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Recent Advancements on Challenges and Cost Effective Solution for Removal of Boron from Sea Water

Savita Kalshan[1], Rajesh Dhankhar[2], Amit Chhilar[3], Preeti Gahlot[4], Poonam Yadav[4]
[1, 2, 3,4] Department of Environmental Science,
M.D.U, Rohtak-12001, Haryana

***Abstract*:- Rapid growth and development of seawater desalination using reverse osmosis membrane technology in recent years has developed the problem of high boron concentration in Irrigated and potable water. This review provides a summary of the recent advancement challenges and cost effective solution of removal of boron using reverse osmosis membranes technology in desalination of seawater application. In seawater, boron exists as an inorganic trace element in the form of boric acid. This Study investigating the impact of boron on plant and animal and most important controlling factors of membrane configuration system describes such as pressure and pH for rejection of boron using reverse osmosis (RO) membranes technology. This review will present a comprehensive overview of the recent advance reverse osmosis configuration for deboronation technology by using two stage reverse osmosis configuration.**

Keywords: *Reverse osmosis, Deborination, Boron, Seawater*

1. INTRODUCTION

Rapid growth and development of population leads to global scarcity of water in many areas around the world. Increasing water supply is a challenging task for development of sustainable, energy efficient technology. Desalination is the most reliable and standard method to secure freshwater for a rising population without harming the environment. Desalination plants are established by many countries such as Oman, Spain, Cyprus, United Arab Emirates, Malta, USA, Saudi Arabia, Italy, Singapore, Greece and Australia (National Academics Press, Washington, DC, 2008). Israel gets 55% of potable water by using desalination technology and helping India to installed desalination plants. India's national water mission identifies desalination a major tool and technology to make brackish and seawater accessible and usable for the people.

Moreover 21,000 desalination plants worldwide produce approximately 13 gigalitres of potable water per day. In India, 1,000 desalination plants set up having capacity at about 291,820 cubic meters per day. Among them highest installed capacity of desalination plant in India achieved by Tamil Nadu, Gujarat and Chennai. Freshwater and groundwater contamination or water scarcity is the major reasons have forced industrial and institutional areas to go for desalination of seawater. Approximately half of these desalination plant used seawater as a feed water (Porteous *et al*., 1983).

Desalination is essential technology which means removing salts and other minerals by using different processes. These processes are mainly categories into two groups, such as membrane separation and thermal distillation technology. Reverse osmosis membrane separation is generally more efficient for removal of salts and dissolved minerals and produce demineralized potable water (National Academics Press, Washington, DC, 2008 & Porteous *et al*., 1983). The National Institute of Ocean Technology (NIOT), located at Chennai in India has developed world's first low temperature thermal desalination plant. But the thermal distillation based desalination is mainly more energy consuming as compare to membrane based desalination and this disadvantage leads to shift from thermal distillation to membrane based desalination (Strathmann *et al*., 2011).

Rapid growth of reverse osmosis membrane based seawater desalination for few decades leads to attention for removal of boron in seawater (Tu et al., 2010). In seawater, boron occurs in the form of boric acid and average concentration of boron in seawater is 4.6 mg/l approximately; however, in Eastern Mediterranean sea boron concentration is 9.6 mg/L (OECD *et al.,* 2014). Although boron is essential for growth and development of animals, plants and excess concentration of boron can leads to serious health and ecological damages such as causing skin eruptions, depression and gastrointestinal disturbances in human [7]. In Eilat, Israel recognized high concentration of boron in 1997, when farmers using the treated water for irrigation of agricultural land and noticed toxicity of boron on crops. Therefore, boron identified as the trace element that cause toxicity in agricultural field (Fritzmann, *et al.,* 2007). Boron toxicity also reported in many countries where alkaline soil with low rainfall and leaching can cause toxicity of boron such as Africa, West Asia and Australia (Richold *et al.,* 1998). Therefore, removal of boron as a trace element is essential in all reverse osmosis membrane based seawater desalination technology. The first investigation process on removal of boron using reverse osmosis membrane technology occurred in 1969 (Graber, *et al*.,1970).

This review provides recent advancement on challenges and cost effective solution for development of reverse osmosis membrane from perspectives of membranes materials, membrane fabrication and reverse osmosis desalination configuration for rejection of boron. This paper also explains several configurations to increase the rejection of boron using reverse osmosis membranes based seawater desalination technology.

