Chapter 1

Introduction

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Abstract

In this chapter, a summary of different synthetic polymers-based water/gas separation techniques is given. It includes the separation of solutes from wastewater and also the purification of gases from various cocktails. Moreover, a summary of individual chapters of this book entitled ‘Polymeric Membranes for Water Purification and Gas Separation’ is shown in the conclusion section.

Keywords

Polymers, Membranes, Water Purification, Gas Separation

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Figure 1. a) Schematic diagram of pore-flow membrane vs. solution-diffusion membrane transport. b) Diagrammatic representation of major membrane filtration methods.

1. Background

Some areas of the world, especially the developing countries, have been severely affected by acute water shortages. This is due to freshwater pollution which has been caused by the addition of macro-, micro- and nano-pollutants. Advanced water purification

technologies, which need less energy to purify contaminated water, are important to develop. Membrane technology is considered as one of the efficient methods to purify wastewater in several routes [1]. Four common types of polymeric membranes, such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) are used to remove particles of desired sizes (See Fig. 1). Particles/solutes pass through MF and UF typically follow pore-flow mechanism, whereas RO membrane obeys solution-diffusion mechanism as revealed in Fig 1 (a). Meanwhile, the NF membrane goes along with a combination of pore-flow and solution-diffusion mechanisms. Based on pore types and their distribution, membranes are of two types, such as symmetrical/depth filter and asymmetric/screen filters as shown in Fig. 2. Symmetric membranes have a uniform pore structure throughout the thickness. This membrane retains solutes within the membrane (*i.e.* into the pores) and the mechanism of solutes capture follows simple size sieving, Brownian diffusion, adsorption, and electrostatic adsorption. On the other hand, asymmetric membranes consist of a thin active layer with fine pores overlaying a thicker support layer. This support layer typically has larger pores, which provide mechanical support to the active thin layer, but show little resistance to water flow. The asymmetric membranes separate solutes through the surface active layer of the membrane in a very thin film [2].

Figure 2. Structural representation of symmetric and asymmetric membrane structures. The figure is adapted with permission from the American Chemical Society [3].

1.1 Polymers for membrane fabrications

Many synthetic polymers are being used for membrane fabrication because of their high thermal, chemical and mechanical stabilities. To make a flat sheet or hollow fiber membranes, polymers should be flexible enough in such a way that one can easily fold them appropriately. Many synthetic polymers [4] are available for this purpose such as poly(phenylene oxide) polyesters, cellulose acetates, polypropylene, polyurethanes, polyetherimides, cellulose, polycarbonate esters, polyphenylene sulfide, ethyl celluloses, polyvinylidene fluorides, polyacetylenes, cellulose acetate butyrate, polyamide esters, polytetrafluoroethylene, poly(trimethylsilylpropyne), polyamide-hydrazide, polyacrylonitrile, cellulosic ester, polyetherketones, poly(phthalazine ether sulfone ketone), polyamides, cellulose nitrates, polycarbonates, polyamideimides, polyester carbonate, polyethersulfones, sulfonated poly (phthalazine ether sulfone ketone), polyureas, sulfonated polysulfones, poly(trialkylsilylacetylenes), polyvinylalcohol, polysiloxanes, polyimides, polyvinylchloride, polyvinylchloride, polyethylenes and polyvinylchloride. Such polymers have been used to fabricate different membrane processes [5]. However, some of these polymers have limitations and are not commonly practiced industrially. In general, we use very common polymers for membrane fabrication in our laboratory. In particular, one can use polysulfone, poly(acrylonitrile)-poly(vinyl chloride) copolymers, poly (vinylidene fluoride) and poly(acrylonitrile) for the synthesis of MF and UF membranes. Some other polymers such as nylons, cellulose acetate, poly(tetrafluoroethylene) and cellulose nitrate blends are also used in MF membranes preparation [6, 7]. In addition, poly (ether sulfone) has been extensively used for UF membranes. Polymers like polyester, polyether, polyamide and polyimide are useful for NF membranes. For fabricating the RO membranes, one can choose polysulfone coated with aromatic polyamides and cellulose acetate. However, all of these preceding polymers can be used to fabricate different types of membranes; their membrane performance could be drastically varied due to physicochemical differences as revealed in Table 1.

Table 1. Commonly used polymers for separation membranes in the membrane industry [8].

