Review Article

Application of the Reverse Osmosis Process in Water Treatment in Iran

Fatemeh Mohebbi[1], Mohammad Bagher Miranzadeh[2], Rouhullah Dehghani[2], Heshmatollah Moradpour[2], Davarkhah Rabbani[2], Saeid Karami Oshtorjani[3]

[1]Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran, [2]Department of Environmental Health Engineering, Faculty of Health, Kashan University of Medical Sciences, Kashan, Iran, [3]Department of Occupational Health Engineering, Isfahan Health Center, Isfahan, Iran

Abstract

Reverse osmosis (RO) is one of the water treatment processes based on solvent mass transfer using a semipermeable membrane to separate the inorganic, organic and toxic substances from drinking water. The purpose of this study was to review the researches done in Iran on the RO. This narrative review investigated the 200 original articles published during 1998 - 2022. Water quality, RO, desalination, and membrane processes were used as keywords in this study. The search was accomplished in the website of reliable journals and many databases, including Web of Science (ISI), Ovid, PubMed, Google Scholar, Scientific Information Database, Iran Medex, and Magiran. In order to extract their contents, 69 articles were selected. This study showed that between the studied elements, fluoride and free chlorine in the effluent of RO are less than the WHO guideline levels. The elements measured in the different studies are not the same and each study has been designed based on the needs and available facilities and the opinions of researchers on the specific elements. Elimination of free residual chlorine can increase the risk of waterborne diseases. Reduction of fluoride to less than the guideline level can increase the number of decayed teeth among consumers. It is recommended to investigate the impacts of the drain of RO plants on environment.

Keywords: Household, membrane processes, reverse osmosis, water purification, water quality, water treatment plant

Introduction

Human life and health depends on safe drinking water more than anything else, so efforts to provide safe water are of particular importance.[1-3] Nowadays, due to climate changes and population increase, reduction of water resources per capita and increase in physical, chemical, and microbial pollution, water crisis has been raised as one of the major global problems.[3-5] The chemical and microbial quality of drinking water has significant effects on people's health, because drinking water is one of the ways to supply the essential minerals to the human body.[6,7] Existing of some chemical elements in drinking water will be hazardous for consumers.[8,9] Based on this, the technology of desalination of seawater and brackish water of underground aquifers, springs and rivers are continuously being developed.[10] Middle East countries have 54% of the desalination capacity in the world, followed by America with 23%, Europe with 10%, and Africa with 5%. Among the Persian Gulf countries, the United Arab Emirates with 35%, Saudi Arabia with 24%, Kuwait with 14%, Qatar with 8%, Oman with 14%, and Bahrain with 5% have the highest desalination capacity.[11-16] Reverse osmosis (RO) with 64% and multistage flash distillation with 23%, multieffect distillation with 8% are, respectively, the most widely used technologies for seawater desalination in the world. Electrodialysis technology has taken only 4% of the world's water desalination capacity.[17-19] The RO process was discovered by Nollet in 1748.[20] This process is currently the most complete membrane technology for water desalination with a relatively low cost.[21-23] The largest seawater desalination device in the world is the Hadera RO plants located in Israel.[24] RO has the ability to achieve the

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Address for correspondence: Prof. Davarkhah Rabbani, Department of Environmental Health Engineering, Faculty of Health, Kashan University of Medical Sciences, Kashan, Iran.
E-mail: davarrabbani@gmail.com

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standards of chemical and microbial quality of drinking water.[25] Furthermore, this technology has been used to remove organic substances,[25,26] dangerous pollutants,[27] and seawater salts with an efficiency of more than 99%.[28,29] RO technology, especially in the production of desalinated water, has been greatly developed in the last 40 years. In addition, the use of this technology is expanding in water-scarce countries, especially in the Middle East and Africa.[30-33] Due to the increase in salinity of underground water in tropical and dry areas in countries such as Iran and the increase in water consumption in these areas, RO plants have been considered for water desalination.[34] Therefore, the purpose of this study was to review the researches done in Iran on the RO.

