Desalination of Seawater Using Reverse Osmosis Method

Talukder, Rituparna
Lamar University

Pratoy Kumar Proshad
Daffodil International University

https://doi.org/10.5109/7157961

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 9, pp.117-122, 2023-10-19. 九州大学大学院総合理工学府
バージョン：

Desalination of Seawater Using Reverse Osmosis Method

Rituparna Talukder[1*], Pratoy Kumar Proshad[2]

[1]Lamar University, Texas
[2]Daffodil International University, Dhaka
*Corresponding author email: rtalukder@lamar.edu

Abstract: *Water is the basis for both the beginning and continuation of humanity. The emergence of saltwater desalination as a workable solution is a result of the depletion of freshwater supplies and the rising global demand for clean drinking water. The southern region of Bangladesh is suffering from a severe lack of drinkable water, as the coastline areas have saline water that cannot be consumed. As a result, employing our technology to clean surface water rather than relying on limited subsurface water is a more efficient alternative. Reverse osmosis, the most used method of desalination, removes salts and minerals from saltwater by forcing it through a membrane under high pressure. Similar to how pure water is important for economic development, energy is a crucial component of social and industrial progress so, the energy required for desalination need to be produced using two environment friendly ways as mention in this paper.*

Keywords: Desalination; Reverse-Osmosis; Renewable energy; Solar energy; Windmills.

1. INTRODUCTION

Coastal places, secluded areas, and desert regions all lack access to sources of useable water and energy. But these are essential for the social and economic well-being of the modern world. Many new problems gravely jeopardize governments' capacity to supply clean, cheap power and water.

The only essentially endless sources of water are the oceans. The major problem with them, though, is their high saltiness. Total dissolved salts (TDS), which are used to measure salinity, range from 35,000 to 45,000 ppm in seawater, which has a greater salinity. The World Health Organization (WHO) states that the acceptable limit for salinity in water is 500 parts per million (ppm), with a maximum of 1000 ppm under specified situations, however ocean water has a much higher salinity [1]. Seawater desalination would therefore be a solution to the issue. It would be preferable to desalinate this water to address the issue of water scarcity. Both the treatment and delivery of water depend on readily available, affordable electricity. Renewable energy sources can be used to generate the necessary energy. It comprises largely renewable sources like sunlight, wind, river currents, and geothermal heat.

Already, some nations have undertaken projects to desalinate seawater using renewable energy sources, reducing their reliance on fossil fuels. A PV-RO brackish water desalination plant was set up in Riyadh, Saudi Arabia. It is attached to a solar still that generates 5 m3/day of product. The blowdown from the RO unit (10 m3/day) serves as the feed water for the solar still [2]. On the Island of the County of Split and in Dalmatia, there is also a RO system powered by a wind farm [3]. Utilizing hybrid wind-solar systems to power a desalination unit is a potential alternative due to the complementing qualities of wind and solar resources, as the wind is typically stronger when the sun is not out and vice versa [4].

The biggest contributor to the global lack of fresh water is now recognized to be human-caused contamination of natural water sources. Uneven distribution is a further issue. For instance, only 1% of the world's population resides in Canada, yet boasts a tenth of the planet's freshwater surface. For instance, only 1% of the world's population resides in Canada, yet boasts a tenth of the planet's freshwater surface. Only 10% of the water utilized globally is used for household requirements; the majority, 70%, is used for agricultural, 20% for industry, and the remaining 5% is used for industry. For all this, the desalination method is a must to fulfil this huge freshwater requirement. Desalination process needs a lot of energy, to cope up with this problem, the renewable energy will be the perfect solution.

