



# A comprehensive review on surface modified polymer membranes for biofouling mitigation



Victor Kochkodan<sup>a</sup>, Nidal Hilal<sup>a,b,\*</sup>

<sup>a</sup> Qatar Environment & Energy Research Institute (QEERI), Doha, Qatar

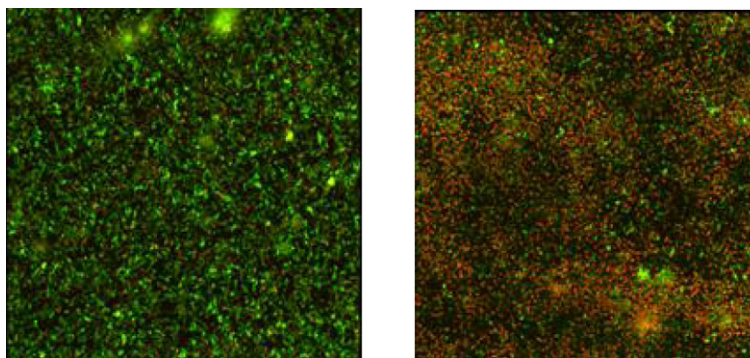
<sup>b</sup> Centre for Water Advanced Technologies and Environmental Research (CWATER), College of Engineering, Swansea University, Singleton Park, Swansea SA2 8PP, UK

## HIGHLIGHTS

- An overview on fabrication and properties of low-biofouling composite membranes.
- Biofouling phenomena on the membrane surface have been discussed.
- Fabrication studies on low-biofouling composite membranes have been surveyed.
- So far, none of the modified membranes were able to completely prevent biofouling.
- A removable antifouling layer is of special interest for biofouling mitigation.

## GRAPHICAL ABSTRACT

Confocal images of the membrane surface after *P. aeruginosa* PAO1 growth; initial NF-90 membrane (a) and the LbL modified composite membranes with poly(sodium 4-styrene sulfonate)/poly(hexamethylene biguanide) (b)



a)

b)

## ARTICLE INFO

### Article history:

Received 2 August 2014

Received in revised form 12 September 2014

Accepted 14 September 2014

Available online 5 October 2014

### Keywords:

Desalination

Membrane biofouling

Low-biofouling composite membranes

Surface grafting

Coating

Nanoparticles

## ABSTRACT

Biofouling is a major problem in environmental membrane separations because it leads to higher operating pressures, more frequent chemical cleaning, shortened membrane life, and compromised product water quality. The paper presents an overview on fabrication and properties of low-biofouling composite membranes for pressure-driven membrane processes. At first, biofouling phenomena and membrane surface properties which affect membrane biofouling have been discussed and the main objectives for the development of composite membranes for biofouling mitigation have been outlined. Thereafter the recent studies on the preparation of low-biofouling composite membranes using interfacial polymerization, surface grafting, coating of a protective layer and surface modification with nanoparticles have been critically summarised.

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\* Corresponding author at: Centre for Water Advanced Technologies and Environmental Research (CWATER), College of Engineering, Swansea University, Singleton Park, Swansea SA2 8PP, UK. Tel.: +44 1792 606644.

E-mail address: [n.hilal@swansea.ac.uk](mailto:n.hilal@swansea.ac.uk) (N. Hilal).

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## 1. Introduction

During the last decades pressure-driven membrane processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been widely used for water treatment and desalination [1–4]. However, one of the main problems arising upon the operation of the membrane units is the membrane fouling, which seriously hampers the application of membrane technologies [4,5].

Membrane fouling is an extremely complex phenomenon that has not been defined precisely yet. In general, the term is used to describe the undesirable deposition of retained particles, colloids, macromolecules and salts, at the membrane surface or inside the membranes pores. Depending on the membrane process and chemical nature of foulants several types of fouling can occur in membrane systems, such as inorganic fouling or scaling, organic fouling colloidal fouling and biofouling [4–9].

Inorganic fouling or scale formation at the membrane surface results from the increased concentration of one or more inorganic salts such as  $\text{CaCO}_3$ ,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  and  $\text{Ca}_3(\text{PO}_4)_2$  beyond their solubility limits and their ultimate precipitation onto the membranes [4,8].

With organic fouling, dissolved organic compounds in water, such as proteins, humic substances, and polysaccharides, have been implicated as strong, irreversible membrane foulants in pressure-driven membrane processes [9]. Natural organic matter (NOM) is the main organic foulant for membrane treatment of surface waters, brackish waters and sea water [10]. It has been demonstrated that the hydrophobic fraction of NOM was the major factor causing permeate flux decline due to strong adsorption on the membrane surface, while the hydrophilic fraction of NOM had a relatively small effect on the membrane fouling [11].

Colloid fouling refers to membrane fouling with colloidal and suspended particles in the size range of a few nanometres to a few micrometers. These might be inorganic colloids such as silica, iron oxides/hydroxides, hydroxides of heavy metals and organic colloids such as aggregated NOM and proteins [12,13].

Biofouling is a term used to describe all instances of fouling where biologically active organisms, such as microorganisms, fungi, viruses and excreted extracellular biopolymers are involved [7,9,14]. Biofouling of the surface of synthetic polymer membranes used in water treatment application is a commonly encountered problem that can dramatically diminish the treatment process efficiency and cost effectiveness [9,15]. Biofouling is inherently more complicated than other membrane

fouling phenomena because microorganisms can grow, multiply and relocate on the membrane surface. Usually, membrane biofouling is initiated by irreversible adhesion of one or more bacteria to the membrane surface followed by fast growth and multiplication of the sessile cells in the presence of feed water nutrients [7,15]. With time, the initial sessile microbial population can eventually form a confluent lawn of bacteria (i.e. biofilm) on the membrane surface [16]. Whereas, the basic processes of bacterial adhesion and biofilm formation are similar in membrane systems and other natural and industrial systems, membranes are perhaps uniquely impacted by pressure-driven water and solute transport phenomena that serve to influence biofouling kinetics.

Typical adverse effects of membrane biofouling include (i) a reduction in membrane water flux due to establishment of a gel-like diffusion barrier (i.e. the biofilm), (ii) an increase in solute concentration polarization accompanied by lower solute rejection (in RO and NF membranes), (iii) an increase in the module differential pressure ( $\Delta P$ ), (iv) biodegradation and/or biodeterioration of the membrane polymer or other module construction materials (e.g. polyurethane-based glue lines), (v) establishment of concentrated populations of primary or secondary human pathogens on membrane surfaces, (vi) increased energy requirements; this is due to the higher pressure requirements to overcome the biofilm resistance and the flux decline [4,9,15].

Membrane fouling, as well as its prevention, has been a subject of many studies since the early 1960s when industrial membrane separation processes emerged. Membrane fouling can be somewhat controlled by the selection of an appropriate membrane, adjustment of the operating conditions in a membrane element, including hydrodynamics and operating pressure, and appropriate pre-treatment of the feed solutions [4,5,9]. However, very often these actions are not sufficient to cope with fouling. In many cases, the fouling is irreversible and the membrane elements must be replaced thus imposing a large economic burden on membrane plant operation (up to 50% of the total costs) [5,17].

A common approach to prevent the microbiological fouling of the membranes is an appropriate preliminary treatment of feed water. This enables to decrease the content of bacteria and nutrients consumed by the bacteria during their activity in water [9,14,16]. However, such a pre-treatment is rather labour consuming and expensive. Additionally, even 99.99% removal of bacteria from a feed stream cannot guarantee the elimination of bacteria growth on the membrane because microorganisms can

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