Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/56/20240670

Technical analysis of seawater desalination

Siyuan Zhu

Suzhou Science & Technology Town Foreign Language School, Jiangsu Province, China, 215163

3477284541@qq.com

Abstract. As the population grows and the economy thrives. The amount of edible water has decreased, and this phenomenon is raising awareness about water supply. Dumping salt into a bucket of water may seem like no big deal, but reversing the process is a lot more complicated than people might think. Seawater desalination technology is also a hot topic of research. There are two major techniques for desalting. One is distillation, and the other is reverse osmosis filtration. This essay mainly discusses how the two techniques work and what benefits human beings can possibly obtain from the future development of such technology based on existing literature and statistical data, namely prosperity. The result shows that the reverse osmosis process uses less energy in comparison to thermal distillation. However, desalination is not as easy as we expected. Regarding energy consumption and cost efficiency, scientists have to maintain high productivity while reducing the impact on the environment.

Keywords: Desalination, Distillation, Reverse Osmosis, Filtration, Desalting, Sea Water.

1. Introduction

Desalination, also called desalting, is the removal of dissolved salts from seawater, whether through distillation or membrane filtration. It is energy- and capital-intensive, making it unfeasible in many dry areas. According to the WHO, the edible limit of salinity in water is 500 ppm, somehow, the salinity can be up to 9,000 ppm, and sea water has salinity of 35,010–45,010ppm. For water consumption worldwide, about 70% is used by agriculture, 20% by industry, and only 10% is used for household needs [1]. Dubai is one of the most advanced and rich cities in the Middle East. Although it is a coastal city and seems to have an unlimited water supply, this is not the case, as mentioned. Dubai was quite dependent to the underground water reservoir before the invention of desalination, because the high ppm of sea water making it not suitable for drinking and domestic usage. Nowadays, Dubai has enough funding for both thermal distillation and reverse osmosis filtration to provide adequate amount of pure water, so that the lack of water has become no big deal any more. When it comes to the whole picture instead of concentrating on just few aspects of two manners of desalination, it is completely a different picture. Scientists have to consider not only the energy and cost, but also the life expectancy of semi-permeable membranes and disposal of the concentrates. Those questions that have yet been solved will be addressed in the near future by researchers, and when the major problems are eradicated, it is believed to have a surge in HDI (Human development index). The main aim of this essay is to comprehend the two ways of desalination, and clarify the advantages and the disadvantages of thermal distillation and reverse osmosis. The research will bring prosperity mainly to the drought area, and proposing ideas to the general public.

2. Background introduction

There is a lot of research on seawater desalination in the academic community. For example, Xie Lixin et al. introduced various methods and principles of seawater desalination, summarized the research status of seawater desalination technology, and analyzed and compared the application status of seawater desalination technology [2]. Yin Jianhua et al. compared the investment, operating costs, and technical performance of several major seawater desalination technologies in their research. Finally, analyzed the development trend of low-temperature multi effect seawater desalination technology [3]. Regarding the previous research on desalination, two techniques have been well developed. To address the increasing fresh water demand due to population growth, the first desalination plant was built in the 1960s. Two objectives are set and pursued in order to optimise efficiency and minimise cost, as energy costs are increasing all the time. One is promoting efficiency, and the other is investigating new ways. The concept of desalination was first introduced by the Royal Navy; the aim was to facilitate autonomy with less pure water stored on the ship. The first desalination unit was invented by G. and J. Weir in 1885 in Glasgow (Scotland), and this technique continuously developed, ultimately entering the horizon of civilians. Additionally, RO developed slower compared to thermal distillation, but it is still applied in many fields due to its energy-saving properties [4]. To sum up, in the 18th century, desalination was mainly done through steam engines in the military sector. In the 20th century, desalination turned out to be a technology to satisfy civil purposes. Reverse osmosis has become the mainstream for contemporary desalination.

Although 97% of the water resource worldwide is salty and less than 1% is edible for humans, the supply of water is not a problem resulting from the water cycle that enables the circulation of water [5]. For instance, polluted water and even urine can be purified through evaporation by the sun and separated by rain. The major problem faced by many people is the unequal distribution of pure water. This has led to extreme phenomena, whether having abundant water like in Venice or just no water in many drought areas. There are many coastal cities in the world where pure water is not as abundant as it seems to be because salty water cannot be directly drunk by humans. Before the invention of desalination, the purity of the water was not adequate to sustain civil use at all [6].

