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Brine removal technology methods, review paper

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Abstract

An estimated 40% to 70% of the total water in desalination technologies is released as brine. In addition to high salinity concentrations, these liquid wastes contain different chemical components depending on the type and method of treatment. This brine causes a change in the marine environment due to its high ability to change the salinity, alkalinity and temperature of sea water, which affects the growth and size of aquatic life and disturbs marine diversity. There are several common methods for disposing of brine. These methods include sewer drainage, evaporation ponds, surface water drainage, deep well injection, and sprinkler irrigation.
Evaporation and discharge methods into seawater are among the least expensive methods and are appropriate if appropriate conditions are available, such as a hot climate and spacious lands. The most efficient but most expensive method is zero liquid discharge. Whatever the method used, the main factor, in addition to the cost, is to reduce the environmental impact so that the discharge of brine waste does not cause a change in the marine environment or groundwater.

Keywords: *Brine, ZLD, Evaporation, Cost, Efficiency*

1. Introduction

With the continued scarcity of water resources suitable for human consumption, the option of desalinating sea water or groundwater has become a good option for many countries in the world that suffer from a shortage of fresh water [1,2]. The prevailing technology in the water desalination system is reverse osmosis technology because of its low cost compared to thermal desalination, but one of the most important negatives that is taken on this technology is the discharge of large quantities of brine, which has a negative impact, especially in closed places with limited options [1,3].
In the reverse osmosis technique, in addition to the desalinated water, large quantities of brine are thrown, which is estimated at 40-70% of the total raw water entering the plant [4, 5]. The amount of brine released depends on the quality of the raw water, as well as the effectiveness of the equipment used. If the brine solution is not disposed of properly, it has undesirable effects on the soil and the movement of salinity into waterways and underground stores [6]. Therefore, the main challenge for using reverse osmosis technology lies in how to dispose of the salt water or find a way to recover it to avoid unwanted effects on the environment [7].
The behavior of salt water lies in two main issues: cost and environmental protection. Cost is the key element in selecting a treatment technology, with the cost value ranging from 5% to 33% of the total desalination cost, which mostly depends on the quality of raw water and the quantity and characteristics of brine disposal [7]. This study includes a review of the common methods for the disposal of brine.

2. Brine characteristics

The brine solution is the liquid waste leaving the water desalination plant as waste containing high concentrations of salts in addition to dissolved minerals [8].
The chemical composition and properties of the solution depend on the quality of the water fed to the desalination plant, the quality of the desalinated water required and the type of processes used to produce the desalinated water. Therefore, the difference in chemical composition and concentrations must be taken into account when choosing the treatment method for the brine [9, 10].
In general, the brine contains the following ingredients [11, 8, 3]:

1. High concentrations of salts, during pretreatment stage.

2. High alkalinity Due to the calcium sulfate and calcium carbonate compounds, the alkalinity of the brine is twice that of the treated raw water.
3. There are toxic metals in different proportions as a result of the materials added to the filters during the desalination process.
4. The temperature of the brine is somewhat high as a result of the high temperature of the processes during processing.

Khordagui [12] studied the chemical properties of brine in some RO stations in Gulf countries, and the results were as shown in Table 1.

Table 1: Characteristics of brine water from desalination plants in Gulf region [12].

Parameters	Qidfa II Fujairah seawater	Abu-fintas Doha/Qater seawater	Qidfa 1 Fujairah seawater	BWRO Um Quwain	BWRO Ajman
Temperature. °C	29.1	40-44	32.2	32.4	30.6
TDS, ppm	57,935	52.000	54,795	8,276	10,114
Electrical conductivity	79.6	NR	77.0	11.33	16.49
pH	7.99	8.2	6.97	6.7	7.46
Mg, ppm	2,096	7600-7700	2,025	282	413
Ca, ppm	631	1300-1400	631	173	312
HCOj. ppm	149.5	3900	159	570	561
Total hardness, ppm	207	NR	198	32	NR
Na, ppm	18,293	NR	17,294	2,315	2,756
SO_4, ppm	4,800	3900	4,200	2,175	1.500
Free Cl, ppm	NR	Trace	NR	0.01	NR
Cl, ppm	31,905	29,000	30,487	2,762	4,572
SiO_2, ppm	17.6	NR	1.02	145	23.7

*NR, not reported.

