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Comparison of polyamide nanofiltration and low-pressure reverse osmosis membranes on As(III) rejection under various operational conditions

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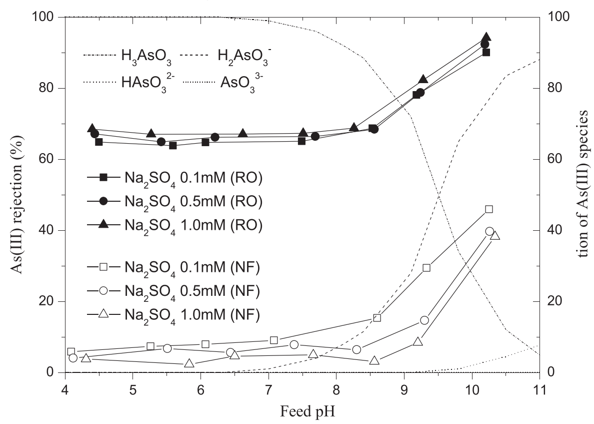
HIGHLIGHTS

- NF and low-pressure RO are promising technology for As(III) removal;.
- An NF and an RO membranes made from same material are compared;.
- Feed pH value affects the removal efficiency most for both NF and RO;.
- RO performed better than NF at any feed pH value.

GRAPHICAL ABSTRACT

Arsenite is dissociable with the first pKa at 9.2. The retention ratio of arsenite by both the NF and the low-pressure RO membrane is significantly enhanced with pH increase from around 8.5. The effect of ionic strength on the retention ratio is more significant for NF than for RO.



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ABSTRACT

A nanofiltration (NF) membrane and a low-pressure reverse osmosis (LPRO) membrane both with aromatic polyamide selective layer from the same manufacturer were employed for the comparison of their performances in terms of As(III) rejection and filtration flux under a variety of operational conditions. In addition to the smaller membrane pore size, the LPRO membrane possesses much more dissociable functional groups than the NF membrane. When the feed pH was below the pKa_1 value (9.22) of H_3AsO_3, for which the steric hindrance is the only rejection mechanism, the removal efficiencies by NF and LPRO were about 10% and 65%, respectively. When the feed pH was higher, for which electrostatic effect began to take effect, the removal efficiencies could reach 40% and 90% for NF and LPRO, respectively. The rejection performance of LPRO was marginally affected by the feed As(III) concentration or ionic strength, although ionic strength had a strong effect on the filtration flux. In contrast, feed As(III) concentration and ionic strength had little effect on the filtration flux but great influence on the As(III) rejection performance of NF. The filtration flux was enhanced with the increase of transmembrane pressure for either NF or LPRO. The NF model could predict the general trend of the effects of the filtration flux, the feed water chemistry and its own concentration on As(III) rejection ratio by the NF membrane, but the rejection ratios were over-predicted.

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1. Introduction

Some naturally occurring trace contaminants such as arsenic in groundwater have significant negative health impacts to humans. Acute and chronic arsenic poisoning via groundwater intake has been reported in Bangladesh, Chile, China, Mexico, and etc. [1–3]. The dominant species of arsenic in groundwater is arsenite (As(III)), although arsenate (As(V)) may also be of significant concentration. Among the various available technologies, nanofiltration (NF) and reverse osmosis (RO) membrane separation processes are recommended as best technologies for safe drinking water production, attributed to their high efficiency in removal of, in addition to arsenic, most molecular and ionic contaminants in the water [4–7]. The rejection mechanisms governing NF/RO systems are rather complicated which however normally include steric hindrance and electrostatic repulsion [6].

By far, numerous studies have been conducted on the arsenic removal by using NF/RO (Table 1) [2,8–11]. Generally, these studies showed that most NF/RO membranes had a higher rejection ratio to As(V) than to As(III), especially in the circum-neutral pH range. As(III) is believed more mobile and toxic than As(V) [8]. According to the arsenic chemistry (pKa_s for H_3AsO_3 are 9.17 and 13.5, and that for H_3AsO_4 are 2.26, 6.77 and 11.5, respectively) [3,12], the predominant species for As(III) and As(V) at pH 7 are uncharged and anionic, respectively. Anionic species are normally better rejected [13–15]. Unfortunately, oxidation is not an easy way to enhance the arsenic removal efficiency since oxidant could easily damage the employed NF/RO membranes.

A brief literature review of the previous studies showed that the rejection ratio to As(III) by NF/RO differed largely, which ranged from 5% only to higher than 99% (Table 1). Normally, an RO membrane had a higher rejection ratio than an NF membrane [16–19], apparently caused by the stronger steric effect of the former than that of the latter, as is generally also the case when compared among the various NF/RO membranes [12,20–22]. It clearly demonstrates the critical importance of the selected membrane in determining the As(III) rejection. As listed in Table 1, the NF/RO membranes that had been studied include that from Dow FilmTec, Nitto-Denko, Osmonics Desal, Fluid Systems, Hydranautics and etc.