3. Thermal distillation

3.1. Definition

One of the oldest processes for treating saltwater and brackish water to make it potable is thermal desalination, often known as distillation. The concepts of boiling, evaporation, and condensation serve as its foundation. Water is heated until the evaporation condition is reached. While the vapour is condensed to create fresh water, the salt is left behind. Modern steam generators, waste heat boilers, or the removal of back-pressure steam from turbines in power plants are used to generate the necessary thermal energy [7].

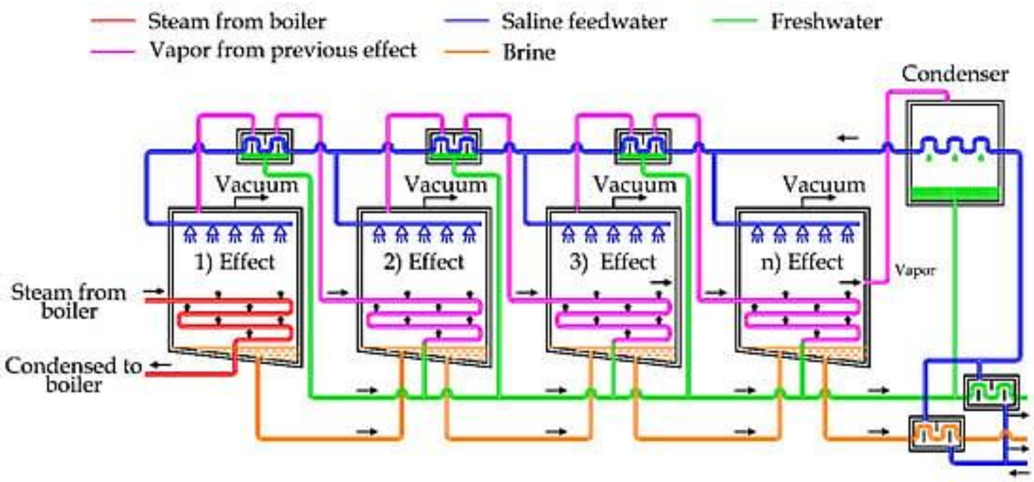

Figure 1. Thermal distillation [7].

With consideration for the geometry of the heat exchangers or the relative flow direction of the brine and vapor, MED units may be set up in a variety of ways. To maximize heat recovery, the effects can be put together in one line or two parallel lines, each operating at a different pressure. MED can be categorized as Low Temperature (below 90 °C) or High Temperature (above 90 °C) according on the Top Brine Temperature (TBT). (Figure 1)

3.2. Advantages and disadvantages of thermal distillation process

- The input fluid's purity is less crucial than it is in the RO process technique. As a result, distillation's pre-treatment and running expenses are cheap.
- In comparison to the MSF plant, distillation uses less energy.
- Distillation plants have a better performance efficiency than MSF plants, thus this method is more effective versus the MSF process in terms of transfer of the heat and the price of producing pure water [7].

4. Reverse-osmosis filtration (RO)

Reverse-osmosis filtration (RO), which is a process that applies pressure to a membrane that only allows water molecules to pass to produce pure water, requires only 25% more energy than the thermodynamic limit.

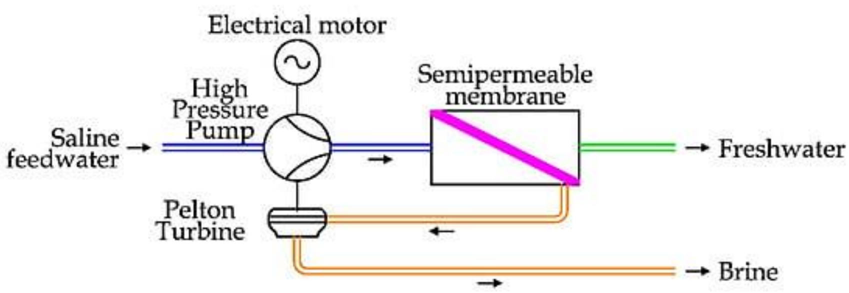

Figure 2. Reverse-osmosis filtration(RO) [7].