Materials and Methods

This is a review study using the keywords of water quality, RO, and environmental effects, through searching in websites related to reliable medical and health journals and reliable databases including: Web of Science, Ovid, PubMed, Scientific Information Database, Google Scholar, and Medline. Articles from 1998 to 2022 were reviewed with an emphasis on the use of RO desalination. A total of 200 sources were reviewed, and finally, 69 sources were selected with more focus on studies conducted in Iran. In this study, we reviewed the articles pertaining to the chemical, microbial, and biological quality of desalinated water. Our focus was specifically on the application of RO in Iran.

Results and Discussion

Numerous studies conducted between 2002 and 2022 have assessed the water quality produced by RO water desalination systems. Variations exist in the parameters evaluated across these studies, with each study's design influenced by specific requirements, available resources, and researchers' preferences. Total hardness has been the focus of the majority of studies, while residual-free chlorine has received comparatively less attention. The results of common parameters measured in different studies are shown in Table 1.

Residual free chlorine

Residual free chlorine plays a critical role in maintaining microbial safety within distribution networks.[20] Rajaei *et al*.,[40] Yari *et al*.,[38,39] Naghipour *et al*.,[37] Gholami-Borujeni *et al*.,[36] Babaei *et al*.,[41] and Nourmoradi *et al*.[42] observed that residual free chlorine levels were below the maximum permissible limit in their investigations, while Aghababaei[43] documented optimal levels in their study. The presence of residual free chlorine in the optimal level in the final purified water is necessary to eliminate possible secondary pollution. The removal of residual chlorine by household water purification devices over time causes the formation of biofilm in the storage tank by the bacteria present in the network water; as a result, the number and variety of bacteria in the water produced by these devices increases.[57] In the study of Abolli *et al*. in Garmsar, the average of the total residual free chlorine was reported as optimal, but its amount was zero in 22.23% of the samples.[44]

Fluoride

Fluoride enhances enamel remineralization and inhibits bacterial activity, thereby strengthening tooth enamel and significantly reducing the risk of dental caries. However, excessive fluoride intake—particularly during the tooth development phase in children—can lead to dental fluorosis, a cosmetic condition that causes discoloration and mottling of the teeth.[20] Studies conducted by Yari *et al*.[38] and Jafaripour *et al*.,[53] Deghani *et al*.,[45] Naghipour *et al*.,[37] Miranzadeh and Rabbani,[46] Aghababaei,[43] Abolli *et al*.,[44] and Badeenezhad *et al*.[47] showed that fluoride was less than the optimal level and in order to maintain the health of the teeth and prevent their decay, the fluoridation process of water purified by RO has been recommended by some of these researchers.[46]

pH

The pH of drinking water not only affects chemical stability and corrosion potential, but also influences the balance between carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions.[20] The pH level of purified water using RO plants in the studies of Naghipour *et al*.,[37] Gholami-Borujeni *et al*.,[36] Alipour *et al*.,[50] Deghani *et al*.,[45] Malakootian *et al*.,[51] Aghababaei,[43] Nourmoradi *et al*.,[42] Badeenezhad *et al*.,[47] Pourjamali *et al*.,[49] Babaei *et al*.,[41] and the study of Miranzadeh and Rabbani[46] have been reported as optimal. While in the studies of Yari *et al*.[38,39] and Khodadadi *et al*.,[48] it was declared less than the optimal level. The lowest pH value was 6.35 related to the study by Yari *et al*.[38,39] and the highest value was 7.7 related to the study by Khodadadi *et al*.[48]

Total hardness

In the studies conducted by Deghani *et al*.,[45] Yari *et al*.,[38] Jafaripour *et al*.,[53] Rajaei *et al*.,[40] Pourjamali *et al*.,[49] Sadigh *et al*.,[54] Malakootian *et al*.,[51] and the study of Ghannadi and Farhadpour in the villages of Iran,[52] the level of water hardness in water samples taken from RO is less than optimal and in the studies of Naghipour *et al*.,[37] Miranzadeh and Rabbani,[46] Aghababai *et al*.,[43] Badeenezhad *et al*.,[47] Khodadadi *et al*.,[48] and Alipour *et al*.,[50] it has been reported as optimal. Considering that calcium and magnesium salts reduce the risk of cardiovascular diseases,[58] and on the other hand, to prevent corrosion in water pipes, a hardness of more than 100 mg/l is necessary; therefore, in some studies, the addition of calcium and magnesium compounds have been recommended to the product water of these devices with the aim of reducing their corrosivity, which should be discussed elsewhere.[46,59]

