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Review

Progress in the modification of reverse osmosis (RO) membranes for enhanced performance

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ABSTRACT

RO membranes, the core elements for RO process formed using polyamide, have found prominent space in membrane technology. RO membranes with better application perspective could be achieved by precise controlling the kinetics of IP reaction and surface modification strategy. Despite huge progresses, great challenges still exist in trade-off between flux, rejections and fouling. More works are necessary to enhance the performance and stability of RO membranes via surface modification. Further insights into the use of natural monomers are necessary. It is anticipated that this article can provide clues for further in-depth evaluation and research in exploring more advanced RO membranes.

Contents

Abbreviations: AA, Acrylic acid; ABM, Aquaporin-based biomimetic membranes; AEPPS, N-aminoethyl piperazine propane sulfonate; AgNPs, Silver nanoparticles; AQP, Aquaporin; $BaCl_2$, Barium chloride; BDSA, 2,2′-benzidinedisulfonic acid; BSA, Bovine serum albumin; BTEC, 3,3′,5,5′-biphenyltetraacylchloride; CCTS, Carboxylated chitosan; Cl^-, Chloride ion; COOH-MWCNTs, Carboxylated multiwalled carbon nano-tubes; CNTs, Carbon nanotubes; CSA, Camphorsulfonic acid; Cu, copper; Cu^{2+}, Copper (II) ion; CuNPs, Copper nanoparticles; DAHP, 1,3–diamino-2-hydroxy propane; DMSO, Dimethyl sulfoxide; DTAB, Dodecyltrimethyl ammonium bromide; FDR, Flux decline ratio; Fe, Iron; FRR, Flux recovery ratio; GA, Glutaraldehyde; H_2O, Water; H_3PO_4, Phosphoric acid; HFAPA, Hexafluoro alcohol-containing polyamide layer; HFP-mAP, 2,2-Bis(3- amino-4-hydroxyphenyl) hexafluoropropane; GO, Graphene oxide; HEMA, Hydroxyethyl methacrylate; HFP-mAP, 2,2-Bis(3-amino-4-hydroxyphenyl)hexafluoropropane; iLSMM, In-situ hydrophilic surface modifying macromolecules; IP, Interfacial polymerization; IPA, Isopropyl alcohol; IPC, Isophthaloyl dichloride; $K_2S_2O_8$, Potassium persulfate; LbL, Layer by layer; LDH, Layered-double hydroxide; MeO, 2-Methoxyethanol; MMIM-DMP, (1,3-dimethylimidazolium dimethyl phosphate; MA, Maleic anhydride; MAA, Methacrylic acid; $MgCl_2$, Magnesium chloride; $MgSO_4$, Magnesium sulfate; MIL, Micro-imprinting lithography (MIL); MMAHPOEM, Methyl methacrylate–hydroxy poly (oxyethylene) methacrylate; MMT, Montmorillonite; MPD, m-phenylenediamine; MWCNTs, multiwalled carbon nanotubes; Na_2SO_4, sodium sulfate; NaCl, sodium chloride; NaClO, Sodium hypochlorite; Na_2HPO_4, Disodium phosphate; NOMs, Natural organic matters; NPs, nanoparticles; OMIC, 1-octyl-3-methylimidazolium chloride; OPD, O-phenylenediamine; NIPAm, N-isopropyl acrylamide; P(NIPAM-co-Am), Poly(N-isopropylacrylamide-co-acrylamide); PA, Polyamide; PAA, Poly acrylic acid; PEG, Poly (ethylene glycol); PEI, polyethylenimine; PF, Permeate flux; PFDA, Perfluorodecyl acrylate; PPD, P-phenylenediamine; PIP, Piperazine; PSF, Polysulfone; RIGP, Redox-initiated graft polymerization; RO, Reverse osmosis; SA, Sodium alginate; SDS, Sodium dodecyl sulfate; SiO_2, Silicon dioxide; SIP, Sequential interfacial polymerization; SPVA, Sulfonated polyvinyl alcohol; SWCNTs, Single walled carbon nanotubes; TA, Tannic acid; TEA, Trimethylamine; TEBAB, Triethyl benzyl ammonium bromide; TEBAC, Triethyl benzyl ammonium chloride; TF, Thin film; TFC, Thin film composite; TFN, Thin film nanocomposite; TiO_2, Titanium dioxide; TMBAB, Trimethyl benzyl ammonium bromide; TMC, Trimesoyl chloride; TOB, Tobramycin; VIM, Vinylimidazole; WF, Water flux; ZnO, Zinc oxide.

