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Review

A review of reverse osmosis membrane fouling and control strategies

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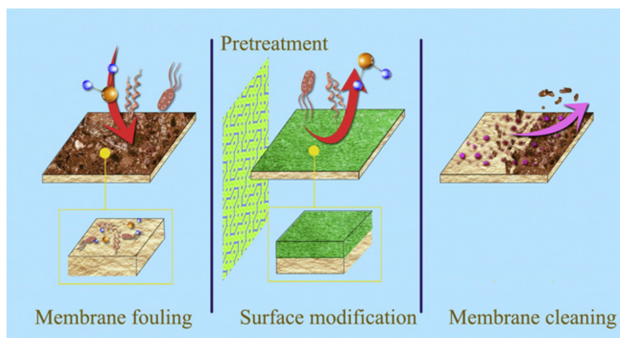
HIGHLIGHTS

- RO membranes are prone to fouling in different forms.
- Current control strategies can mitigate fouling but cannot prevent fouling completely.
- Novel membrane materials have great potential to control fouling effectively.
- Statistical analysis revealed strong research interest in RO fouling and mitigation.

GRAPHICAL ABSTRACT



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ABSTRACT

Reverse osmosis (RO) membrane technology is one of the most important technologies for water treatment. However, membrane fouling is an inevitable issue. Membrane fouling leads to higher operating pressure, flux decline, frequent chemical cleaning and shorter membrane life. This paper reviews membrane fouling types and fouling control strategies, with a focus on the latest developments. The fundamentals of fouling are discussed in detail, including biofouling, organic fouling, inorganic scaling and colloidal fouling. Furthermore, fouling mitigation technologies are also discussed comprehensively. Pretreatment is widely used in practice to reduce the burden for the following RO operation while real time monitoring of RO has the advantage and potential of providing support for effective and efficient cleaning. Surface modification could slow down membrane fouling by changing surface properties such as surface smoothness and hydrophilicity, while novel membrane materials and synthesis processes build a promising future for the next generation of RO membranes with big advancements in fouling resistance. Especially in this review paper, statistical analysis is conducted where appropriate to reveal the research interests in RO fouling and control.

Abbreviations: AA, acrylic acid; AOM, algal organic matter; BSA, bovine serum albumin; CC, chemical coagulation; CEOP, cake enhanced osmotic pressure; CNTs, carbon nanotubes; DAF, dissolved air flotation; DOC, dissolved organic carbon; DTAB, dodecyltrimethyl ammonium bromide; EC, electrocoagulation; ED, electrodialysis; EDTA, ethylene diamine tetra acetic acid; EfOM, effluent organic matter; EIS, electrical impedance spectroscopy; EPS, extracellular polymeric substances; EXSOD, ex-situ scale observation detector; MF, microfiltration; NF, nanofiltration; NIPAM, *N*-isopropylacrylamide; NOM, natural organic matter; PDA, polydopamine; PEI, polyethylenimine; PV, pervaporation; PVA, polyvinyl alcohol; RO, reverse osmosis; SC, surface coating; SDS, sodium dodecyl sulfate; SG, surface grafting; SWRO, seawater reverse osmosis; TEP, transparent exopolymer particles; TFC, thin film composite; UF, ultrafiltration.

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Contents

1. Introduction

Water shortage is one of major challenges in many places around the world (Adeniji-Oloukoi et al., 2013; Avrin et al., 2015; Garcia-cuerva et al., 2016; Hibbs et al., 2016). It is exacerbated by water pollution from agricultural residues, sewage as well as industrial waste (Yao et al., 2016). In order to meet the rising demand for fresh water, strategies like water reuse and seawater desalination have already been applied (Bartman et al., 2011; Gu et al., 2013). Membrane technology is one of the most promising ways to produce high quality water (Lin et al., 2016; Ochando-Pulido et al., 2016; Tang et al., 2016b).