2. DESALINATION OF BORON

2.1 Boron in seawater

Boron is a common element found as a trace element in nature and covalently bound with oxygen in the form of borate, boric acid, tetraborate, etc in lithosphere and hydrosphere. In hydrosphere boron exists in the form of boric acid and similarly, lithosphere boron exists as a borate mineral. The existence of boron in different water bodies varies significantly. Boron exists as lesser concentration in conventional sources such as groundwater and surface water. The average concentration of boron varies from 2-100 mg kg^{-1} in soil and 1-500 mg kg^{-1} in the Earth's crust (Parks *et al.*, 2005). The average concentration of boron is usually less than 0.1mg/l in freshwater. Boron is an element used as boric acid in various industrial and pharmaceutical products such as medicines, antiseptic eye lotion, printing, lather making, hard steel, dying soaps and detergents applications. WHO in 2004 recommended a maximum concentration of salt is 350 mg/L and a maximum concentration of boron is 0.5 mg/L in potable water (WHO Guidelines, 2004). However, in 2011 the WHO raised the recommended concentration of boron from <0.1 mg/L to 2.4 mg/L in potable water (WHO Guidelines ,2011). Therefore, the prescribed level of boron varies between countries as seen in Table 1.

Table 1. Level of boron in various countries

Country	Organization	Boron limit (mg/L)	Reference
	World Health Organization	2.4	13
Australia	National Water Quality Management Strategy	4	7
India	Bureau of Indian standard (BIS)	0.5	14
New Zealand	Ministry of Health	1.4	15
Canada	Health Canada	5	16
Europe	European Union	1	17

2.2 Chemistry of Boron

A basic concept and phenomena of boron chemistry is important for the development of cost effective configuration for boron removal or deborination technology. Boron is a non-metallic element of group 13 in the periodic table and due to non-metallic character the chemistry of boron and its compounds are exists as unique property. The symbol representation of boron is B and quantum configuration of boron is $1s^2$ $2s^2$ $2p^1$. In environment, boron is exists in the form of boric acid, borate, or borosilicate mineral and similarly in water, it behaves as a Lewis acid. In seawater boron dissociation occurs by accepting a hydroxyl ion to form the tetra-hydroxyborate ion:

$$B(OH)_3 + 2H_2O \longleftrightarrow [B(OH)_4]^- + H_3O^+ \quad ;pKa = 9.23 \ldots\ldots\ldots\ldots (1)$$

At relatively low pH only the mononuclear species are present such as $B(OH)_3$ and $B(OH)_4^-$ and at higher pH 10 only the poly-nuclear ion species would be formed such as $[B_3O_3(OH)_5]^{2-}$ and $[B_4O_5(OH)_4]^{2-}$ (Power *et al.*, 1997). The formation of these ionic species is results to the interaction of molecules of boric acid and borate ions in solution:

$$B(OH)_3 + 2B(OH)_4^- \longleftrightarrow [B_3O_3(OH)_5]^{2-} + 3H_2O \qquad (2)$$

However, below these pKa 9.23 values, boric acid exists as un-dissociated form and the radius of boric acid ion is large, in the range 0.244-0.261 nm (Banasiak *et al.*, 2009). Thus, boric acid is poorly hydrated from reverse osmosis membrane desalination due to its small hydrated radius.

2.3 Toxicity of Boron

Boron is an important micronutrient and leads to toxicity to plant, animal and human at higher concentration. Boron at higher concentration leads to adverse health impact on plants as shown in Table 2. Boron can causes problems and toxicity mainly in agricultural field of arid and semi-arid areas due to its high saline soil and low rainfall leads to increase concentration of boron (Reid *et al.*, 2007). The excessive impact of boron in plants leads to toxicity such as decreasing of chlorophyll content and cell division in plants, photosynthesis inhibition, etc (Reid *et al.*,2007). Similarly in human long-term exposure of excess concentration of boron leads to contaminated of food and water. These contaminations of boron lead to various disorders and diseases such as cardiovascular, nervous system, alimentary systems disorders, cellular metabolism, etc (Kot *et al.*,2015). At present recommendation to prevent plant toxicity of boron in irrigation water lower than 0.5 mg/L for currant, lemon orchards and blackberry (Bodzek *et al.*, 2016 & Hilal *et al.*, 2011) and for grapefruit, avocado, orange, walnut, apricot and strawberry agriculture recommendation level of boron is 0.5 to 1.0 mg/L (Bodzek *et al.*, 2016 & Hilal *et al.*, 2011). Therefore, recovery of boron content in seawater sources is very necessary for potable water and irrigation water.

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Table 2 Tolerance level of agricultural crop for boron
(Source: Gupta, et al., 1985 & Canadian Environmental Quality Guidelines 1999).

