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Influence of boron on rejection of trace nuclides by reverse osmosis

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HIGHLIGHTS

- RO membrane can perform a favorable rejection of trace nuclide and a moderate rejection of boron.
- The existence of excessive boron can improve the nuclide rejection by RO.
- RO membrane can facilitate radioactive waste minimization.

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ABSTRACT

Reverse osmosis (RO) has been proved to be an effective technology in the treatment of low level radioactive wastewaters (LLRWs) in nuclear power plants (NPPs). However, particular attention must be paid to any possible negative influence of excessive boron on the performance of membrane units. In this paper, influence of excessive boron on trace nuclide rejection by reverse osmosis had been investigated in a laboratory-scale cross-flow membrane filtration unit. The results demonstrate a positive influence. The increase scope of 1% to 8% can be observed in the nuclide rejection with the boron concentration variation from 0 to 1000 mg · L^{-1}. Temperature increase can improve the passage of boron to the permeate side, without obvious loss of nuclide rejection. Increasing the operation pressure or pH values, however, improves trace nuclide decontamination and boron rejection simultaneously. In general, RO unit can perform a favorable rejection of trace nuclide and a moderate rejection of boron. The membrane concentrate contains less boron, which facilitates the volume minimization by evaporation.

1. Introduction

With the rapid development of nuclear energy in China, a broad spectrum of low level radioactive wastewaters (LLRWs) has been generated and must be purified prior to discharging to the environment. Usually, the most widely used technologies employed for the clean-up of LLRWs in Nuclear Power Plants (NPPs) are evaporation and ion-exchange [1,2]. However, the evaporation process gives rise to high energy consumption and corrosion problems, while the ion-exchange process will produce amounts of exhausted resin in which most radioactive nuclides accumulate and must be transported to disposal sites for long-term storage after cementation.

In recent years, membrane technology has received high attention in the treatment of LLRWs with additional advantages coming from the low energy consumption, minimized maintenance and human exposure [3]. Among various membrane-separation processes that are used for the radioactive decontamination of water, pressure driven processes, including reverse osmosis (RO) have already proven themselves as the most versatile methods [4]. RO technology has been employed successfully in several nuclear facilities, such as Chalk River Laboratories in Canada [5], Nine Mile Point station (NMP), Comanche Peak NPP and Dresden NPP in the United States [6,7], as summarized in Table 1.

Research on the treatment of LLRWs by RO was conducted in the 1980s, which enabled design of a full-scale system consisting of cross-flow microfiltration, spirally wound reverse osmosis (first stage), and

Table 1
Applications of reverse osmosis for nuclear waste processing [8].

Membrane process	Facility	Wastes processed
Reverse osmosis	AECL Chalk River (Canada)	Reactor coolant clean-up with boric acid recovery
Reverse osmosis with conventional pretreatment	Nine Mile Point NPP (USA)	BWR floor drains and various other wastes
	Pilgrim NPP (USA)	BWR floor drains and various other wastes
Reverse osmosis with ultrafiltration pretreatment	Wolf Creek NPP (USA)	PWR floor drains, reactor outage waste, spent resin sluice water, and other wastes
	Comanche Peak NPP (USA)	Floor drains, resin sluice water, boron recycled water
	Bruce NPP (Canada)	Aqueous wastes from steam generator chemical cleaning

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Table 2
Characteristics of RO membrane materials.

Membrane	Material	Surface charge	Specific flux ($L \cdot m^{-2} \cdot h^{-1}$)	R_{stable} (%)	R_{min} (%)
BW30	Polyamide	Negative	45.05	99.50[a]	99.00[a]
BW30FR	Polyamide	Negative	45.05	99.50[a]	99.00[a]
BW30XFR	Polyamide	Negative	48.42	99.65[a]	99.40[a]
LE	Polyamide	Negative	49.55	99.30[b]	99.00[b]
XLE	Polyamide	Negative	48.78	99.00[c]	98.00[c]

[a] 2000 ppm NaCl, 15.5 bar, 25 °C, 15% recovery, pH = 8;
[b] 2000 ppm NaCl, 10.3 bar, 25 °C, 15% recovery, pH = 8;
[c] 500 ppm NaCl, 6.9 bar, 25 °C, 15% recovery, pH = 8.

tubular reverse osmosis (second stage) [9]. Generally, RO system can provide α and β rejection of above 90% [10]. The treatment of ^{137}Cs-contaminated water by RO demonstrated an efficient removal, with ^{137}Cs rejection of above 90%, even higher than salt rejection [11,12]. In the treatment of radioactive liquid waste at Chalk River Labs, the overall radioactive rejection by RO membranes was detected as 99.5%, and decreased to 95.0% after operation for 4000 h [13]. By means of Toray advanced seawater reverse osmosis membrane (UTC-80R), the very high rejection of more than 99% had been observed in the removal of Cs, Sr, and I from saline water [14]. In most cases, the RO process had to be conducted as a multi-stage operation. A three-stage reverse osmosis unit, that was used to clean up liquid wastes with salinity of 300–800 mg · L^{-1}, produced a permeate with a specific activity 200–14,000 times lower than that of the feed and a retentate with a specific 7–15 times higher activity [15]. In some cases the three-stage RO