2. METHODS AND PROCEDURE

Desalination plants and renewable energies are two different technologies but using those technologies can create a self-sufficient and eco-friendly system that can contribute to our nature and make desalination process easier. Here we can see how those systems play a vital role in this project. The followings are the methods and concepts considered for such a desalination plant:

2.1 Desalination unit

Desalination can be achieved by using a number of techniques [5]. This may be classified into the following categories:

1. Phase-change or thermal process and
2. Membrane or single -phase process.

To prevent scaling, foaming, corrosion, biological growth, and fouling, all operations necessitate a chemical pre-treatment of raw seawater. They also necessitate a chemical post-treatment. Reverse osmosis (RO) was chosen for this plant because, among other things, it can remove lead, pesticides, fluoride, medicines, arsenic, and other pollutants from water. Additionally, a RO system can also remove chlorine using a carbon filter, improving the flavor, smell, and appearance of the water while being simple to use with other facilities.

2.2 Reverse Osmosis:

Reverse osmosis relies on the properties of semipermeable membranes, which, when used to separate water from a salt solution, allow fresh water to enter into the brine compartment under the influence of osmotic pressure. If a pressure larger than this value is given to the salty solution, fresh water will migrate from the brine into the water compartment.

The pumping of feed water at a pressure greater than the osmotic pressure is the only energy need, according to theory. In practice, greater pressures—typically between 50 and 80 atm—are necessary to let sufficient water to pass through a unit area of membrane. The number of salts in the raw water and the condition of the membrane have an impact on a RO system's output. The membranes, which function as very small filters, are extremely susceptible to fouling, both biological and non-biological. Careful pre-treatment of the feed is required before it is permitted to contact the membrane surface in order to prevent fouling.

2.3 Principles of Reverse Osmosis:

The reverse osmosis (RO) technique for desalinating saltwater depends on the basic osmotic laws and the application of external pressure to force the separation of water molecules from dissolved salts and contaminants. This section clarifies the fundamental ideas behind reverse osmosis and offers insights into the underlying mechanics that make RO an effective and commonly used method for desalinating saltwater.

A. Osmosis and Osmotic Pressure:

Osmosis is a natural phenomenon that happens when two solutions with various solute concentrations are separated by a semi-permeable membrane. The semi-permeable membrane serves as a barrier in the process of desalinating saltwater, allowing only water molecules to pass through while preventing the passage of dissolved salts. To equalize the solute concentration on both sides, water must be moved from an area with lower solute concentration (the "dilute side") to a region with higher solute concentration (the "concentrated side"). The osmotic pressure, which is the pressure required to stop more water flow across the membrane, drives this movement of water until equilibrium is established.

B. Reverse Osmosis:

As the name implies, the osmosis process is reversed in reverse osmosis. To force water molecules through the semi-permeable membrane from the concentrated side to the dilute side, external pressure larger than the osmotic pressure on the concentrated side must be applied. The outcome is the generation of freshwater on the dilute side, known as permeate, and a concentrated stream of seawater on the concentrated side, known as brine or reject. By doing this, the dissolved salts and contaminants are left behind. The efficient removal of salts from saltwater is made possible by the selective penetration of water across the membrane while rejecting solutes.

C. Membrane Selection and Characteristics:

The type of membranes employed in the procedure determines how well reverse osmosis works. The pore diameters and surface properties of various membrane types, including cellulose acetate and thin-film composite (TFC) membranes, differ. To accomplish the desired water flux and salt rejection, the selection of the proper membranes is essential. Desalination efficiency and water production rate are typically traded off as a result of high salt rejection and decreased water flux.

D. Energy Requirements:

In order to pressurize saltwater and overcome the osmotic pressure, reverse osmosis needs an additional energy source. Seawater desalination involves significant energy consumption, and how effectively that energy is used directly affects the process' ultimate cost. The development of energy-efficient systems, including energy recovery devices and improved membrane materials, as a result of advancements in RO technology helps reduce energy consumption and increase the sustainability of desalination processes.