This technology was developed in the 1980s and involves installing a water turbine (Pelton) to transmit energy from the main HPP to the brine flow. A battery-powered motor is employed to meet the pump's energy requirements. The primary HPP increases the pressure over the whole saline feedwater flow (Figure 2).

DOI: 10.54254/2755-2721/56/20240670

The RO has pipes to conduct seawater from the ocean, but most of the water source will be obtained from a pre-treatment plant, which will be illustrated in the next paragraph. Seawater, propelled by high pressure, is forced to pass through a semi-permeable membrane. Then, pure water that is conducted by another pipe is transmitted to the pro-treatment plant for adding minerals. The RO plant membrane generally uses less energy than the distillation process. To sum up, the water source goes through the stages of intake, pre-treatment, and pro-treatment [8]. Seawater sources account for 63% of the total desalination capacity in the globe. Thermal activities create 61% of this water. In the majority of coastal nations, thermal filtration is utilized to desalinate seawater [9]. The use of RO systems is the primary option for numerous developed and emerging nations that are now beginning to think about saltwater desalination, despite being the second-most significant seawater treatment method globally.

Pre-treatment and pro-treatment process are indispensable for RO filtration, because we have to eradicate the harmful substances to protect the RO membranes. Sea water has a wide range of constituents that can damage the membranes, especially those made of cellulose acetate, which are designed to work below 35 °C and have a strict PH tolerance. Even with the existence of a pretreatment process, the life expectancy of the membranes is one to two years before replacement is needed. Additionally, the pipes are prone to retaining residue, which requires constant maintenance and adds cost to the production. For the pro-treatment process, it actually includes two processes: one for the pure water and the other for the concentrated salt water. For pure water, the major transformation is adding minerals and nutrients to ensure the water is not completely pure. Drinking pure water in the long term will destroy the balance between acid and base because the PH value of pure water is 5.0 to 7.0, which is acidic. Besides, drinking pure water will also lead to a lack of nutrients, specifically minerals. The pro-treatment process will be conducted in a virus- and bacteria-free condition on behalf of human health. Apart from the addition of minerals, the disposal of waste also raises attention because never before has such a large amount of concentrated water been discarded into the ocean. There are three ways of disposing of the concentrated water, but of course the producers cannot directly inject the concentrated water into the ocean as it will eventually bottom out and threaten countless marine organisms. The first way of disposing is through a diffuser. Producers use the theory of diffusion, which is defined as the movement of molecules from a higher concentration to a lower concentration until equilibrium is reached.

The second is to dispose of the concentrated water through combined pipes; one transfers the concentrated water and the other transfers pure water. The salinity of the solvent (concentrated water and pure water) can be adjusted with the salinity of the ocean through different cross-sectional areas and flow rates. The third way of disposal is direct injection of the brine into the soil. There are many sayings about the more environmentally friendly usage of the final products of desalination, which are pure water and brine, respectively. Pure water is not edible for humans but is probably suitable in some other fields, namely some chemical reactions that need pure water as the reactant. However, if we make good use of the brine to extract the minerals that we want, brine disposal and water processing can be solved simultaneously when a large proportion of minerals are extracted and only a little is retained according to the water salinity standard. The fact is that it costs a lot and ultimately raises the price of the final minerals obtained from brine, which results in a depletion of demand as there are also other substitutes. Basically, without demand, there is no future, and it is not feasible at all.

5. Discussion

Energy consumption: In terms of the direct energy consumption of desalination, the reverse osmosis method is significantly better than the single-purpose distillation method, but not significantly better than the dual-purpose distillation method. Because the reverse osmosis membrane has a short life, the cost of replacing the membrane is high, and the membrane itself reflects energy consumption. For the distillation method, the direct energy consumption of the process varies greatly from region to region, and a technical and economic comparison needs to be determined.

Total cost of seawater desalination: Due to the life of the membrane and the limitation of the membrane device, the membrane method is still in a disadvantageous position in the large-scale treatment of seawater. Because the water production cost of reverse osmosis is adversely affected by membrane life and device scale that exceeds the benefits of low energy consumption, it is generally believed that when the capacity of the desalination plant exceeds 6000t of fresh water per day, the dual-purpose distillation method is more economical than the reverse osmosis method.