3. Effect of brine disposal on the marine environment

Even with the use of approved methods for discharging brine, its disposal has a negative impact, especially on the marine environment. If appropriate methods of disposal are not applied, one plant is sufficient to leave a negative impact on the environment [13].
The brine has the ability to change the average temperature of sea water, in addition to its high salinity and alkalinity, and its density is estimated to be 1.6-2.1 times that of sea water. All of this can lead to disturbance of marine diversity [14,15].
In particular, one of the most important effects of discharge brine into seawater is the so-called (lethal osmotic shock) due to dehydration that affects fish as well as marine organisms [16, 17]. Another effect is called a decrease in turgor pressure, which leads to the long-term extinction of many marine species [18].

4. Brine removal technology

4.1. Coastal seawater brine disposal

Most desalination plants are located directly on the coast, so the brine discharge is directly ocean outfall. More than 90% of desalination plants dispose of brine in this way. The purpose of downstream discharge is to dilute the brine by mixing naturally under the tidal phenomenon, first artificially through diffusers for the purpose of mixing the brine with seawater. The disadvantage of this method is that sometimes the mixing capacity in watery areas is insufficient for wildlife stability [19, 20].

4.2. Inland brine disposal

When the desalination plants are far from the coast and established inside the lands, these stations resort to different methods for the purpose of disposing of their brine solution. The most common methods are evaporation pond, drainage to deep wells, sprinkler irrigation for salt-tolerant plants, drainage to surface water and the zero liquid discharge technique [21]. For desalination, plants located offshore, the desalination options are as follows:

4.2.1. Evaporation ponds

Evaporation pond technology is used successfully for brine desalination, especially in countries with hot and dry weather, and therefore higher evaporation rates. Evaporation ponds are built on low cost land because they require large areas [22]. It has been observed that small ponds are used in desalination plants in the United States. Whereas in Saudi Arabia, vast lands were used as brine evaporation ponds, which ranged in size from 13.6 to 43.3 hectare [23, 24]. Brine evaporation ponds are modeled after that of septic ponds, with solid salt waste accumulating at the bottom of the pond while the large surface of the pond allows water to evaporate. The salts are periodically disposed of in a suitable landfill.
The following points should be considered when choosing a fumigation technique for brine removal [25, 26, 19]:

1. This technique is suitable for small plants that release water in moderate amounts, and in areas with low cost land.
2. It depends directly on sunlight to complete the evaporation process.
3. Evaporation rates decrease as bottom salt concentrations increase, which requires cleaning at certain intervals.
4. Evaporation ponds are preferably lined, otherwise the brine will seep into the ground water.

4.2.2. Deep well injection

In this technique, the brine produced as waste from the desalination plant is injected into deep layers of groundwater through deep boreholes that penetrate the soil layers. This method is commonly used to dispose of toxic and hazardous industrial and municipal waste. This is the best way to get rid of heavy metals because it prevents their sedimentation before disposal. [27,28]. The most important points to consider before injection are [28]:
1. Ensure that waste is not spilled to other locations.
2. The capacity of the aquifer is compatible with the operational life of the desalination plant.
3. Underground hydraulic isolation is provided from all porous media surrounding the site.
4. Geological assessment of the site and determination of depth before drilling wells.

One of the disadvantages of this method is that it may contribute to groundwater pollution in the absence of a good underground reservoir, as well as soil pollution. Nanayakkara et al. (2020) [29] studied the environmental impacts of using deep well technology to drain brine from low-pressure reverse osmosis processes in the Northern Province of Sri Lanka. Where the results showed high soil acidity as well as low potassium compared to the neighboring unpolluted soil, and this indicates the exchange of hydrogen and potassium ions originally present in the soil with calcium and magnesium ions present in the brine.

4.2.3. Spray irrigation

Irrigation of salt-tolerant plants is a limited and modern technique for brine removal. Where there are plants that are less sensitive to salinity, such as ornamental plants and the mangrove plant, which is grown on the banks of rivers and lakes and is considered a good resistance to salinity [19].
The most important obstacles associated with irrigation with brine are [10, 30, 31]:
1. The natural seasonality of the plant, as the plants may grow for one season only.
2. This technology is applied to small stations only because its efficiency is low.
3. Another alternative technique should be available while using brine irrigation when there is no need for irrigation as mentioned above.
4. The capacity and efficiency of this technique is determined by the climate and irrigation demand, in addition to the plant's tolerance of high salinity concentrations.
5. There may be a negative impact on groundwater under the irrigation areas.
6. There is a risk of contamination of the soil with heavy metals or nitrates that may be part of the brine components.