E. Concentrate Disposal:

The proper disposal of the concentrated brine stream, also known as concentrate, is one of the difficulties with reverse osmosis desalination. The concentrate is normally released back into the ocean; therefore, it needs to be managed properly to minimize any potential environmental effects. Sustainable brine disposal techniques are being developed through research and innovation, including brine mixing and concentrate resource recovery. Understanding the fundamentals of reverse osmosis lays the groundwork for further investigation into the salination of seawater using the RO method's essential elements, performance variables, and improvements. Researchers and professionals may build effective and environmentally responsible reverse osmosis desalination systems to address the problems associated with worldwide water scarcity by understanding these principles.

2.4 Energy generation unit

Renewable energy sources can be used to produce energy [4]. Solar, wind, hydro, geothermal, and biomass energy are the top five sources of renewable energy [6]. Solar energy can be employed in this plant with RO systems as a prime mover source to power the pumps [7] or with photovoltaic panels to generate electricity directly [8].

Wind energy can also be used as a main source of energy. Due to the high cost per unit of electricity produced by solar cells, photovoltaic power plants incorporate energy-recovery turbines.

2.5 Solar Energy:

The electromagnetic radiation from the sun creates solar energy, which is a sort of renewable and unrestricted energy. It generates power and heat in an entirely sustainable and cost-free manner. Mirrors and panels, like photovoltaic cells, may collect solar energy. It consists of a collection of cells that use the so-called "photoelectric effect," in which specific materials may take in photons and release electrons to produce an electrical current, to directly convert solar light into electricity.

Since PV solar panels don't emit heat, they can't be utilized to store solar energy, but their surplus output can be sent into the grid for general consumption. The best approach to produce all of your own energy is through solar energy.

2.6 Solar Energy Utilization:

The integration of solar energy with reverse osmosis (RO) desalination offers a promising pathway towards sustainable water solutions in water-scarce regions. This section explores the fundamental principles of solar energy utilization in desalination processes, focusing on solar photovoltaic (PV) and solar thermal technologies as potential energy sources for powering RO desalination.

A. Solar Energy Capture and Conversion:

Solar energy capture is the process of harnessing sunlight and converting it into usable energy for desalination. Solar PV technology utilizes semiconductor materials to directly convert sunlight into electricity through the photovoltaic effect. Solar thermal technology, on the other hand, concentrates solar radiation to generate heat for various applications, including desalination.

B. Solar-Powered Reverse Osmosis Desalination:

Solar-powered RO desalination combines the principles of reverse osmosis with renewable solar energy to produce fresh water from seawater. Solar PV arrays or solar thermal collectors serve as the primary energy source to power the high-pressure pumps required for the RO process. The generated electricity or heat can be used directly or stored in batteries or thermal storage systems for continuous operation during periods of low or no sunlight.

C. Design and Optimization of Solar-Powered RO Systems:

The design and optimization of solar-powered RO systems involve various considerations to maximize energy efficiency and desalination performance. Proper system sizing, location selection, and orientation of solar panels are critical to ensuring optimal solar energy capture. Additionally, advanced control algorithms and tracking systems can enhance energy yield and adapt to varying solar irradiation levels.

D. Solar Energy Storage:

Solar energy storage plays a crucial role in solar-powered RO desalination. Since solar energy availability varies with weather and daylight conditions, energy storage solutions such as batteries or thermal storage systems are essential for maintaining continuous operation and meeting water demand during non-sunlight hours.

E. Environmental Sustainability:

The utilization of solar energy in desalination offers significant environmental benefits compared to traditional fossil fuel-based methods. Solar-powered RO systems reduce greenhouse gas emissions and dependence on finite fossil fuels, contributing to environmental sustainability and mitigating climate change impacts.

F. Economic Viability:

Economic considerations play a pivotal role in the adoption of solar-powered RO desalination. The costs associated with solar PV or solar thermal technology, system installation, operation, and maintenance are evaluated against the economic savings achieved through reduced energy consumption and long-term operational efficiency.

G. Integration with Water Infrastructure:

The integration of solar-powered RO desalination with existing water infrastructure is essential for efficient water distribution and storage. Smart grid technologies and advanced control systems enable real-time monitoring and optimization of water supply, enhancing overall system performance.

