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A study of the osmotic membrane bioreactor process using a sodium chloride solution and an industrial effluent as draw solutions

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HIGHLIGHTS

- Both DS tested were useful to carry out an OMBR process for treating wastewater.
- COD removal efficiencies were always higher than 80%.
- Salt reverse flux was higher when the industrial wastewater was used as DS.
- Industrial waste water as DS had less membrane fouling and higher water flux.
- Industrial waste water was a DS very attractive for the OMBR operation.

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ABSTRACT

Osmotic membrane bioreactor (OMBR) is an emerging membrane process which has gained interest in the recent years because of the low energy consumption and the high effluent quality. The osmotic membrane bioreactor combines a forward osmosis (FO) membrane and a biological treatment. However, salt reverse flux is the main problem because of the negative effect of the salt concentration increase in the reactor on the microbial activity. This is the reason why the study of a suitable draw solution (DS) is very important in the overall performance of the reactor. This study compares the process performance using two draw solutions: a 53 g L^{-1} NaCl solution and a real waste water solution (waste water from an absorption column consisting mainly of SO_4^{2-} and NH_4-N with concentrations of 153 g L^{-1} and 19 g L^{-1}, respectively). The comparison is focused on the salt reverse flux during the reactor operation, the mixed liquor characteristics, the membrane fouling and the overall performance. The results indicated that the industrial wastewater showed a higher salt reverse flux, but also a less severe fouling and a higher the osmotic pressure difference in comparison with the NaCl solution. In terms of chemical oxygen demand (COD) removal efficiencies, both draw solutions attained values higher than 80%, though the efficiency was slightly lower when the industrial effluent was used as DS. This was related to the higher conductivity reached in the bioreactor when the industrial effluent was used as draw solution. In spite of it, the use of this industrial effluent as draw solution is strongly recommended because of the high permeate fluxes yielded, the low membrane fouling and the lack of necessity of regenerating the draw solution.

1. Introduction

Water scarcity is further intensified due to climate change, high population growth, and environmental pollution. Nowadays, it already affects billions of people around the world [1]. Overall, efforts for developing and improving novel wastewater treatments and reclamation processes have been progressively introduced, focusing efforts on reusing water even achieving pa drinking water quality [2]. In the recent years, membrane bioreactors (MBR) have gained importance for the municipal and industrial wastewater treatment [3]. Whereas a conventional MBR uses ultrafiltration (UF) or microfiltration (MF) membranes, an OMBR works with FO membranes.

Thus, the OMBR is an emerging wastewater treatment technique that combines FO membranes and a biological reactor [4]. In this way, integrating FO membranes in a biological reactor offers many advantages, such as excellent water quality and very low

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energy consumption (since OMBR process works without applying mechanical pressure) [5,6]. A common OMBR includes a bioreactor, a FO separation unit and a DS system that makes possible the regeneration of the DS or the provision of fresh DS. FO membranes allow water permeation across the FO membrane from activated sludge feed solution to the DS [4,7,8]. The osmotic pressure difference from one membrane side to the other, due to the low-salinity of activated sludge and the high-salinity of the DS, is the driven force of the OMBR [9]. The selection of the DS is of paramount importance, since the salt concentration difference between feed and draw solutions can cause the salt reverse flux due to the Fick's law.

The main advantage of the FO nonporous membranes is the high rejection capacity for trace organic compounds [10], pathogens [11] and ions [12]. However, membrane fouling, salinity build-up in the bioreactor and cellular debris accumulated in the mixed liquor are key issues on the OMBR performance. On the one hand, membrane fouling is due to organic fouling, inorganic fouling and biofouling [13]. Organic fouling is due to the adsorption of organic compounds (such as SMP) on the membrane surface or in the membrane pores [13]. The organic substances accumulation together with reversible and irreversible attachment of bacterial cells and extracellulars polymeric substances (EPS) on the membrane surfaces drives to biofilm formation (biofouling) [9]. Inorganic fouling is caused by salts precipitation onto the membrane surface [14]. Membrane fouling implies a water flux reduction, a membrane life decrease and an increase of the operational costs [15–17].

In order to mitigate the membrane fouling, a suitable and periodic membrane cleaning is required. The cleaning of FO membranes installed in an OMBR is more complex than the one of the UF or MF membranes in a MBR. UF or MF membranes are usually cleaned by means of hydraulic or chemical backflushing, whereas FO membrane requires an osmotic backflushing. This type of cleaning needs invert the membrane water flux across the membrane. For it, the hypersaline solution is located in the feed tank, whereas distilled water is placed in the DS tank. In this way, water will flow from the DS to the feed side of the membrane, removing organic and inorganic substances from the membrane active layer [9].