Corrosivity

The effect on the corrosivity properties of water is one of the topics that has been given less attention in relation to membrane water desalination methods. Desalination processes such as RO remove almost all the minerals from the water and produce a stream that lacks calcium and buffering capacity. As a result, due to corrosivity, water supply pipes and structures

Table 1: Results of studies on the quality parameters of water desalinated by reverse osmosis during 2006–2022 compared to maximum permissible level

Measured parameter	MPL*[35]	<MPL	=MPL	>MPL
Free residual chlorine (mg/L)	0.2–0.6	[36-42]	[43]	-
Fluoride (mg/L)	1	[37,38,43-47]	-	-
pH	6.5–8.5	[38,39,48]	[36,37,41-47,49-51]	-
Total hardness (mg/L $CaCO_3$)	500	[38,40,45,49,51-54]	[37,43,46-48,50]	-
Total coliforms (MPN**/100cc)	0	-	[43,45,48,50]	[38,41,42,47,55,56]
Sulfate (mg/L)	250	[40,46,51,54]	[43,45,47]	-
Nitrite (NO_2) (mg/L)	3	-	[40,43,45-48,50,51,54]	-
Nitrate (NO_3) (mg/L)	50	-	[40,43,45-51,54]	-
Electrical conductivity	-	-	[36,38,39,41,42,44,46-50,54]	-
TDS *** (mg/L)	1000	-	[38,41,42,44,46-48,50,54]	-
Alkalinity	-		[37,38,43,50]	

*MPL: Maximum permissible level, **TDS: Total dissolved solid, ***MPN: Most probable number

are damaged, so it needs additional treatment.[60,61] The main factors that affect the chemical stability of water include alkalinity and calcium concentration. Alkalinity is an indicator to determine the buffering capacity of water, and the higher the alkalinity, the greater the ability of water to resist pH changes.[62] A decrease in pH can be caused by disturbing the balance of anions and cations, causing water to become acidic, and as a result, it increases the corrosiveness of water.[63,64]

Coliform bacteria

In the studies conducted by Massoudinejad *et al*.,[55] and Yari *et al*.,[38] Babaei *et al*.[41] and Nourmoradi *et al*.,[42] Ebrahimi *et al*.,[56] and Badeenezhad *et al*.,[47] Coliform bacteria index has been reported in the water samples from the devices under the study. However, it was not reported in the studies conducted by Deghani *et al*.,[45] Alipour *et al*.,[50] Abolli *et al*.,[44] Khodadadi *et al*.,[48] and Aghababaei.[43] Among the reasons for these microbial contamination, not replacing the used membrane on time and the formation of biofilm on the membrane, as well as secondary contamination during the sample storage stage or the culture and storage stage in the incubator are mentioned.[45] Furthermore, the study conducted by Massoudinejad *et al*. showed that there is a significant relationship between the number of heterotrophic colonies and the storage time and duration of operation of the RO membrane.[55]

Sulfate

At high concentrations, sulfate, particularly in the presence of magnesium, can have a laxative effect and cause diarrhea in consumers. This effect is more pronounced in individuals unaccustomed to such water composition.[20] The amount of sulfate in the studies conducted by Miranzadeh and Rabbani,[46] Rajaei *et al*.,[40] Malakootian *et al*.,[51] and Sadigh *et al*.[54] is less than the acceptable level and in the studies of Deghani *et al*.,[45] Aghababaei,[43] and Badeenezhad *et al*.[47] have been reported as acceptable. The lowest amount of sulfate was 3.83 mg/L related to the study of Sadigh *et al*.[54] and the highest amount was 106 mg/L in the study of Badeenezhad *et al*. A large reduction of sulfate in drinking water leads to the loss of water taste to a large extent.[47]