Boron concentration	Affected Crops
(<1.0 mg/L)	Orange, blackberry, citrus, peach, grape, onion, garlic, sweet potato, wheat, mung bean, sesame, strawberry, Jerusalem, apricot, pecan, etc.
(1.0-2.0 mg/L)	Capsicum, pea, carrot, radish, potato, cucumber, lima bean, pumpkin, zinnia, olive, tomato, sunflower, etc.
(>2 mg/L)	Lettuce, cabbage, celery, turnip, Kentucky bluegrass, corn, artichoke, tobacco, mustard, clover, squash, etc

2.4 Boron Analysis

Boron is the inorganic trace element exists in aqueous solution as boric acid and analyzed by spectrophotometric method. Spectrophotometric method is based on colorimetric reactions of boric acid with particular reagents in the sample solution. These methods are only used for analysis of contaminated field of boron. However, this method is not good for detection of boron due to numerous interference and low sensitivity (Sah & Brown *et al.,* 1997). The main disadvantage of spectrophotometric method is detection limits of spectrophotometer are lesser than various emission spectrometry such as inductive coupled plasma mass spectrometry (ICP-MS) or inductive coupled plasma atomic emission spectrometry (ICP-AES). Now a days, ion chromatography (IC) has used for analytical detection and monitoring of boron concentration in seawater.

3. MEMBRANE PROCESS FOR BORON REJECTION

3.1 Reverse osmosis (RO)

Reverse osmosis (RO) membrane technology is the most important conventional technology for purification of contaminated water. In this technology hydraulic pressure applied to force permeate water through reverse osmosis membrane and retains the salt ions as shown in fig 1 (Shenvi *et al.,* 2015). Reverse osmosis mostly used for wastewater treatment and desalination of brackish and seawater. Reverse osmosis multiple membranes are used at different pH for the removal of boric acid present in seawater. However, the lesser size of boron ion poorly hydrated due to absence of electrostatic repulsion. Most of the state-of-the-art RO membranes fail to achieve a boron rejection in higher concentration due to its lesser size and electrostatic repulsion (Tagliabue *et al.,* 2014). In this year, many researchers are focusing on challenges and cost effective solution for high boron rejection ability of reverse osmosis processes through development of membrane.

Fig1. Single stage reverses osmosis membrane system

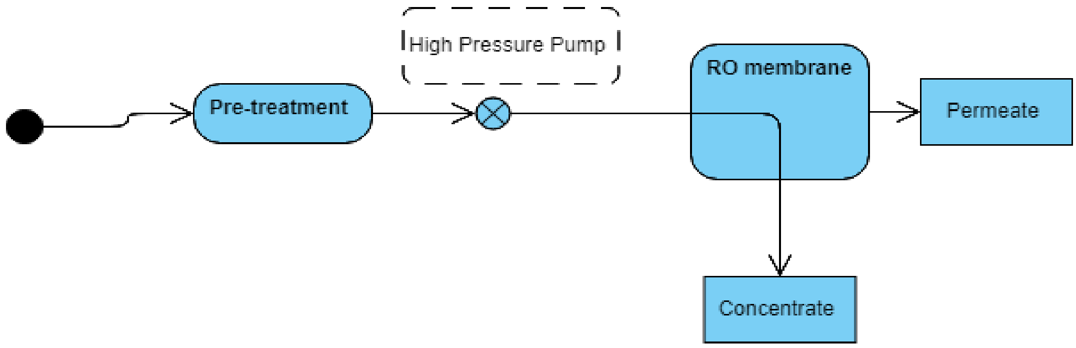

Fig1. Single stage reverses osmosis membrane system

3.2 Reverse osmosis membrane development

The reverse osmosis membrane is major key element of membrane based purification technology. In conventional reverse osmosis membranes filtration technology cellulose-polymers and polyamide thin film composite (TFC) membrane are used during purification of wastewater (Shenvi *et al.,* 2015). In boron removal process mainly TFC membrane used which is typically consist of three layers as shown in Fig 2; such as, a polyester fabric substrate, ultrathin polyamide selective layer, a micro porous support layer.

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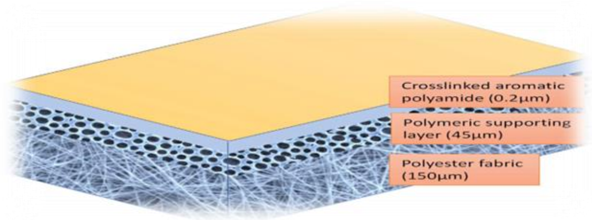

Fig 2.A typical structure of TFC Reverse Osmosis membrane (Tagliabue *et al.*, 2014)

TFC is a tighter and complex selective layer with smaller pore size and reduced affinity towards content of boron to enhance affinity towards water (Tomaszewsk *et al.*, 2016). Table 3 represents various commercial RO membranes, with their boron rejection percentage and pH provided by the various manufacturers company (Dominguez-Tagle *et al.*, 2011).