One of the most important problems described in the OMBR operation is the high increase of the salt concentration in the bioreactor. This phenomenon is due to the rejection of the feed ions by the FO membrane and, at the same time, by the salt reverse flux (salt passage from the DS to the bioreactor). The control of the salt reverse flux is a key factor for the reactor performance. The salt concentration increase in the bioreactor will reduce the effective driving force for water permeation through the membrane, change the microbial community characteristics, rise the SMP and EPS in the bioreactor [18]. Recently, several authors have investigated these critical issues in OMBR technology to improve its application. Luo et al. [19] studied the salt reverse flux for water reuse in a OMBR using different draw solutions. They concluded that ionic organic draw solutes can mitigate salinity build-up in the mixed liquor. Bell et al. [9] compared the fouling behavior of two different FO membranes, cellulose triacetate membranes and polyamide thin film composite (TFC) membranes. This group of authors published that TFC membranes were more prone to fouling during a long-term OMBR study. However, more studies both in pilot and in full-scale plants are necessary to gain knowledge leading to achieve a better OMBR performance.

This work aims to study the performance of an OMBR comparing the use of two DS in terms of water flux, reverse salt flux, biological stability and membrane fouling. For it, two OMBR experiments were carried out at the same experimental conditions but using different draw solutions, a sodium chloride solution and an actual industrial wastewater solution of ammonium sulphate. The use of actual industrial effluents in OMBR has been hardly reported in the bibliography. Until now, previous studies have reported results with synthetic wastewater as draw solution. Particularly, the use of a residual ammonia absorption solution has already been not described.

2. Materials and methods

2.1. Synthetic wastewater

The simulated wastewater used for the experiment consisted of bacteriological peptone, meat extract (both supplied by Panreac, Spain) and tri-sodium phosphate 12-hydrate (from Panreac, Spain). The concentrations of these chemicals were selected in order to achieve a COD:N:P relation of 100:5:1 mg L^{-1} to ensure the appropriate nutrients amount. Chemicals were mixed and dissolved in tap water. The wastewater solution (influent to the OMBR) was prepared three times per week. COD of the simulated wastewater was 4000 mg L^{-1}.

2.2. Draw solutions

In this study, the performance of two different DS was compared. On the one hand, a sodium chloride solution with a concentration of 53 g L^{-1} and conductivity of 68 mS/cm was used in test 1. This sodium chloride concentration was selected in order to mimic the saline characteristics of a wastewater from the table olive processing according to Malheiro et al. [20] and Ferrer-Polonio et al. [21]. On the other hand, a liquid effluent from an absorption process for ammonia removal was the DS in the test 2. This wastewater was generated in an industrial wastewater treatment plant and its composition mainly consists of ammonium sulphate (SO_4^{2-} and NH_4-N concentrations of 153 g L^{-1} and 19 g L^{-1}, respectively). This waste water had a conductivity of 130 mS/cm and pH very low (1.2). Therefore, pH was increased up to 4.0 to ensure that the FO membrane was not chemically damaged.

2.3. FO membrane and OMBR plant

The FO membrane used in this study was CTA-NW membrane from HTI (USA). The commercial membrane material is cellulose triacetate (CTA) supported by an embedded polyester screen. According to previous research in OMBR (Lay et al. [14] and Wang et al. [18]), active layer was placed in the membrane module facing feed solution (FO mode) to carry out the experiments in order to prevent membrane fouling, especially pore clogging in support layer.

Fig. 1 shows a scheme of the OMBR laboratory plant used in this study. The plant was equipped with a separated bioreactor with an effective volume of 1 L. The bioreactor contained a mechanical stirrer (Velp Scientifica, Spain) to agitate the mixed liquor (feed solution to the FO membrane) and a air pump EHEIM 100 (Spain) to provide air in order to keep an oxygen concentration in the bioreactor around 2 mg L^{-1}.

The membrane module was CF042-FO (Sterlitech, USA) with capacity for a flat sheet membrane with an effective area of 42 cm^2. The flow rate in both channels of the FO module was 30 L h^{-1}. The feed and the draw solutions were pumped through the system by means of two peristaltic pumps (Pumpdrive 5006, Heidolph, Germany). In addition, the conductivity values both in the feed and draw solutions were registered using two conductivity meters model CDH-DS1 from Omega Engineering (United Kingdom). The water mass permeation through the membrane was monitored by the measuring of the evolution of the draw solution weight with the time. Thus, a digital scale PKP (Kern Instruments,