Electrically conductive spacers for self-cleaning membrane surfaces via periodic electrolysis

Hadeel Subhi Abida, Boor Singh Laliha, Paolo Bertoncelloa, Raed Hashaikehb, Ben Cliffordc, David T. Gethinb, Nidal Hilall,a

a Centre for Water Advanced Technologies and Environmental Research (CWATER), College of Engineering, Swansea University, UK
b Chemical Engineering Department, Khalifa University of Science and Technology, Masdar Institute, Masdar City, P.O. Box 54224, Abu Dhabi, United Arab Emirates
c Centre for Water Advanced Technologies and Environmental Research (CWATER), College of Engineering, Swansea University, UK

A R T I C L E   I N F O

Keywords:
Membrane fouling
Conductive spacer
Electrolysis
Self-cleaning
Bubble generation

A B S T R A C T

The use of an electrically conductive membrane has attracted significant interest in water treatment technology due to remarkable performance in fouling mitigation domain. In electrochemical systems, when external potential is applied, water electrolysis occurs and the generated gases efficiently clean the membrane surface. However, fabricating and integrating conductive membranes in current water treatment modules are challenging. The present work applies, for the first time, the electrolysis concept at the spacer component of the module rather than the membrane. Two types of materials were tested, a titanium metal spacer and a polymeric spacer. The polymeric spacer was made conductive via coating with a carbon-based ink comprised of graphene nanoplatelets (GNPs). A membrane system composed of the carbon coated/titanium metal spacer attached to the surface of a polyvinylidene fluoride (PVDF) microfiltration membrane and was assembled to the case of membrane module. The conductive spacers worked as an electrode (cathode) in electrochemical set-up. The membrane system was subjected to fouling and then exposed to periodic electrolysis, wherein in-situ cleaning of membrane surface by hydrogen bubbles generation at the spacer is applied.

1. Introduction

Membrane technology has been highlighted as a promising approach for water purification due to its essential advantages over other counterpart traditional technologies [1]. Constantly, a spacer is employed on the permeate side of the membrane in a module to improve the mechanical integrity of the membrane and allow efficient fluid flow [2]. The essential functions of a spacer mesh are to promote mass transfer and reduce concentration polarization [3]. In a study conducted by Vrouwenvelder et al. [4], it was demonstrated that in the presence of a feed spacer, the biofouling was much higher than when a feed spacer was absent. In a spiral-wound membrane systems, biofouling is dominantly a feed spacer problem. Many approaches have been reported on the modification spacers. Hausman et al. [5] stated their spacer modifications comprises engineering antibacterial polypropylene films via surface functionalization, in which a spacer charged with copper ions. Yang et al. [6] exhibited the coating both spacer and RO membrane with nano-silver, they stated that a higher permeate flux and rejection can be maintained. In addition, Araújo et al. [7] determined the potential of coated spacer and membrane with polydopamine and polydopamine-g-PEG as well as coated spacer with copper to control biofouling. They concluded that biofouling is not inhibited by employing polydopamine-coated, polydopamine-g-poly(ethylene glycol)-coated spacers and membranes, and a copper-coated spacer. In contrast, Miller et al. [8] evaluated by short-term batch protein and bacterial adhesion tests and employed the coated spacer and membrane by polydopamine and poly(ethylene glycol). Recently, Ronen et al. [9,10] revealed that biofouling could be restricted by modification of commercial polypropylene spacers via applying nano-zinc and/or nano-silver coated spacers sono-chemical deposition. An J. et al. [11] prepared hydrophobic spacer-mesh by polyaniline (PANI) coating on stainless mesh which was fabricated through an electrodiposition process to enhance surface hydrophobicity. The fabricated coated mesh films can be employed for frequent separation of organics and oil from water with highly potential selectivity, they also modified spacer film from hydrophobic to hydrophilic by electrodiposition of polypyrrole (PPy) at various electric potential to enhance mesh surface morphology for selective absorption and purification. Sun et al. [12] reported an approach for the modification of commercially stainless-steel mesh, wherein a layer-by-layer graphene assembly technique was adopted.
They stated that their approach may considerably enhance traditional separation system performance and improve removal of organic compounds and oil from water. Darmanin T. and Guittard F [13], investigated computationally the performance of electrodeposition of nano-materials on metal mesh substrates and their impact on the surface hydrophilicity, which can employed in applications of water transportation and bio-sensing systems. A summary of modified coating spacers with materials shown in the literature is presented in Table 1. Among methods to enhance membrane de-fouling performance, much focus has been shifted towards a combined electrochemical system with membrane water treatment processes. An alternative non-destructive, affordable and energy efficient membrane fouling mitigation techniques are required to adopted. This relatively novel approach improved fouling control via either foulants oxidation [14,15] or bubble generation [16,17]. However, from the engineering point view, in-situ membrane fouling control is highly desirable but seems very challenging [18]. Electrolysis is a technique used to produce H2 and Cl2 bubbles from water, in which this is a procedure of decomposition water to the both hydrogen and oxygen, when a potential is applied across the cell. For this purpose, an electrochemical cell is used and it is composed of anode and cathode electrodes separated by solution, which acts as an electrolyte. Traditionally, the mechanism of cleaning during the electrolysis process is due to the micro-bubbles generation at the surface of electrically conductive membrane surface, wherein electrolysis of an aqueous NaCl solution to hydrogen gas at the cathode membrane (at the cathode) and chlorine gas is produced at an electrode (at the anode), according to the following equations:

\[ \text{2H}_2\text{O} + 2\text{e}^- \rightarrow \text{2OH} + \text{H}_2 \]  \hspace{1cm} (1)

\[ 2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^- \]  \hspace{1cm} (2)

The formed hydrogen microbubbles detach the foulants out of the membrane surface to the feed stream [19]. For any additional electrical energy is demanded in terms of overcoming the over-potential that stemming from activation and losses of ohmic within the cell. Electrolysis can be performed with low temperatures less than 100 °C [20]. It was found that the bubbles, generated at the conductive membrane surface (at cathodic electrode), performance, as a physical barrier and can mitigate the foulants deposited at membrane surface during filtration processes [21,22,23]. Fig. 1 illustrates the mechanism of self-cleaning conductive substrate via bubble generation.