The common membrane technologies for water treatment include but are not limited to microfiltration (MF) (He et al., 2016), ultrafiltration (UF) (Sun et al., 2015), nanofiltration (NF) (Ribera et al., 2014), reverse osmosis (RO) (Yang et al., 2017), forward osmosis (FO) (Boo et al., 2012), membrane distillation (MD) (Bush et al., 2016), electrodialysis (ED) (Zhang et al., 2015c) and pervaporation (PV) (Subramani and Jacangelo, 2015). RO membrane technology is widely used in seawater desalination, drinking water production, brackish water treatment and wastewater treatment. RO is currently the most energy-efficient technology for desalination, with energy cost about 1.8 kWh/m^3, which is much lower than that of other technologies (Xu et al., 2013b). Also, RO membrane has the advantages of high water permeability and salt rejection, fulfillment of the most rigorous rules for public health, environmental protection and separation process (López-Ramírez et al., 2006).

However, RO membrane fouling is a main challenge to reliable membrane performance. Fouling is a complicated phenomenon which involves different mechanisms under different circumstances (Khan et al., 2014). For example, a lot of RO projects reusing wastewater with high levels of phosphate are in operation worldwide (Chesters, 2009). In these plants, calcium phosphate scaling on membrane surfaces is a big problem, resulting in poor plant operation and high cleaning and maintenance cost (Chesters, 2009). Membrane fouling could significantly reduce productivity and permeate quality while increasing operation cost due to increased energy demand, additional pretreatment, foulants removal and membrane cleaning, maintenance, as well as reduction in membrane lifetime (Al-Amoudi, 2010; Eric et al., 2001; Kochkodan et al., 2014; Tang et al., 2011). In order to control membrane fouling, a variety of methods such as pretreatment, membrane monitoring, membrane cleaning, surface modification, as well as developing novel RO membranes have been studied (Al-Juboori and Yusaf, 2012; Brehant et al., 2002; Henthorne and Boysen, 2015; Nguyen et al., 2012; Robinson et al., 2016). The application of different methods could result in different control effects and therefore, in practice these techniques are usually applied together to reduce RO membrane fouling.

Statistical analysis revealed that in the last 25 years, over 3000 papers were published to address the issue of RO membrane fouling (shown in Fig. 1, see Supplementary Information for more details on statistical analysis method), indicating researchers' great interest in this area. Specifically, the number of SCI papers published in 2016 increased by around 20 times compared to papers published in 1992 and was around twice as the papers published 5 years ago (i.e., year 2011). A polynomial model was derived to describe the cumulative number of publications from 1992 to 2016, with the equation $P = 0.3735 * Y^3 - 6.881 * Y^2 + 67.139 * Y - 83.109$ ($R^2 > 0.999$), where P is the cumulative number of publications and Y denotes the number of years since 1992. Based on this model, and assuming that no revolutionary breakthroughs in RO membrane technology and alternative technologies as well will be made in the next ten years, then it can be predicted that by the year 2022, the cumulative number of papers published will possibly be about twice that of 2016. Although the research trend may not be predicted precisely simply by this model, it can at least give us an indication that research interest in this field will continue to bloom.

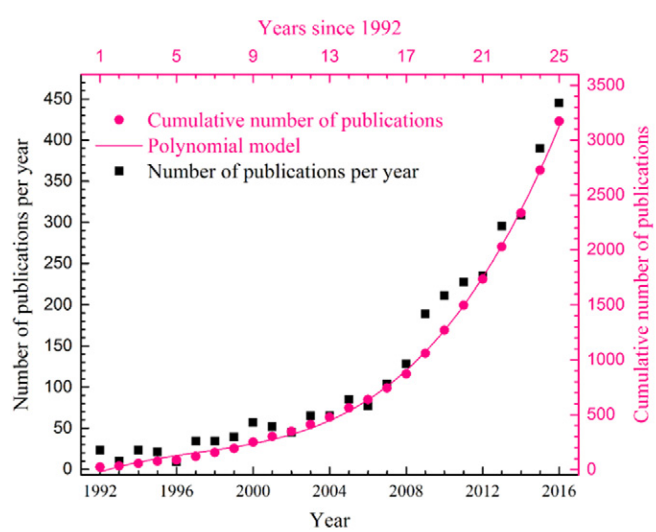

Fig. 1. Number of publications per year and cumulative number of publications on RO fouling over the past 25 years.