Pretreatment aspects of seawater: The seawater entering the distillation unit does not need to be pretreated; only a seawater filter can be installed. The seawater entering the seawater reverse osmosis device needs to be pretreated with flocculation, clarification, filtration, and chlorination. Due to the low utilisation rate of reverse osmosis water, the pretreatment system is large, the investment is high, and the floor space is large.

Other supporting facilities: The distillation method requires start-up steam, so the capacity of the start-up boiler should be considered to meet the needs of the desalination facility, and the make-up water for the start-up boiler should consider a separate water treatment facility for start-up.

In addition, since there is no backup equipment, freshwater sources are required as backup water sources for industrial water. The membrane method does not need to start steam; when the unit starts, the feed water temperature is low, which has a slight impact on the output of the desalination equipment, does not affect the starting water of the unit, and does not need to consider additional starting facilities. The desalination equipment should consider that there is enough spare output to meet the water needs of the equipment during maintenance [7]. In many places where solar resources are plentiful, socioeconomic growth is constrained by a lack of potable water. Therefore, using solar energy for water desalination in countries in the Middle East and Africa that have abundant solar energy is a promising idea for meeting water demand and would undoubtedly help both solve the problem of water scarcity and reduce carbon dioxide emissions through an eco-friendly process [10].

6. Conclusion

Desalination is a technology that can facilitate our lives and boost our economy. It has brought basic necessities to dry areas and saved millions of lives. The major problems facing desalination have been solved, but we still cannot ignore the cost efficiency of every step of desalination. The extraction of minerals from brine after desalting is worth researching and developing as it solves the problem from two perspectives, but cost hinders this technology, so reducing the cost and facilitating efficiency become the goals. Desalination of brackish and seawater is proving to be a dependable supply of fresh water and is helping to address the issues of water scarcity around the world. Desalination using renewable energy sources becomes an acceptable and technically developed option for the developing and stressful energy situation as well as a long-term remedy for water scarcity. Due to the sharp rise in fossil fuel prices and the negative effects of burning fossil fuels, such as environmental pollution and climate change, it is urgent to pair desalination facilities with clean, environmentally friendly energy sources.

Acknowledgment

For one thing, I would like to thank my teachers for all that they have taught me in every phase of this thesis. In addition, for your encouragement and support, I would like to thank all my friends and parents. I could not have completed my thesis without all the invaluable advice and magnificent kindness they gave me.

References

[1] Kalogirou, S. A. (2005). Seawater desalination using renewable energy sources. Progress in energy and combustion science, 31(3), 242-281.
[2] Xie Lixin, Li Bingli, & Wang Shichang. (2003). The current status of seawater desalination technology and a review of various desalination methods Chemical Industry and Engineering Progress, 22 (10), 4.
[3] Yin Jianhua, Lv Qingchun,&Ruan Guoling. (2002). Low temperature multi effect distillation seawater desalination technology. Marine Technology, 21(4), 5.

DOI: 10.54254/2755-2721/56/20240670

[4] Curto, D., Franzitta, V., & Guercio, A. (2021). A review of the water desalination technologies. Applied Sciences, 11(2), 670.
[5] Cao, X., Huang, X., Liang, P., Xiao, K., Zhou, Y., Zhang, X., & Logan, B. E. (2009). A new method for water desalination using microbial desalination cells. Environmental science & technology, 43(18), 7148-7152.
[6] Brogioli, D., La Mantia, F., & Yip, N. Y. (2018). Thermodynamic analysis and energy efficiency of thermal desalination processes. Desalination, 428, 29-39.
[7] Schiffler, M. (2004). Perspectives and challenges for desalination in the 21st century. Desalination, 165, 1-9.
[8] Paulo Baker. (2019). How to Filter Sea Water? Process and Steps Explained https://dashappliances.com/how-to-filter-sea-water/
[9] Lattemann, S., Kennedy, M. D., Schippers, J. C., & Amy, G. (2010). Global desalination situation. Sustainability Science and Engineering, 2, 7-39.
[10] Shatat, M., & Riffat, S. B. (2014). Water desalination technologies utilizing conventional and renewable energy sources. International Journal of Low-Carbon Technologies, 9(1), 1-19.