Polymer	Morphology			Membrane process
	Barrier type	Cross-section	Barrier Thickness (mm)	
Cellulose acetates	Nonporous	Anisotropic	~0.1	RO
	Mesoporous	Anisotropic	~0.1	UF
	Macroporous	Isotropic	50-300	MF
Cellulose nitrate	Macroporous	Isotropic	100-300	MF
Cellulose	Mesoporous	Anisotropic	~0.1	UF
Polyacrylonitrile	Mesoporous	Anisotropic	~0.1	UF
Polyetherimides	Mesoporous	Anisotropic	~0.1	UF
Polyethersulfones	Mesoporous	Anisotropic	~0.1	UF
	Macroporous	Isotropic	50-300	MF
Polyethylene terephthalate	Macroporous	Isotropic track-etched	6-35	MF
Polyamide (aliphatic)	Macroporous	Isotropic	100-500	MF
Polyamide (aromatic)	Mesoporous	Anisotropic	~0.1	UF
Polyamide (aromatic)	Nonporous	Anisotropic/composite	~0.05	RO,NF
Polyether (aliphatic)	Nonporous	Anisotropic/composite	~0.05	RO,NF
Polyethylene	Macroporous	Isotropic	50-500	MF
Polyimides	Nonporous	Anisotropic	~0.1	GS,NF
Polypropylene	Macroporous	Isotropic	50-500	MF
Polysiloxanes	Nonporous	Anisotropic/composite	~0.1<1-10	NF
Polyvinylidene fluoride	Mesoporous	Anisotropic	~0.1	UF
	Macroporous	Isotropic	50-300	MF

Conclusion

Summary of different polymers for water purification and gas separation membranes, having macroporous, mesoporous and nonporous networks, is discussed. Chapter-2 depicts a detailed discussion on different types of synthetic polymers along with their structure and properties. These polymers are generally used for membrane fabrications. Different fabrication techniques, as well as membrane characterization tools, are extremely validated whether they are feasible for lab uses. At the end of this chapter, the authors discuss some membrane module testing systems, such as plate and frame, tubular module, capillary module, hollow fiber module spiral wound modules for separation processes. Chapter-3 covers the uses of polymers, which have been extensively used for MF and UF membrane preparation in water purification. Also, we show how to incorporate different materials as reinforcement agents to improve these membranes' productivity. Besides synthetic polymers, biopolymers are also highlighted in this chapter. At the end of this chapter, we discuss some factors which could influence the overall membrane performances during operation. Thin-film composite membrane is popular for NF-based application. This is well corroborated in Chapter-4. The authors first show the drawbacks of some classical membranes. The preparation methods of such membranes are highlighted too. Many nanomaterials such as metal and metal oxide nanoparticles, carbon-based materials, metal-organic frameworks, double hydroxides nanofillers and so on are discussed in such a way that one can overcome the current limitations of these membranes. In the last part of the chapter, they highlight the fouling types and show the strategy to mitigate the membrane fouling. RO and forward osmosis (FO) are very essential membranes for separation science. Chapter-5 highlights essential information such as the preparation, modification and uses of RO and FO membranes for solutes separation. The authors first show the desirable features of RO and FO membrane for enhanced performance. Then, they discuss the phase inversion, electrospinning, interfacial polymerization, layer by layer etc. for membrane synthesis. To achieve desirable properties, these membranes have to be modified and these topics such as coating, grafting and crosslinking are displayed in detail over there. At last, they draw their perspective to improve these polymeric membranes for water purification. In Chapter-6, we discuss the separation of important gases e.g. O_2/N_2 using polymeric membrane technology. Two important mechanisms of porous and non-porous membrane technology for gas separation are illustrated in the beginning of the chapter. In addition, the asymmetric and symmetric membrane performances for gas separation are investigated. Some of the classical membrane technology's disadvantages are shown, and using various materials to overhaul these drawbacks is discussed. At the end of this chapter, we show the factors, which could directly affect the efficiency of polymeric

membranes for O₂/N₂ separation. Salleh and her coworkers beautifully present the role of different polymers including polyimides, polysulfone, polyetherimides and so on for the separation of CO₂/CH₄ in Chapter-7. They highlight some drawbacks of classical membranes and discuss the strategies to solve these bottlenecks especially by using functionalization, composites preparation, introduction of new additives, and cross-linking methods, and so on. The performances of these membranes are discussed with their gas permeability cum selectivity. They reveal five main types of mechanisms of gas transport. At the end of the chapter, they show the research gaps and give their perspectives for future research design. Overview of membranes for H₂ and N₂ separations from various mixture gases is discussed in Chapter-8. The authors have beautifully written this chapter that is very comprehensive and substantial. They first discuss the history and major applications of both classical and advanced polymers. Performance check and mechanism of gas separation membranes are shown. Major headlines include H₂/CH₄, H₂/CO₂, CO₂/N₂, N₂/CH₄ and other kinds of separations. Challenges of purifying H₂ and N₂ are widely discussed as well as they highlight some membrane design principles. Some techniques of membrane separation optimization such as intrinsic microporosity control using different materials, such as metal-organic frameworks, covalent organic frameworks, porous organic cages, organic macrocyclic molecules, 2D nanosheets and so on are scrutinized. Different kinds of polymer modification techniques are given such as grafting, chain-functionalization, crosslinking and so on.

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