Nitrate and nitrite

Nitrite, one of the nitrogenous compounds, can form carcinogenic nitrosamines in the human body when present above standard limits. Nitrate at elevated levels can be reduced to nitrite in the infant's body, leading to methemoglobinemia, or "blue baby syndrome".[20] Nitrite and nitrate values in the studies conducted by Deghani *et al*.,[45] Naghipour *et al*.,[37] Miranzadeh and Rabbani,[46] Rajaei *et al*.,[40] Aghababaei,[43] Khodadadi *et al*.,[48] Alipour *et al*.,[50] Malakootian *et al*.,[51] Pourjamali *et al*.,[49] Badeenezhad *et al*.,[47] Sadigh *et al*.[54] have been declared as acceptable. The highest levels of nitrate and nitrite were 14.8 and 0.24 mg/l, respectively, related to the studies of Rajaei *et al*. in Arak[40] and Sadigh *et al*. in Ardabil.[54] Furthermore, the lowest amount of nitrate and nitrite was 0.69 and 0 mg/l, respectively, in the studies of Naghipour *et al*. in Rasht[37] and Khodadadi *et al*.[48]

Electrical conductivity and total dissolved solid

Electrical conductivity (EC) indicates the level of dissolved salts in water. It serves as an indirect measure of total dissolved solids (TDSs) and is commonly used to assess salinity or contamination due to industrial discharge. TDSs represent all inorganic salts and minerals dissolved in water.[20] In the studies of Sadigh *et al*.,[54] Babaei *et al*.,[41] Badeenezhad *et al*.,[47] Nourmoradi *et al*.,[42] Gholami-Borujeni *et al*.,[36] Abolli *et al*.,[44] Pourjamali *et al*.,[49] Alipour *et al*.,[50] Khodadadi *et al*.,[48] and Yari *et al*.[38,39] , the levels of TDS and EC were reported to be within acceptable limits. Furthermore, the amount of TDSs in the study conducted by Miranzadeh and Rabbani *et al*. in Kashan[46] was declared acceptable.

Clogging

The clogging of the membranes due to the deposition of solid materials reduces the efficiency and desalination water output. It also includes an increase in head loss and a decrease in service time.[65,66] The main types of deposits on RO membranes include mineral sediments, organic material deposits, suspended and colloidal particles, biological deposits, accumulation of microorganisms, and biofilm formation.[67] The first three types of fouling can be largely reduced through pretreatment of the incoming water, but biofouling cannot be reduced by pretreatment alone[68] because the fouled microbial cells can grow, multiply, and migrate. Even if 99.99% of all bacteria are removed by pretreatment (e.g. with the help of microfiltration or disinfection), a small number of remaining cells enter the system, adhere to surfaces, and multiply in proportion to the biodegradable material of the incoming solution. Thus, membrane biofouling occurs extensively on RO membranes even after thorough pretreatment of the effluent and the addition of disinfectants such as chlorine.[69]

Conclusion

This study revealed that the levels of EC, TDSs, nitrite, nitrate, and sulfate in all the instances of water desalination by RO were at optimal levels. However, microbial contamination exceeded optimal levels in 55% of the studies. Notably, fluoride and free residual chlorine concentrations in RO-treated water were frequently below optimal thresholds, potentially leading to microbial proliferation due to reduced chlorine levels. Most studies indicated that other chemical parameters fell within the optimal range. It is worthnoting that many studies did not clearly define whether purified water by the desalination device could be directly used as potable water or treated and untreated water must be blended.

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Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Davarkhah Rabbani: Conceptualization, Writing – review and editing; Mohammad Bagher Miranzadeh: Investigation, Writing – review and editing; Rouhullah Dehghani: Supervision, Writing – review and editing; Heshmatollah Moradpour: Investigation, Writing – review and editing; Fatemeh Mohebbi: Writing – original draft, Investigation, Visualization, Saied Karami: Investigation, Writing – review and editing.

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