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Strategies for improving the performance of the polyamide thin film composite (PA-TFC) reverse osmosis (RO) membranes: Surface modifications and nanoparticles incorporations

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HIGHLIGHTS

- The main drawbacks of the PA-TFC membranes are presented.
- Strategies in improving the performance of PA-TFC membranes are reviewed.
- Special focus is on surface modifications and nanoparticles incorporations.
- Future developments in the focused special strategies are discussed.

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ABSTRACT

Polyamide thin film composite (PA-TFC) membranes are becoming more and more widely used for water desalination both in industrial and experimental plants due to their superior properties. However, trade-off between the permeability and the salt rejections, fouling and chlorination are seriously restricting their better operational functions. Therefore, various strategies have been explored to tackle these problems, among which surface modifications (e.g., surface coating) and nanoparticles incorporations have been identified to be the most effective ones. Thus, in this review, the state-of-the-art developments and breakthrough in the surface modified and nanoparticles incorporated PA-TFC reverse osmosis (RO) membranes are focused and summarized combining with the prospects. This review provides comprehensive information and gives an outlook on the surface modifications and nanoparticles incorporations, which might supply some clues to explore more advanced and innovative strategies for improving the performance of the PA-TFC RO membranes.

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1. Introduction

Currently, rapid population growth and enhanced living standard, together with the development of agriculture and industry all over the world, are creating increasing demand for the freshwater supplies. There is an urgent and increasing demand for provision of the clean water with drinking water quality. Therefore, water purification technologies have been receiving increasing unprecedented attention in recent years [1,2]. Given the fact that only 0.5% of the total water resource on earth is potable, fresh water, while 97% is seawater, desalination of seawater and saline aquifers has become one of the most potential, promising, and important methods for water purification [3]. According to the separation mechanism, desalination technology can be divided into thermal- and membrane-based desalination. Thermal-based desalination includes multi-stage flash (MSF), multiple effect distillation (MED) and vapor compression distillation (VCD), and the membrane-based desalination includes reverse osmosis (RO), nanofiltration (NF), electrodialysis, and some new technologies such as ion-exchange [4,5]. Membrane separation processes have developed rapidly over the last three decades into the dominant technology for water desalination [6]. RO have developed into the predominant membrane-based desalination technology mainly because it is the most energy-efficient desalination technology to date. The energy cost for the RO has reduced from ~5 kWh/m^3 in the 1990s to 1.8 kWh/m^3 nowadays, which is several times lower than that for other technologies, such as thermal-based desalination methods [7]. In fact, desalination plants, which are mainly attributed to RO system, have been built in more than 200 countries throughout the world, especially in North Africa and the Mideast, where freshwater is scarce [8,9].

It must be noted that in recent years, many rising new and energy-efficient water desalination technologies, such as capacitive desalination/deionization [10–13], membrane capacitive deionization [14,15], microbial capacitive desalination cell [16], desalination using microchannels [3], batteries [17], and microdesalination cells [18], and a series of emergent nanoporous materials with potential desalination applications, such as carbon nanotubes (CNTs), zeolites, and graphene [19], have also attracted much attention. However, such technologies and materials are still not suitable at the present time. The technologies mentioned above are more suitable for the applications in small- or medium-scale systems [3]. The nanoporous materials also encounter many limitations. For instance, membranes based on CNTs have been limited by low salt rejection rates [20]. The relatively low water permeation poses a huge challenge to the desalination applications of zeolites, and the zeolite membranes are more used in pervaporation rather than reverse osmosis process [21–23]. The desalination applications of graphene are just theoretically promising [24]. Consequently, for the large water supply apparatus, traditional technologies, typical reverse osmosis, will still play the major roles.

Despite some other reverse osmosis membranes [25], Thin-film-composite (TFC) reverse osmosis membranes are currently the primary membranes for water desalination. TFC RO membrane typically consists of an active polymer layer, which is dense, amorphous and very thin (<0.2 μm) with the interstitial voids (≤ 0.5 nm) between the polymer chains [26,27]. Most of the active polymer layers are derived from two basic types of polymers: cellulose acetate (CA) and aromatic polyamides (PAs). CA membrane has played a very important role in the water desalination since its first report in 1963 [28]. However, some defects have limited their applications seriously. For example, CA membrane are limited to a relatively narrow pH range (4.5–7.9), susceptible to biological fouling, and easily compacted at a high pressure. Comparatively, PA membranes are superior to CA membranes in many aspects. PA membranes can withstand high temperatures and larger pH variations (1–11) and are more stable to biological attack and pressure compaction. Furthermore, PA-TFC membranes are characterized by excellent permeability to water and high salt rejections as a result of ultra-thin but high cross-linked polyamide skin layer. Therefore, membrane desalination technology has been overwhelmingly dominated by PA and related membranes.

PA-TFC membranes are composed of an outer ultra-thin skin polymer layer (<0.2 μm), a porous middle polysulfone (PSf) support, and a non-woven polyester (PET) fabric base [29]. The membranes are most commonly synthesized using monomers of *m*-phenylene-diamine (MPD) and trimesoyl chloride (TMC) by interfacial polymerization and the process is shown in Fig. 1. Firstly, the supporting layer is immersed into the aqueous solution of MPD for certain times. After removing the excess MPD aqueous solution, the organic solution of TMC is poured and the interfacial polymerization immediately occurs and usually completes in tens of seconds. After the polymerization, the heat curing is always needed to make the further crosslinking of polyamide [30]. Finally, the membranes are washed with deionized water. The fabricated PA-TFC membranes are always stored in deionized water at the temperature of 4–5 °C.

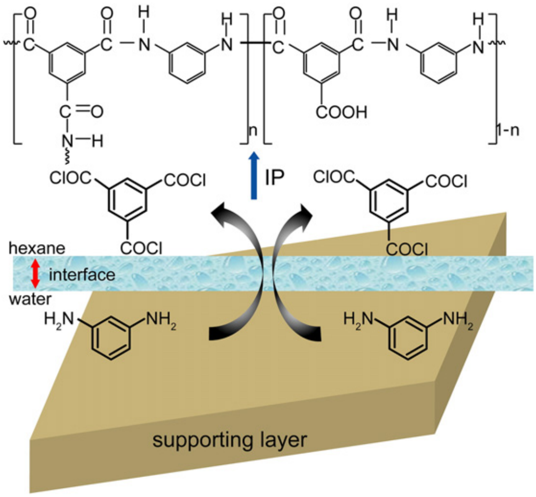

Fig. 1. Schematic illustration for the synthesis of active PA layer on the supporting layer using TMC and MPD as monomers by interfacial polymerization (IP) [31].