H. Technological Innovations:

Ongoing research and technological innovations focus on improving solar energy capture and conversion efficiency, advancing materials, and exploring novel system designs for enhanced desalination performance and economic viability.

I. Case Studies and Performance Assessment:

Analysis of real-world case studies of solar-powered RO desalination plants in different geographical locations provides insights into their performance under varying solar conditions, water demand, and cost-effectiveness.

J. Challenges and Future Directions:

Despite the promising advantages, solar-powered RO desalination faces challenges related to intermittency, system costs, and scalability. The paper explores potential solutions and identifies future research directions to overcome these challenges and promote widespread adoption. In conclusion, understanding the principles of solar energy utilization in reverse osmosis desalination is crucial for developing efficient and sustainable water solutions. The integration of solar PV and solar thermal technologies holds great promise in transforming seawater into a valuable freshwater resource, providing environmental resilience and energy independence in regions facing water scarcity.

2.7 Wind Power:

Wind power is an attractive alternative for seawater desalination, especially in coastal places where wind energy resources are plentiful. such as a windmill. Due to the fact that wind and solar time profiles do not always coincide for some places, the concept of using hybrid wind-solar systems for desalination was developed. It should be clear that modeling utilizing traditional metrological data is necessary to conduct a thorough analysis of the possibility of building such a hybrid system.

A few small-scale experimental pilot plants of this type are reported in the literature, it should be emphasized. The maximum potential aerodynamic efficiency for converting wind to mechanical power in a wind turbine is 59%.

In actuality, the drive to reduce blade costs often results in the building of wind turbines with peak efficiencies only a little below the ideal, let's say 45%. Due to the requirement to shut down the wind turbine in low or strong winds and to limit the output once the rated level is reached, average efficiency is below 45% year-round. A mature technology for power generation, wind turbines are commercially available in a variety of nominal power ranges [9].

2.8 Wind Power integration:

The integration of wind power with reverse osmosis (RO) desalination represents a promising and sustainable solution to address water scarcity challenges in regions with abundant wind resources. This section delves into the fundamental principles of wind energy utilization for powering RO desalination systems, exploring the mechanisms of wind energy capture and conversion and the applicability of wind turbine technologies.

A. Wind Energy Capture and Conversion:

Wind energy is harnessed by capturing the kinetic energy of moving air masses through wind turbines. The aerodynamic design of wind turbine blades facilitates the conversion of wind energy into mechanical energy, which drives an electricity generator. The resulting electrical energy can be used to power various applications, including the operation of RO desalination plants.

B. Wind Turbine Technologies:

Various wind turbine technologies are available, ranging from horizontal-axis wind turbines (HAWTs) to vertical-axis wind turbines (VAWTs). HAWTs are widely deployed and feature a horizontal rotor shaft parallel to the ground. VAWTs, on the other hand, have a vertical rotor shaft, making them suitable for urban and distributed settings. The choice of wind turbine technology depends on factors such as wind regime, site characteristics, and system requirements for desalination.

C. Wind-Powered Reverse Osmosis Desalination:

The integration of wind power with RO desalination involves the use of wind turbines as a primary or supplementary energy source. The electrical energy generated by wind turbines is directed to power high-pressure pumps that drive the RO process. Wind-powered RO systems can operate in grid-connected or standalone configurations, making them suitable for remote and off-grid locations.

Wind Energy Resource Assessment: To optimize the design of wind-powered RO systems, an accurate assessment of wind energy resources is crucial. Wind resource assessment involves analyzing historical wind speed data, wind direction, and turbulence levels at the proposed site. Advanced modeling techniques, such as computational fluid dynamics (CFD) simulations and meteorological data analysis, aid in determining the wind energy potential for desalination applications.

D. Wind Power Variability and Grid Integration:

One of the key challenges of wind-powered RO desalination is the inherent variability of wind resources. Wind speeds can fluctuate on hourly, daily, and seasonal timescales, impacting the stability of the electricity supply. To ensure continuous operation, wind-powered systems may require energy storage solutions, demand-side management, or grid integration to balance supply and demand.

