Chapter 31
Nanotechnology in Engineered Membranes:
Innovative Membrane Material for Water–Energy Nexus

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ABSTRACT

The membrane processes have received extensive attention as comprehensive and interdisciplinary approaches for water-energy nexus. Nanotechnology has induced significant attention in improving membrane performances to mitigate global water and energy scarcity because of its unique characteristics and simple application for membrane fabrication. Nano-sized materials could provide highly enhanced characteristics to a membrane material, resulting in excellent performance enhancement, such as permeability, selectivity, and fouling resistance, of membrane. Carbon Nanotube (CNT), a widely utilized or studied nanomaterial in membrane science, is discussed in this chapter with a focus on its state-of-the-art applications and future prospects. Electrospun nanofiber, which is one of the feasible nano-structured membrane materials, is also discussed as a promising material for water-energy nexus. Therefore, this chapter also describes its application cases and its potential as an innovative membrane for water-energy nexus.

INTRODUCTION

Water and energy are critical, mutually dependent resources. The production of energy requires large volumes of water, and a water infrastructure requires large amounts of energy. Therefore, the nexus between water and energy is a clear agenda for sustainable development. Recently, membrane processes have received considerable attention as comprehensive and interdisciplinary approaches for the

water-energy nexus. This process is considered one of the most realistic and reliable technical solutions to address water/energy challenges. Microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO), forward osmosis (FO), and pressure-retarded osmosis (PRO) in particular have been actively utilized not only in academia but in the industrial field. A membrane material fabrication technology could be a core technology of a membrane process for the water-energy nexus, which requires particularly excellent characteristics and a performance beyond those of the common membrane materials.

Nanotechnology has induced significant attention in improving membrane properties and performances because of its unique characteristics and simple application for membrane fabrication. Nano-sized materials could provide highly enhanced characteristics to a membrane material, resulting in excellent membrane performance enhancements, such as permselectivity, fouling resistance, and mechanical properties. Various nanomaterials, such as carbon nanotubes (CNTs), graphene oxide, titania, alumina, silica, and silver, have been widely studied to fabricate advanced functional membranes due to their unique physico-chemical properties. Despite its potentials, critical issues, such as low stability, leaching problem and self-aggregation, are still challenges that need to be overcome.

CNT, a commonly utilized or studied nanomaterial in membrane science, is deeply discussed in this chapter with a focus on its state-of-the-art applications, implications, and future prospects. Nanotechnology for a membrane includes not only nanomaterials but also nano-structured membrane material. Electrospun nanofiber is a feasible nano-structured membrane material with a one-dimensional structure. The distinct interconnected nanostructure of a nanofiber from nonwoven media can provide unique properties. Therefore, electrospun nanofiber has been actively applied in water filtration membranes. This chapter also describes its application cases and its potential as a new type of membrane for water treatment and energy harvesting processes. This chapter provides not only the advantages of these innovative membranes but also their limitations or challenges.

NANOMATERIAL-EMBEDDED POLYMER MEMBRANES (NANO-ENHANCED MEMBRANES)

The aims of membrane-based processes can be classified into two main categories: water production and energy generation. Fresh water can be obtained from waste water, industry water, and seawater via the MF, UF, RO, and FO processes. On the other hand, different combinations of salinity gradients, such as seawater and river water or seawater brine and seawater, lead to harvesting energy via the PRO process. Currently, polymer-based membranes are widely applied in both academic studies and industrial applications. It is worth mentioning that the convergence of nanotechnology and membrane technology can mitigate global water and energy scarcity by maximizing membrane performance (Figure 1).

A nano-enhanced membrane (NeM), which has been investigated since the 2000s and whose term was proposed for the first time in 2013 (Buonomenna, 2013), is defined as a functionalized membrane with discrete nanoparticles or nanotubes. Over the past decade, nanotechnology has led to a next-generation membrane process in water treatment and has enabled excellent membrane performances, such as high permeability, selectivity, and fouling resistance. NeMs are classified into three categories: inorganic, organic, and bio-inspired NeMs. A commercial ceramic membrane coated with reactive or functionalized nanomaterials is categorized as inorganic NeMs. In organic NeMs, a nanomaterial is blended into a polymer solution, and a nanocomposite membrane is fabricated via phase inversion and interfacial

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