It is also generally accepted that the operational conditions play important roles in As(III) rejection process that uses NF/RO membranes. The most notable operational condition is the feed pH, and almost without exception, the removal efficiency of As(III) was observed higher at enhanced feed pH [12,19,20,23–25]. The feed pH controls both the dissociation extent of As(III) and the surface charge density of the NF/RO membranes. The other operational conditions include the applied filtration pressure, the feed ionic strength, the feed As(III) concentration, the co-existing organic matter concentration and etc [7,11,16,18,19,24,26]. The effect of these operational conditions on As(III) rejection however differs greatly for different NF/RO membranes. It may to some extent explain the big difference of the As(III) rejection ratio in the various studies using the same NF/RO membranes (Table 1).

For a further understanding of the NF/RO process for As(III) removal, in this study, a NF membrane (Desal HL) and a low-pressure RO membrane (Desal AK) both obtained from GE Osmonics are tested for the As(III) removal performance under various operational conditions. The NF and RO membranes were selected because they have very

Table 1
A brief summary of the previous studies on As(III) rejection by using NF/RO membranes.

Membrane	R to NaCl	R to As(III)	Ref.
Fluid Systems TFCL	98.5% (P = 1.52 MPa)	>98% (P = 1.72 MPa, pH = 8)	[7]
Fluid Systems TFC-HR	99.5% (P = 1.55 MPa)	>98% (P = 1.38 MPa, pH = 8)	
FilmTec NF-70	70% (P = 0.5 MPa)	>97% (P = 0.56 MPa, pH = 8)	
Desalination Systems CE	95% (P = 2.76 MPa)	>97% (P = 2.76 MPa, pH = 5.7)	
FilmTec NF-70 4040B	(MWCO = 300)	~50%	[16]
Desal HL-4040 F1550	(MWCO = 300)	~20%	
Hydranautics 4040-UHA-ESNA	(MWCO = 300)	~30%	
Fluid Systems TFC 4921	N/A	~60%	
Fluid Systems TFC 4820-ULPT	N/A	~75%	
Desal AG 4040	N/A	~70%	
Hydranautics 4040 LSA-CPA2	N/A	~85%	
Nitto-Denko ES-10	98.7% (P = 0.24 MPa)	50 60% (P = 0.24 MPa, pH = 3 7)	[23]
FilmTec NF-45-2540	(MWCO = 300)	12% (pH = 6.9)	[17]
Desal DK2540F	(MWCO = 180)	5% (pH = 6.8)	
Nitto-Denko ES-10	>97% (P = 0.75 MPa)	>75% (P = 0.75 MPa, pH < 8)	[12]
Nitto-Denko NTR-729Hf	89% (P = 0.75 MPa)	20% (P = 0.75 MPa, pH < 8)	
Nitto-Denko ES-10	84.3% (P = 0.6 MPa)	55% (P = 0.6 MPa, pH = 8)	[18]
Toyobo HR3155	99.9%	95% (P = 4 MPa, pH = 8)	
FilmTec NF-45	N/A	<20% (pH = 8.1 8.2)	[26]
Osmonics BQ01	50% (J = 8 μm/s)	5 28% (J = 8 μm/s, pH = 8.1 8.2)	[35]
Nitto-Denko ES-10	99.6% (P = 1.5 Mpa)	>75% (P = 0.3 1.1 MPa, pH = 6.8)	[21]
Nitto-Denko NTR-7250	93.0% (P = 1.5 Mpa)	<22% (P = 0.3 1.1 MPa, pH = 6.8)	
Nitto-Denko NTR-729Hf	70.0% (P = 1.5 Mpa)	<22% (P = 0.3 1.1 MPa, pH = 6.8)	
Nitto-Denko ES-10	N/A	~50% (P = 0.25 MPa, pH = 7 8)	[22]
Nitto-Denko NTR7250	N/A	~30% (P = 0.25 MPa, pH = 7 8)	
Nitto-Denko NTR729HF	N/A	~50% (P = 0.25 MPa, pH = 7 8)	
Toray NF	N/A	5%	[24]
FilmTec XLE-2521	98.2% (P ≈ 1 MPa)	71% (P ≈ 1 MPa, pH = 7.2)	[36]
FilmTec TW30-2521	99% (P ≈ 1 MPa)	89% (P ≈ 1 MPa, pH = 7.2)	
FilmTec SW30-2521	99% (P ≈ 1 MPa)	97% (P ≈ 1 MPa, pH = 7.2)	
Woongjin NE 90	87% (P ≈ 0.552 MPa)	41 44% (P = 0.14 0.55 MPa, pH < 8)	[25]
FilmTec SWHR	99.6%	~75% (P = 20 bar, pH = 3.1)	[19]
FilmTec BW-30	99.5%	~60% (P = 20 bar, pH = 3.1)	
FilmTec NF-270	(MWCO = 600)	<11% (P = 3 5 bar, pH = 5)	[37]
FilmTec SW30HR	99.5% (P = 40 bar)	>99% (pH = 7.6)	[20]
Hydranautics SCW5	99.3% (P = 40 bar)	>99% (pH = 7.6)	
FilmTec BW30LE	98.9% (P = 40 bar)	>99% (pH = 7.6)	
Hydranautics ESPAB	99.3% (P = 40 bar)	>99% (pH = 7.6)	
Hydranautics ESPA2	99.1% (P = 40 bar)	>99% (pH = 7.6)	