Ahmad et al. [24] stated through the electrolysis process at the solid-liquid (electrode-electrolyte interface), gas bubbles generate at the electrode surface and when their size be appropriate, they begin to move away from the electrode surface. The gas bubble long stay on the electrode surface lowers the charge transfer reaction at the solid-liquid interface and eventually leads to reduction in the electrolysis process efficiency. Sun et al. [25] presented a comparison by adopting three kinds of electrically-driven anti-fouling mechanisms for the horizontally aligned CNT membranes, so-called electro-reduction electro-oxidation, and ionic-pump in. Both of (BSA) and napthalene (protein solutions) were employed as foulants model. In term of using foulant model, they found that both electrochemical oxidation and/or reduction reaction were effectively in-situ biomolecule de-foulants CNT membranes. Nevertheless, they concluded that the electro-oxidation reaction is remarkably appropriate to the specific number of cycles when potently absorbed foulants are comprised. Wu et al. [21] stated that nanobubbles can be utilized to inhibit the adsorption of proteins as well as to remove the adsorbed foulants. Nanobubbles with a regular size and density were generated on graphite surfaces, wherein electro-chemically controlled by the applied current. It was found that prior to exposure the surface to BSA solution, and with 20 s electrochemically pre-treatment for to the surface enhanced performance and lowered protein coverage to 26–34%. On a conductive surface, pre-adsorbed protein was also prevented by generation of nanobubbles, in which the nanobubbles are produced at the substrate surface and performance as barrier to the foulants layer. Correspondingly, the adsorbed protein was pushed from the solid-liquid to the liquid–vapour interface because of the bubbles growing. Thus, with a lower shear water-stream, the foulants could be readily detached (Fig. 1). Hashaiekh et al. [19] proposed an approach allows in-situ membrane self-cleaning, in which inorganic and biological fouling categories mitigation have been achieved. These adopted cleaning mechanisms comprising micro-bubbles generation at MWNTs coated membranes surface printed with nano silver ink acts as a spacer during electrolysis. They stated that, in present of an aqueous NaCl solution, gas of hydrogen is formed at the conductive membrane surface, which performs as a cathode and at the same time gas of chlorine is formed at a stainless-steel electrode, which performance as an anode, wherein formed hydrogen microbubbles push back the deposited foulants away from the surface of membrane into the flow stream. The consequence of filtration cycle duration on the recovery of flux was studied by Lalia et al. [17] who tested the cleaning efficiency of an electrically conductive nanocomposite CNS/PVDF membranes with filtration of a yeast suspension via applying periodic electrolysis at 2 V for 2–3 min. They found that the flux was reduced to 40% of its initial value after 4.6 h filtration period time. Farah et al.

<table>
<thead>
<tr>
<th>Material</th>
<th>Functionalization technique</th>
<th>Application</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>Functionalization of polypropylene (PP) films by a metal chelating spacer charged with copper ions</td>
<td>copper ions were employed to disinfect water from microbial biofilms</td>
<td>[5]</td>
</tr>
<tr>
<td>Nano-silver</td>
<td>Coating the RO membrane and spacer with nano-silver particles</td>
<td>Permeate flux decline and salt rejection and the effect of silver-coated spacer on antimicrobial activity</td>
<td>[6]</td>
</tr>
<tr>
<td>Polydopamine polydopamine-g-PEG copper</td>
<td>(i) Polydopamine and polydopamine-g-PEG coated spacers and membranes, (ii) a copper-coated spacer</td>
<td>To control biofouling</td>
<td>[7]</td>
</tr>
<tr>
<td>Polydopamine polydopamine-g poly (ethylene glycol)</td>
<td>Polydopamine and polydopamine-g-PEG coated spacers and membranes</td>
<td>To defouling bovine serum albumin, as a model protein, and Pseudomonas aeruginosa, as model Gram-negative bacterium.</td>
<td>[8]</td>
</tr>
<tr>
<td>Zinc oxide nanoparticles</td>
<td>Commercial polypropylene spacer modification through sono-chemical deposition</td>
<td>To suppress biofilm formation</td>
<td>[9]</td>
</tr>
<tr>
<td>Nano-silver partials</td>
<td>Commercial polypropylene spacer functionalization via sono-chemical deposition</td>
<td>To hinder biofouling development</td>
<td>[10]</td>
</tr>
<tr>
<td>Polyaniline (PANI)</td>
<td>PANI-coating on stainless through an electrodeposition technique</td>
<td>To enhance surface hydrophobicity and frequent separation of organics and oil from water</td>
<td>[11]</td>
</tr>
<tr>
<td>Polypyrrol (ppy) Graphene</td>
<td>Ppy-electrodeposition Layer-by-layer method graphene assembly via a dipping method</td>
<td>To improve mesh surface morphology and selectivity absorption from water</td>
<td>[12]</td>
</tr>
<tr>
<td>PolyNaphDOT (Monomer)</td>
<td>Employing electro-polymerization method on stainless steel mesh substrates to induce the nanotubes</td>
<td>This mechanism can be benefit in oil/water separation membranes</td>
<td>[13]</td>
</tr>
</tbody>
</table>

Table 1: Modified coating spacer, to enhance traditional separation system performance.
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات