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Removal of bisphenol A (BPA) from water by various nanofiltration (NF) and reverse osmosis (RO) membranes

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HIGHLIGHTS

- The removal of bisphenol A (BPA) by various NF and RO membranes.
- Better BPA rejection with polyamide membranes than cellulose acetate membrane.
- Almost complete rejection for BPA with polyamide based RO membranes.
- Higher BPA rejection with tight NF 90 than with loose NF270.

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ABSTRACT

The removal of an endocrine disrupting compound, bisphenol A (BPA), from model solutions by selected nanofiltration (NF) and reverse osmosis (RO) membranes was studied. The commercially available membranes NF 90, NF 270, XLE BWRO, BW 30 (Dow FilmTech), CE BWRO and AD SWRO (GE Osmonics) were used to compare their performances for BPA removal. The water permeability coefficients, rejection of BPA and permeate flux values were calculated for all membranes used. No significant changes in their BPA removal were observed for all tight polyamide based NF and RO membranes tested except for loose NF 270 membrane. The polyamide based membranes exhibited much better performance than cellulose acetate membrane for BPA removal. Almost a complete rejection (≥98%) for BPA was obtained with three polyamide based RO membranes (BW 30, XLE BWRO and AD SWRO). But cellulose acetate based CE BWRO membrane offered a low and variable (10–40%) rejection for BPA.

1. Introduction

Endocrine disrupting compounds (EDCs) originated from natural or man-made synthetic substances can influence our endocrine system [1]. It was reported that EDCs disturb the endocrine system by mimicking, blocking or disrupting functions of hormones mostly. As a result of this, they affect the health of humans and animals species badly [2]. There are many industrial activities that cause the release of EDCs into underground waters, rivers and lakes [3]. Since they are not completely removed during conventional wastewater treatment processes, this has led to their occurrence in these kinds of water resources [4]. Therefore, the removal of EDCs from wastewater is required before discharging the treated wastewater to the environment [5]. Recently, removal of some EDCs by selected nanofiltration (NF) and reverse osmosis (RO) membranes has been studied extensively [5–19].

Bisphenol A [BPA, 2,2-bis(4-hydroxyphenyl)propane] is an endocrine disruptor and is widely used as a material for the production of epoxy resins, phenol resins, flame retardants, polycarbonates, polyacrylates, polyesters, and lacquer coatings on food cans [20,21]. These processes generate aqueous effluents containing high concentrations of BPA in industrial effluents. The European Commission Scientific Committee on Food (EC SCF) recommended a TDI (tolerable daily intakes) of 0.05 mg/kg body weight (bw) per day for BPA in the context of its use in food contact plastics [22]. The US Environmental Protection Agency (EPA) has the same safety level as the EU. The EPA has established a maximum acceptable or reference dose for BPA of 0.05 mg/kg bw/day [23].

In this study, selected NF and RO membranes were tested and compared for their performances in BPA rejection from water. Some of the membranes used in this study were not reported in the literature before for BPA removal from water. In addition, the effect in the structural changes of the membranes on BPA rejection along with their water permeability values was discussed.

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Nomenclature

SWRO	seawater reverse osmosis
BWRO	brackish water reverse osmosis
RO	reverse osmosis
NF	nanofiltration
MWCO	molecular weight cut off

2. Experimental

2.1. Materials

A lab-scale cross-flow flat-sheet membrane test unit (SEPA CF II, Osmonics) was used in the experimental studies. This test unit can accommodate any types of flat-sheet membrane ($19 \times 14\,cm^2$) with a full 140 cm^2 of effective membrane area and is equipped with two stainless steel cells to work under a large range of applied pressure. Feed tank is made of high density polyethylene with a capacity of 50 L. A Hydra Cell D/G-03-X type high pressure pump was used to pressurize the feed solution and Hydraulic Hand Pump (Enerpac, maximum pressure 69 bar) to pressurize the cell holder.

