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Hybrid electrocoagulation/electroflotation/electrodisinfection process as a pretreatment for seawater desalination

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HIGHLIGHTS

- Continuous electrocoagulation is used as a pretreatment for seawater desalination.
- This removes dissolved organic matter (DOC) through an electroflotation process.
- An electrodisinfection effect is assessed from microorganism removal.
- More than 50% DOC and 90% microorganism removal were achieved at 0.5 kW h/m^3.
- This pretreatment is efficient and cost-effective to protect reverse osmosis process.

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ABSTRACT

The main objective of this study was to examine the feasibility of a hybrid electrocoagulation/electroflotation/electrodisinfection (EC/EF/ED) process in treating seawater prior to desalination treatment using reverse osmosis process. Residual dissolved organic carbon (DOC) and heterotrophic bacteria concentrations were measured. A continuous treatment using aluminium electrodes was investigated, which lead to a complex gas-liquid-solid mixture in which aluminium flocs and hydrogen gas bubbles enhanced pollution removal. Experimental results showed that DOC removal efficiency increased when the current density increased and when the inlet flow rate decreased. The best performance of DOC removal (69.0%) was recorded while imposing 20 mA/cm^2 and 320 s residence time when inflow pH was 4. Heterotrophic bacteria were completely removed for the highest current densities (20 mA/cm^2). In the EC process, a low concentration of total chlorine species (up to 0.45 mg/L) resulting from the oxidation of chloride anions was formed, which promoted the removal of microorganisms, even though these were mainly removed by the coupled effects of the electric field and the bacteria entrapment in hydroxide flocs. Finally, EC/EF/ED as a one-step pretreatment method was shown to be efficient to replace the conventional methods prior to desalination by reverse osmosis as it was proved to remove efficiently organic matter and microorganisms from seawater: with 0.8 L/h and 14 mA/cm^2, 50% of DOC and nearly all the microorganisms could be removed at less than 0.5 kW h/m^3.

1. Introduction

The world population growth is dramatically increasing nowadays, and many areas in the world are already or are becoming water-stressed. In addition, the freshwater resource is overexploited or misused in human activities, without reuse most of the time. Given that the quasi-totality of water present on Earth is seawater, desalination is relevant to tackle the freshwater scarcity problem (Fritzmann et al., 2007; Greenlee et al., 2009). Reverse osmosis, which is cost-efficient in comparison to other desalination processes, has still to face the challenge of membrane fouling. Once the membrane is fouled, the water flux declines and maintenance actions must be performed, such as an increase in the feed

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pressure, membrane cleaning or replacement. These imply additional treatment costs. Considering that the reverse osmosis (RO) membrane replacement depends on the efficiency of pretreatment, the high importance of the latter in seawater desalination must be underscored: the pretreatment and RO replacement costs assessed respectively to 12% and 6% of the average capital expenses in seawater RO facilities (Henthorne and Boysen, 2015). Improper seawater pretreatment can result in an earlier fouling of RO membranes, a decreased RO membrane life, or even a complete seawater RO plant shutdown. Hence, the robustness of seawater RO system depends mainly on the efficiency of pretreatment methods. Considering that conventional pretreatment processes have difficulty to meet some of the parameters required for feeding RO units with seawater, there is nowadays an increasing interest of intense research on the alternative pretreatment methods more efficient in comparison to the conventional processes; namely, these parameters are a silt density index (SDI) less than 3, the removal of total organic carbon from seawater to 0.5 mg/L or less at which biofouling is unlikely to occur, and the inhibition of the production of carcinogenic substances during chlorination.

Membrane fouling is caused by the deposit of inorganic or organic colloids (colloidal fouling), by the dissolved organic matter (organic fouling), by the adhesion of microorganisms and by the precipitation of mineral components on the membrane (scaling) (Guo et al., 2012; Henthorne and Boysen, 2015). Conventional RO pretreatments that encompass clarification/dissolved air flotation, coagulation-flocculation, scale inhibitors, granular media filtration and non-conventional pretreatments, such as membrane processes including microfiltration, ultrafiltration and nanofiltration, are used to prevent membrane fouling (Guo et al., 2012; Landaburu-Aguirre et al., 2016). However, those conventional and non-conventional pretreatments are not efficient to avoid organic fouling and biofouling, which explains the current trend of using hybrid processes including adsorption or coagulation coupled with membrane processes (Tansakul et al., 2011; Landaburu-Aguirre et al., 2016). Organic fouling is the most problematic process since it implies bio-fouling as well. Organic substances serve especially dissolved organic carbon as nutrients to the microorganisms, which results in the long term in bio-fouling even when an effective disinfection process is applied (Flemming et al., 1997). Hence, an efficient pretreatment to remove organic matter from seawater is much needed.

Given their limits to avoid efficiently the bio-fouling and organic fouling, conventional pretreatments such as coagulation are being replaced by membrane processes, especially ultrafiltration. However, even if ultrafiltration turns out to be efficient to remove colloids, particles and microorganisms from seawater, this membrane process is not able to remove efficiently organic matter as in many studies it has been reported that the removal efficiency of DOC by ultrafiltration alone was around 10% (Tansakul et al., 2011; Resosudarmo et al., 2013). This difficulty of UF to reduce effectively concentration of DOC results from the fact that DOC of seawater is particularly composed of low molecular weight molecules that can flow through the pores of the UF membrane. For a better DOC removal, a hybrid process associating activated carbon adsorption coupled with ultrafiltration has been used at pilot-scale for the removal of DOC from seawater and the efficiency can reach more than 70% (Tansakul et al., 2011; Monnot et al., 2016). Unfortunately, industrial seawater reverse osmosis plants using membrane pretreatment have faced many performance challenges, such as the inability to meet design capacity, excessive downtime and maintenance, and higher membrane replacement costs (Voutchkov, 2010). As for an economic evaluation, conventional pretreatment systems are poorly efficient and have a relatively high operating cost, resulting from excess consumption of chemicals, filtrate and energy. However, this is counterbalanced by the low capital expenses because equipment is robust and requires low maintenance. Conversely, membrane pretreatment systems are expensive, especially because membrane require frequent cleaning and need to be replaced from time to time (Prihasto et al., 2009). If data on the operating cost of pretreatments is scarce in the literature, Jamaly et al. (2014) reported estimates about 0.43 and 0.39 $\$/m^3$ water for conventional and ultrafiltration pretreatments, respectively.

Electrocoagulation/electroflotation (EC/EF) has been reported to remove efficiently a wide range of pollutants from water/wastewater (Emamjomeh and Sivakumar, 2009), as well as to act as a disinfection process (Wei et al., 2011; Tanneru et al., 2014). Furthermore, EC/EF has been found efficient as a pretreatment method prior to membranes processes such as microfiltration (Ben Sasson and Adin, 2010; Tanneru and Chellam, 2012), ultrafiltration (Yahiaoui et al., 2011) and nanofiltration (Aouni et al., 2009; Ahmed et al., 2012) for wastewater/water treatment. Even if there are handful of studies on EC/EF hybrid process as a pretreatment for seawater desalination, EC/EF has been gaining a particular attention on its potential as a pretreatment method for seawater desalination in the last two decades (Timmes et al., 2009; Yi et al., 2009; Timmes et al., 2010), which has been reviewed by Saiba et al. (2010). In the recent literature, EC/EF has often been reported to be an eco-friendly as well as a cost-effective process in comparison to other physicochemical processes. Energy consumption being the major cost item of operating cost of EC/EF process besides the cost of electrode material especially when using aluminum electrodes, this hybrid process as a seawater pretreatment method would offer an additional advantage of lower energy consumption given the high conductivity of seawater. In addition, this offers the opportunity to use renewable solar energy to supply power to EC/EF units.

Thus, EC/EF can be considered as an alternative one-step pretreatment method for seawater desalination, especially because this hybrid process has been found efficient to remove all kinds of foulants from water and wastewater that are responsible for all types of reverse osmosis membrane fouling. EC/EF process is a hybrid non-specific electrochemical water and wastewater treatment that is based on the electrodissolution of a soluble metal anode and on the electrolytic generation of H_2 bubbles on the cathode once a constant direct current or voltage is applied between the electrodes. After spontaneous hydrolysis, the metal cations turn into various hydroxide species that intervene in pollutant abatement, while the gas produced electrolytically favors sludge separation by flotation, leading to a complex gas-liquid-solid multiphase system. As in electrodisinfection (ED), the electric field in EC/EF may also exhibit a disinfection ability and chloride anions present in seawater may be oxidized in chlorine, which is in turn transformed into $ClOH/ClO^-$ as a disinfectant (Kraft, 2008).

On the basis of our previous work describing the use of batch EC process as a reverse osmosis pretreatment (Hakizimana et al., 2015), the present work intends to investigate the applicability of EC/EF/ED as the pretreatment in a continuous process prior to the seawater desalination by reverse osmosis and the influence of operating parameters, such as current density, flow rate and inlet pH in order to determine the optimum operating conditions. The process efficiency was deduced from the evolution of several parameters characterizing the different types of fouling processes: dissolved organic carbon (DOC) was measured for organic fouling and bio-fouling propensity was deduced from the enumeration of microorganisms.

2. Electrocoagulation theory

EC/EF process is a hybrid non-specific electrochemical water treatment that uses the electrodissolution of a metal (aluminum in our case) for pollution abatement. It consists in dissolving in situ metal