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Introduction

Reverse osmosis (RO) refers to high pressure driven membrane process where membranes retain certain molecules, ions or solute particles depending on chemical affinity, pore size and surface charge. The advantages of RO includes full automation and more compact, operate with no phase change, easy expansion, easy maintenance and low cost. Currently, RO are used for seawater desalination, wastewater treatment, brackish water treatment and drinking water production due to their low energy consumption in comparison to other desalination processes such as distillation and multi-stage flash thermal processes [1–5]. RO technology can produce clean water from seawater and brackish water [6,7]. RO membranes can guarantee high water permeability, high rejection of almost all neutral species >1 kDa and salts. Furthermore, this technology has the advantages of fulfilling most rigorous rules for separation process, environmental protection and public health [8].

Thin film composite (TFC) RO membranes typically are made up of three layers including a microporous support interlayer, an ultrathin polyamide (PA) selective layer (top), and a polyester fabric at the bottom which acts as the support (Fig. 1). This aforementioned multilayer feature allows individual layer to be tailored independently in order to a membrane with desirable properties [9]. In TFC membranes, the PA selective layer is responsible for solute rejection, while the support interlayer provides strength to the membrane during membrane separation. The PA skin-layer also determines the resistances to membrane fouling and chlorine [2]. In RO applications, the membranes should be mechanically and chemically stable under high pressures for a long operation period, while attaining a desirable water flux (WF) and rejection of salt characteristics. A key advantage of TFC membranes is that the bottom support and top thin active layer can be separately selected and optimized to gain desirable separation performance with stability and compression resistance [3,10–12].

In recent years, interfacial polymerization (IP) of TFC membrane has proven to be a desirable method with excellent properties, such as selectivity and fouling resistance [14,15]. IP is generally achieved by condensation reaction of an acid chloride and an amine at interface of an organic and aqueous solution to form PA skin-layers [13,16]. In IP, the reaction is easy to apply and the self-inhibiting of the reaction through the reactants supply and an active layer can be produced within 50 nm range. One of the key advantage of IP is that the reaction is self-controlled (the use of exact stoichiometry is not necessary), by controlling the diffusion of limited reactants supply through the formed interfacially polymerized layer [17].

Although a number of patents and scientific papers have been found on RO membrane, unfortunately, there is no state-of-art report on PA RO membranes that describes their modifications in respect to performance under one roof. To fill this gap in the literature, this article provides potential benefits to readers in order to enhance their knowledge and skill in this field. The article starts with a brief introduction of RO membranes, followed by the most significant focus of this study involving their modifications methods (such as controlling the kinetics of IP reaction and surface modification). The key technical challenges that can be encountered in the fabrication process of the TFC RO membrane and the possible approaches that could be employed to overcome these limitations are also highlighted. The wide scope of the article signifies the huge potential of RO for future development and research.

Modifications of TFC RO membrane

After the development of TFC membrane by Cadotte [18], numerous works has been reported on the synthesis and applications of RO membrane. Table 1 shows the progress in

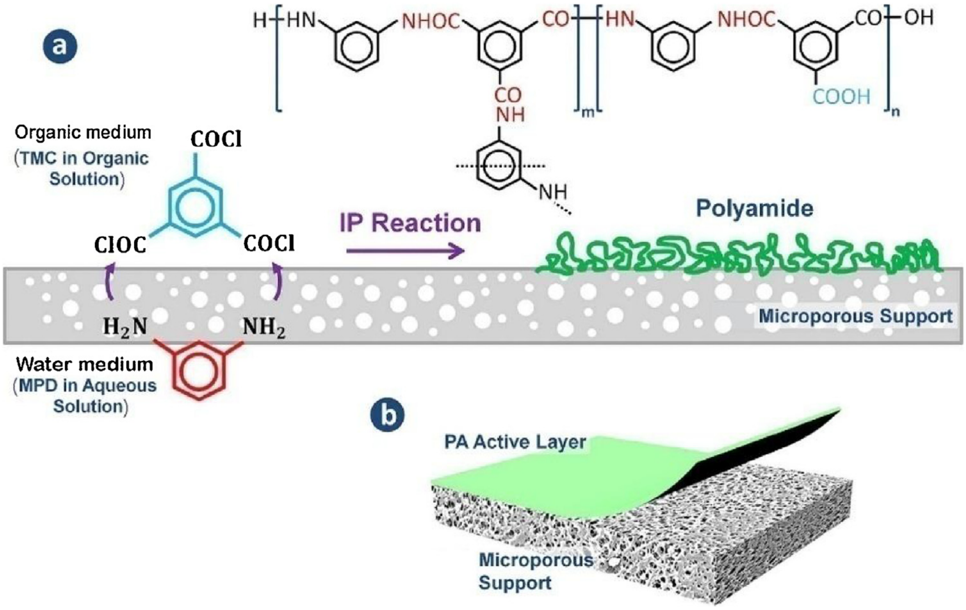

Fig. 1. (a) Schematic illustration of the interfacial polymerization (IP) reaction between Trimesoyl chloride (TMC) and m-phenylenediamine (MPD) on the surface of support – where n and m in polymer structure signifies the linear and the cross-linked parts, respectively (n + m is equal to 1). (b) Structure of resultant membrane [13].

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