E. Energy Storage Solutions:

Energy storage technologies, such as batteries or mechanical storage systems, play a vital role in enhancing the reliability and stability of wind-powered RO systems. They enable the storage of excess energy during periods of high wind speeds and its release during low wind conditions or non-sunlight hours for continuous desalination operation.

2.9 Key component of desalination plant

A. Intake plant: a building used to collect and pump untreated water into the desalination chamber.

B. Pre-treatment: Using a filtration system to remove suspended materials to prevent fouling and adding chemicals to the raw water to prepare it for future processing.

C. The primary method for extracting dissolved salts and minerals is the reverse osmosis chamber.

D. Post-treatment: Adding the necessary minerals and chemicals to keep the water's quality and pH level in check.

E. Outlet: a location where treated water is kept for future use.

2.10Plant description

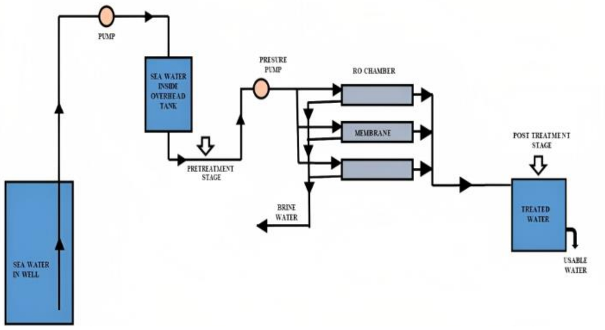

Fig. 1. Desalination Plant Diagram.

Here in the Fig. 1, there is a dug well where the sea water gets stored and from there, the water gets transferred in overhead tank using a pump. From the overhead tank a pump pushes the water in the RO chamber with the required pressure. The membranes of RO chamber extract the brine from the water and release it in a brine storage and the fresh water gets stored in a different reserved tank.

On the coast, vertical bore holes are used to construct dug wells. The sandy soil serves as a natural prefilter, improving the quality of the feed water. Additionally, impingement and entrainment issues are avoided. However, the water supply from drilled wells is usually insufficient for huge plants. Multiple dug well construction might be the answer to this issue.

An overhead tank is constructed due to collect the water from dug wells. The tank will collect water from it by a pump. The collected water will be treated with chemicals or Nano filters. Pre-treatment is mandatory to avoid fouling, minimize particulate. prevent scaling and for lowering operating pressure.

The overhead tank is connected to the RO Compartment. Here a pump is used to provide necessary pressure to occur osmosis processes properly. The RO chamber has two output lines. One carries the fresh water to the next step and other carries the brine water out of it. If the water is going to dispose into the sea it is needed to take care of its concentration to maintain balance under sea.

The brine water is like a by-product here. By using a turbine, we can recover energy from brine water and the water can also be used for industrial purposes such as sodium and salt production. These are optional here.

The fresh water is stored in this reservoir. The quality check will occur in this step. As RO removes minerals from water, we need to add necessary amount of minerals this time. However, this is the whole procedure complete the process.

The fresh water can be carried and distributed from this reservoir. This is also mentionable here, for carrying water and generating water pressure by using pump electric power is needed. So, the PV solar plant and wind turbine provided the needed energy supply here .as the weather condition may vary time to time, the both type of renewable energy supply is needed carry out water supply. Energy can be stored for emergency uses and also the excess energy can be supplied to the power grid for other purposes.

2.11Requirements to build a sustainable desalination plant

A. Plant capacity varies depending on demand, from little to huge.

B. Total number of stages based on the allocated funds.

C. The final water quality is 500 mg/L of total dissolved solids (TDS), which is within World Health Organization (WHO) guidelines.