The NF and RO membranes employed were the products of membrane manufacturers Dow FilmTech and GE Osmonics. As NF membranes, tight NF 90 (MWCO: 200 Da, Dow FilmTech) and loose NF 270 (MWCO: 200–300 Da, Dow FilmTech) were used. According to the membrane manufacturers, both NF membranes have polyamide thin-film composite structures with a microporous polysulfone as supporting layer. The only difference between both NF membranes is the composition of the membrane top layer. The active layer of the NF 270 membrane is a very thin semi-aromatic piperazine based polyamide layer, whereas NF 90 contains a fully aromatic polyamide active layer [24]. Four RO membranes were also employed during the tests along with the NF membranes. Three of them are made of thin film polyamide (AD SWRO, GE Osmonics; BW30 and XLE BWRO, Dow FilmTech) and the other one is made of cellulose acetate (CE BWRO, GE Osmonics). The properties of the membranes used are listed at Table 1.

2.2. Methods

Permeability coefficient (L_P) may be defined as the amount of permeate transported through the membrane unit area per unit time by unit driving force gradient. Membrane permeability constants were measured by passing laboratory-grade (Milli-Q®) water from membrane in order to see whether there is a relation between BPA removals with membrane permeability constants. A digital frequency drive was used for adjusting concentrate flow rate to work at constant feed flow rate conditions. During permeability experiments, permeate and concentrate flow rates were measured at every 15 min.

Prior to each experimental run for BPA removal, the model solutions were prepared by spiking BPA (Sigma Aldrich, <97%) at a concentration of 50 mg/L with laboratory-grade (Milli-Q®) water at neutral pH. Unlike other studies reported in the literature, here higher BPA concentration (50 mg/L) in the feed was used in order to monitor the performance each membrane for their BPA rejection in a short period easily using a spectrophotometric method. After selecting the best membranes having a high BPA rejection, lower concentrations may be used with more realistic values in the future studies. A 15 L of BPA spiked feed water has been used as feed solution for the tests. Fresh membranes were first soaked into pure water for approximately 24 h for conditioning at dark. The experiments were operated in a batch recycle mode in which both concentrate and permeate streams are returned to the feed reservoir to keep the feed concentration constant during the test period. The operating pressure (10 bar) and volumetric flow rate were adjusted through the concentrate outlet valve. All experiments were performed at room temperature (around 25 °C) and each test was repeated twice.

The concentrate flow rate was kept constant at 1.6 L/min. Samples from feed tank, concentrate and permeate streams were taken after each half an hour for measuring the concentration of BPA, total dissolved solids (TDS), conductivity and temperature. Flow rates of concentrate and permeate streams were also recorded after each half an hour. The concentrations of BPA in the samples were determined by a spectrophotometric method using a Shimadzu UV-1800 model spectrophotometer (λ: 276 nm). Mettler Toledo conductivity meter and Mettler Toledo digital pH meter were used to measure TDS, conductivity, salinity, temperature and pH values of the samples.

Solute rejection, R, is defined, as a percentage, by Eq. (1):

$$R\,(\%) = 100 \times \frac{C_f - C_p}{C_f} \quad (1)$$

where R: rejection, C_f: concentration of BPA in feed stream, C_p: concentration of BPA in permeate stream.

Permeate flux, J_v, is defined by Eq. (2):

$$J_v\,(L/hm^2) = \frac{V}{S}t \quad (2)$$

L_p, the membrane water permeability constant, which depends on the structure of the membrane was calculated by Eq. (3):

$$L_p = \frac{J_v}{\Delta P - \Delta\pi} \quad (3)$$

J_v: permeate flux ($L/m^2\,h$), ΔP: differencial pressure applied across the membrane (bar), $\Delta\pi$: osmotic pressure difference between feed and permeate (bar).

3. Results and discussion

According to the data given in Table 2, pure water permeability of the membranes employed can be arranged in the order of NF 270 > NF 90 > XLE BWRO > CE BWRO > BW 30 > AD SWRO. Permeability studies were done in order to investigate if the size exclusion is the main mechanism parameter for BPA rejection or not.

Table 1
Characteristics of the membranes.

Membrane name	Class	Membrane material	Maximum T (°C)	Maximum P (bar)	pH range
*AD SWRO	SWRO	PA TFC	50	83	4–11
*CE BWRO	BWRO	CA	30	31	5–6.5
+XLE BWRO	BWRO	PA TFC	45	41	2–11
+NF 270	NF	PA TFC	45	41	3–10
+N F90	NF	PA TFC	45	41	3–10
+BW 30	BWRO	PA TFC	45	41	2–11

* GE Osmonics membranes [25].
\+ Dow FilmTech membranes [26].