Table 3 various commercial RO membranes with boron rejection.

Membrane type	Manufacturer	pH	Boron rejection (%)
FILMTECTM SEAMAXXTM	DOW chemical	8	81.8
FILMTECTM SW30ULE-400i		8	86.4
FILMTECTM SW30XHR-400i		8	93
FILMTECTM SW30XLE-400i		8	91.5
FILMTECTM SW30HRLE-370/34i, SW30HRLE-400		8	92
TM820E	Toray	8	91
TM800V		8	92
TM800K		8	96
TM820M		8	95
TM820C		8	93
TM820R		8	95
SWC4 MAX	Hydranautics	7	93
SWC5 MAX		7	92

3.3 Reverse osmosis parameters

Several operating parameters effected boron removal during reverse osmosis membrane desalination process such as pH, pressure, temperature, concentration of boron in permeate water recovery etc. (Hilal *et al.*, 2011& Ezechi *et al.*, 2012). Among them, pH control is the most widely used parameter for boron rejection. It was representative that the removal of boron concentration at lower pressure and neutral pH enhance from 30% to 83% and at high pressure and pH 10.5 boron content rejected up to 90–99% (Oo & Ong *et al.*, 2012 , Rahmawati *et al.*, 2012). There are various studies directed towards to achieved the challenges for removal of high boron concentration in potable and irrigation water. Most of these studies involve reverse osmosis membrane process for boron removal at particular.

Hydraulic pressure also influences the rejection of boron from reverse osmosis membrane processes. It has been demonstrated by several experimental studies that the boron rejection increases rapidly with increasing the membrane pressure (Teychene *et al.*, 2013, Koseoglu *et al.*, 2010, Kheriji *et al.*, 2015, Güler *et al.*, 2011, Kezia *et al.*, 2013, Kheriji *et al.*, 2013 & Yavuz *et al.*, 2013). It was reported that seawater reverse osmosis membranes, i.e., Toray UTC-80AB and Dow FilmTec SW30HR, exhibited a boron rejection increase from 74% to 84% at 15.5 bars to 92–97% at 48.3 bar, (Koseoglu *et al.*, 2010).

3.4 RO seawater desalination configuration

Two stage reverse osmosis system is efficiently used for the removal of boron from seawater because single stage reverse osmosis reverse osmosis reject the salt concentration up to its desirable limits but it fails to reject boron concentration during membrane filtration. The seawater boron removal can be achieved by only two or three stage reverse osmosis membrane where water under high pressure and at pH 6-7 pass through membrane and produce permeate water. This permeate water becomes the feed water for the second pass of the membrane at pH 11 and effectively remove the boron content to the level of WHO guidelines for drinking water (<0.5 mg/L) as shown in fig 2.

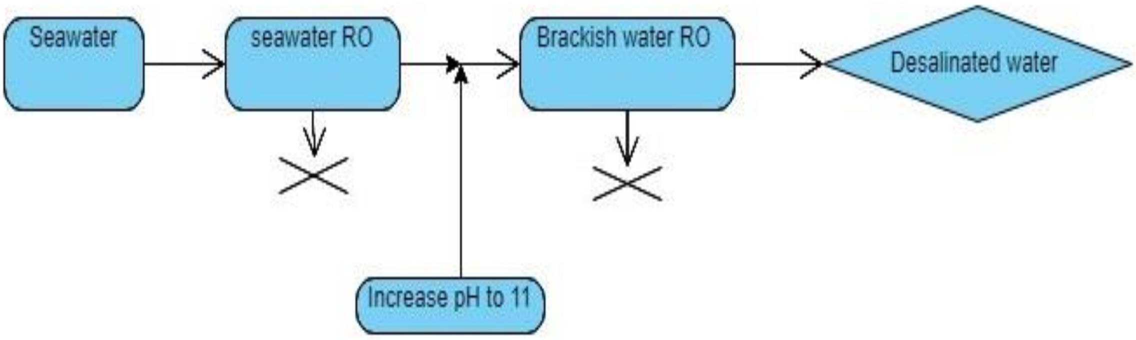

Fig 3. Two-pass desalination and boron removal system

4. CONCLUSION

Boron removal using various membranes is the most important research topic in recent years. In this review, we have to analyze the recent advancement challenges and cost effective solution for removal of boron from seawater and this objective provides useful insight for development of advance configuration of reverse osmosis membrane for deborination. The two stage reverse osmosis system enhanced boron rejection and reduce the operating cost of the consumer. This configuration system at different operating pressure and pH provides high recovery of boron according to WHO guidelines of potable water. Therefore, this method is economically and environmentally ecofriendly recover and recycled the boron from seawater.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest We declare that there is no conflict of interest associated with this manuscript.

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