D. Chemicals like acid, any polymer, and nano filtration are necessary for pre-treatment. A polymer eliminates the need of degasification. But oxygen removal is still necessary. A deaerator will therefore be required. An oxygen scavenger is added to the feed stream in a manner similar to how acid is treated. TDS level softening and maintenance using nanofiltration before treatment.

E. Requirements for post-treatment: The product water has to have minerals added for drinking. needs to be post-treated to stop the distribution system from corroding chemically.

F. Construction materials: Typically, desalination water is caustic and salty in nature. Therefore, it is important to use the right non-metallic or highly alloyed materials for the components, such as stainless steel. Solar and wind energy systems are primarily environmentally benign and long-lasting energy sources.

G. Operation and maintenance requirements: A thorough understanding of maintenance and operation is required for the entire process.

H. Pump kinds and sizes should be chosen based on the aim and budget.

3. RESULTS AND DISCUSSION

The results of the research can be defined based on some parameters but not on any single goal. This research was to achieve the main goal of desalinating sea water, but it needed to be done without causing any harm to the environment. The energy required for the desalination is renewable energy. This energy generation was two-way; one was from solar power and the other one was from wind power. Maybe there could be an option to supply the energy too, based on the production rate of the energy and reserved power.

In the case of producing fresh water, the amount of production is dependent on the salinity level and ppm amount of the water. But the average amount will be enough based on the cost and plant size. The brine water produced in this system will be used too, as it could be used in producing Sodium Hydroxide, or Caustic Soda, through a fairly simple process, and this Sodium Hydroxide is used to pretreat seawater going into the desalination plant as well.

4. CONCLUSION

As resources for fresh water is decreasing and the demand is increasing, the need of desalination to cope up with the requirement is a must. The coastal areas have lots of water but they don't have enough drinkable water though. By using desalination process, they have the highest possibility of producing lots of drinkable water. Accelerating the development of innovative, renewable-based water production methods is necessary. There is a need for considerably greater R&D efforts than are now being made in Europe [10].

These initiatives ought to involve closer collaboration with research organizations, the desalination industry, and especially Europe's Mediterranean, Middle Eastern, and African neighbors. The spread of knowledge, teaching, and training about desalination also needs to be accelerated. From an economic and environmental perspective, desalination systems that can be powered by wind, solar, and other renewable sources are quickly becoming feasible.

5. REFERENCES

[1] Riaz, N. and Sultan, M. (2021) ‘Investigation of adsorption and desorption characteristics of metal-organic frameworks for the development of Desalination Systems’, Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES), 7, pp. 261–267. doi:10.5109/4739231.

[2] Hasnain SM, Alajlan SA. Coupling of PV-powered RO brackish water desalination plant with solar stills. Desalination 1998;116(1):57–6.

[3] Vujcic R, Krneta M. Wind-driven seawater desalination plant for agricultural development on the islands of the county of split and Dalmatia. Renewable Energy 2000;19:173–83.

[4] KALOGIROU, S., 2005. Seawater desalination using renewable energy sources. Progress in Energy and Combustion Science, 31(3), pp.242–281.

[5] Goswami, D.Y. & Zhao, Y., 2009. In Proceedings of ISES world congress 2007 (Vol.1-vol.5) solar energy and human settlement. Berlin, Heidelberg: Springer Berlin Heidelberg.

[6] Anon, 2017. Renewable energy sources - energyfive. Energy Five. Available at: https://energyfive.net/ [Accessed August 26, 2022].

[7] Kalogirou, S.A., 2018. Introduction to renewable energy powered desalination. Renewable Energy Powered Desalination Handbook, pp.3–46.

[8] Luft W. Five solar energy desalination systems. Int J Solar Energy 1982;1:21

[9] Swellam W. Sharshir et al. (2022) ‘An entirely solar-powered hybrid thermal-membrane desalination system integrated with solar heaters and preheating technique’, Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES), 8, pp. 84–89. doi:10.5109/5909066.

[10] Grutcher J. Desalination a PV oasis. Photovolt Int 1983; June/July:24.