitable support, then immersed in a coagulation bath containing a non-solvent, where an exchange of solvent and non-solvent takes place and the membrane is formed [8]. Schematic presentation of processes after polymer solution immersion in a non-solvent bath is shown in Fig. 2. The solvent diffuses into the coagulation bath (at a flux = J_2) whereas the non-solvent will diffuse into the cast film (at a flux = J_1). After a certain time the exchange of solvent and non-solvent proceeds until the solution becomes thermodynamically unstable and demixing takes place. A solid polymeric film finally is obtained with an asymmetric structure. Usually at $J_2 \gg J_1$ "skin" UF membranes with pore size of 10–300 Å are obtained, while at $J_2 = J_1$ mainly MF membranes with pore size of 0.2–0.5 μm are fabricated.

For membrane technologies, the development of the first high-flux anisotropic acetate cellulose (CA) RO membranes via immersion precipitation by Loeb and Sourirajan [10] was one of the most critical breakthroughs in desalination. Today, extensive knowledge exists on how to 'tailor' the membrane's pore structure including its cross-section

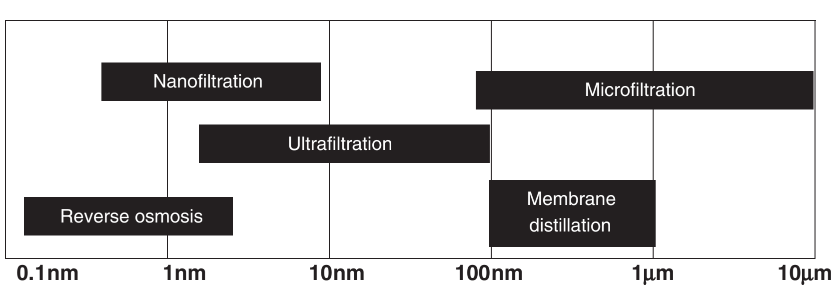

Fig. 1. Average pore size of the membranes used in different membrane processes.