4.2.4. Zero liquid discharge (ZLD)

This technology was developed by the University of South Carolina [32]. This technology desalinates water without discharging an aqueous solution as desalination waste, i.e. zero liquid discharge (ZLD). This process focuses on producing fresh water and useful salts such as crystalline sodium chloride salt (NaCl). This technology depends in all its steps on electrolysis. In general, zero liquid systems consist of concentration stages and evaporation stages, where the liquid evaporates completely and crystals and salts precipitate [33]. The first essential step is to recover the sodium chloride salt and discard a waste solution containing magnesium hydroxide (MgO_2) and bromine (Br_2). The next step is to crystallize sodium chloride into a salt that can be used industrially, and treat the waste by evaporation and drying [34].

One of the main disadvantages of this method is that it is not economical and very expensive, and the reason for this is due to the high energy requirements for the purpose of operating the equipment. In addition, the purchase of machinery and equipment for this technology is very expensive compared to investment. Therefore, the ZLD technique is impractical if an alternative is available for draining the brine [20, 35] Discharging liquid waste, brine, into bodies of water (ocean, lake, river, etc.) is one of the most common systems for disposing of the brine resulting from the water desalination process due to its low cost compared to other systems [31]. However, this method has a number of limitations, including that the volume of drained water must be less than the volume of surface water so as not to negatively affect the marine environment. Also, when the desalination plant is far from the coast, establishing a drainage pipe is very expensive in terms of construction, maintenance and operation [10].
Table 2 represents a cost comparison between brine disposal methods. It is clear that the lowest cost is the direct discharge method, provided that it does not cause harm to the marine environment [36].

Table 2: Summary of comparison between brine removal methods [36]

Method	Principle	Environmental challenges	Cost (US \$/m^3$_{brine\ rejected}$)
Evaporation pond	The salt water is collected in ponds and the brine is then evaporated. The resulting salts are then collected.	Groundwater pollution and soil salinization	3.28-10.04
Sewer discharge	The salty waste generated by desalination plants is discharged into the sewage system	Inhibition of bacterial growth in the waste water treatment plant	0.32-0.66
Surface water discharge	The brine is released into the surface water	Marine environment pollution	0.05-0.30
Land application	Using salt water to irrigate herbs and crops that tolerate high salinity	Soil salinization	0.74-1.95
Deep-well injection	Brine is injected into porous subsurface rock formations	Groundwater pollution and soil salinization	0.54-2.65

5. Conclusion

Desalination of seawater or groundwater represents a good option for many countries in the world that suffer from a shortage of fresh water. The prevailing technology in the water desalination system is reverse osmosis due to its low cost compared to thermal desalination, but one of the most important drawbacks that criticizes this technology is the discharge of large quantities of salt water, which has a negative impact. Especially in closed spaces with limited options. Brine treatment lies in two main points: cost and environmental protection. The characteristics and composition of the brine solution must be known to choose the appropriate treatment method, as the chemical composition depends on the quality of the water that feeds the desalination plant, the quality of the desalinated water required, and the type of processes used to produce desalinated water. There are several common methods for disposing of brine. These methods include sewer drainage, evaporation ponds, surface water drainage, deep well injection, and sprinkler irrigation. In countries with hot climates and high evaporation rates, evaporation ponds can be used provided low-cost land is available. One of the methods used is injecting brine into deep layers under groundwater, which is called well injection. In this method, it is taken into account that the concentrated brine solution does not leak into other areas, and the water-bearing layer must be isolated hydraulically from other media. The method that is least harmful to the environment is irrigation with concentrated saline solutions for plants that tolerate high salinity and are less sensitive to salinity. The ZLDR technique is the most efficient of the methods, but the most expensive, as it includes concentration stages (membrane techniques) and evaporation and crystallization stages (thermal techniques). This technology may have an indirect impact on the environment due to its high energy consumption. The last and least expensive method is direct discharge into bodies of water, sea or ocean, when establishing desalination plants near the coast. However, it may cause harm to the marine environment when large amounts of liquid brine are released.

Even with the use of approved methods for draining salt water, its disposal has a negative impact, especially on the marine environment. If appropriate disposal methods are not applied, one factory is enough to leave a negative impact on the environment.

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