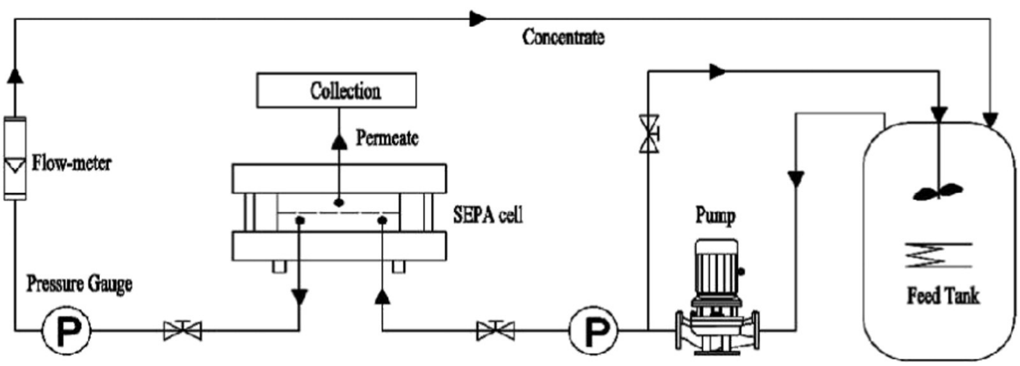

Fig. 1. Scheme of the RO set-up.

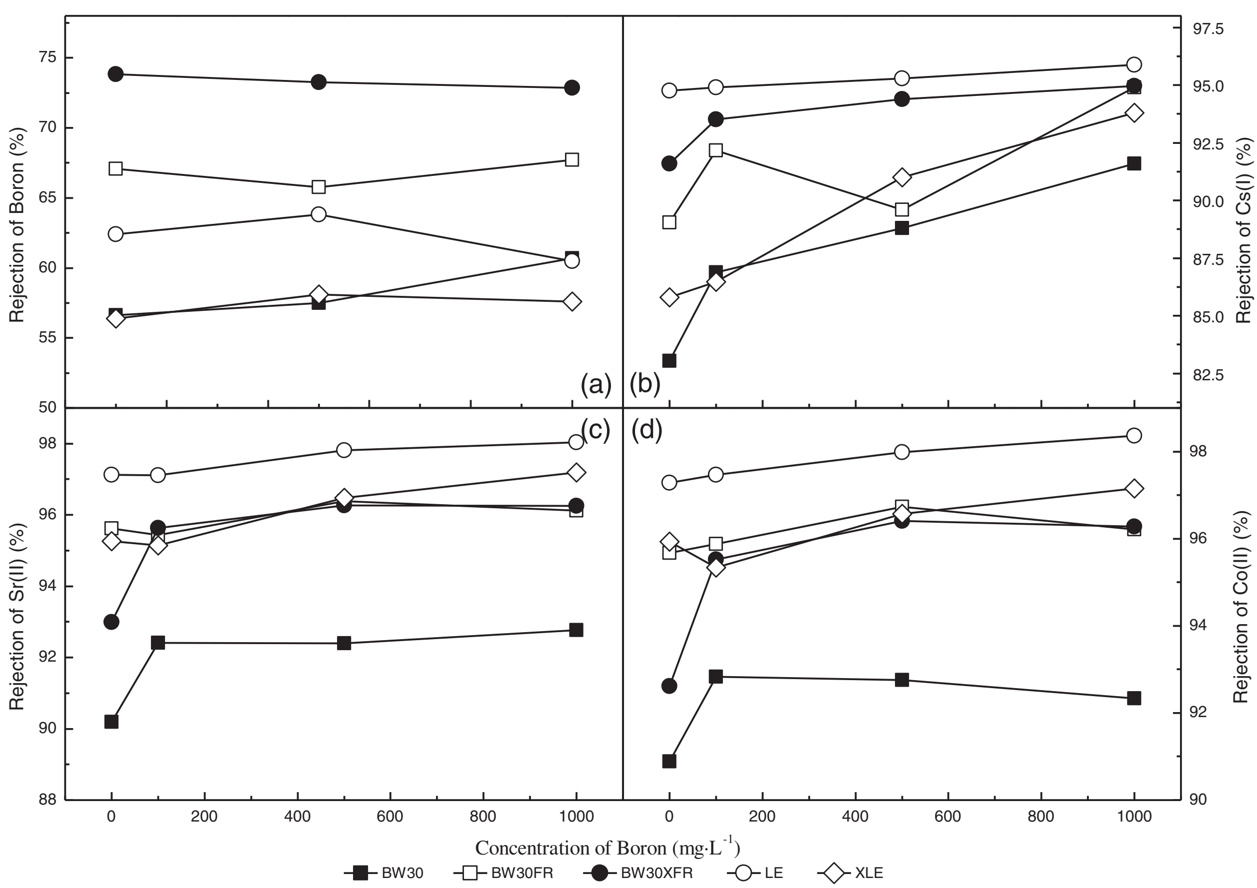

Fig. 2. Effects of boron on the membrane rejections (a: Rejection of boron; b: rejection of Cs(I); c: rejection of Sr(II); d: rejection of Co(II)).