Comparative Analysis of Desalination Technologies: Energy Performance and Renewable Energy Integration with Focus on Reverse Osmosis Systems

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Abstract. Faced with the scarcity of freshwater resources, desalination represents a strategic solution to meet the growing water needs. This article presents a comparative analysis of the main desalination technologies: membrane processes (reverse osmosis, electrodialysis) and thermal processes (multi-stage flash distillation MSF, multi-effect distillation MED). Reverse osmosis dominates with 69% of the global capacity, thanks to its low energy consumption (3-6 kWh/m³) and its competitive cost ($0.45-1.72/m³) compared to thermal processes (up to 25.5 kWh/m³). The study examines the couplings with renewable energies: photovoltaic systems (2.5 kWh_{el}/m³, <2 $/m³), wind (2.8 kWh/m³), and solar thermal with organic Rankine cycles (2.35 kWh_{mec}/m³, 0.6 $/m³). The results show that reverse osmosis coupled with renewable energies offers promising performance for sustainable desalination.

Keywords: Desalination, Reverse osmosis, Renewable energies, Energy efficiency.

1 Introduction

Water is necessary for life, yet many countries, especially developing countries and the MENA region, suffer from a lack of fresh water. According to the United Nations Environment Program (UNEP), one third of the world's people live in countries where there is not enough freshwater for everyone, and good quality drinking water is increasingly scarce. This situation is projected to get worse with chronic water scarcity expected by 2040. Agriculture, which consumes 80% of global

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water resources, will be particularly affected, and as a sector critical to food security, poverty reduction and overall economic stability, the growing water crisis poses serious challenges for sustainable development [1, 2]. The total amount of water on Earth is approximately 1.4 billion km³. Among this water, 97.5% is in the oceans and 2.5% is freshwater, found in the air, glaciers, and groundwater. Of this total, only about 0.014% is directly usable by humans and other forms of life.

Thus, considerable efforts are now necessary to make new water resources available to reduce the water deficit in countries that lack it [3]. The World Health Organization (WHO) says that drinking water can contain up to 500 ppm of salt, and up to 1000 ppm in some cases. Most of the water on Earth has a salinity of up to 10,000 ppm, while seawater typically has a salinity between 35,000 and 45,000 ppm due to the salts it contains.

Desalination is a process that transforms saltwater into two types of water: freshwater, which contains little salt, and brine, which has a lot of salt. Desalination of seawater has become one of the most important commercial processes for providing freshwater to many communities and industrial sectors, playing a crucial role in the socio-economic development of several developing countries, particularly in Africa and the Middle East, which suffer from freshwater shortages.

There is a lot of ongoing research, especially on renewable energy technologies, to find new ways to produce drinking water. Currently, more than 7,500 desalination plants are in operation worldwide, producing several billion litters of water each day. Fifty-seven percent of them are in the Middle East [4], where conventional heat and electricity production plants are one of the most widespread commercial processes. They are essential for supplying the community and industrial sectors, particularly in densely populated areas.

However, since these facilities operate using fossil fuels, their operating costs become very high, and the pollution they generate is increasingly recognized as extremely harmful to the global environment. Moreover, these plants are not economically viable in remote areas, even by the seaside, where seawater is abundant. Many of these areas also face a lack of fossil fuels and insufficient electricity supply.

The development of compact small-scale desalination systems is therefore essential to meet the needs of the population in these regions [5]. Desalination of water using solar thermal energy is recognized as a viable method for producing fresh water from salt water [6], particularly in isolated areas. Using a natural source of clean energy in desalination processes would significantly reduce the pollution responsible for global warming.

The present study aims to propose a review of the published scientific literature on a comparative analysis of different desalination technologies, their advantages and disadvantages, as well as their economic and energy aspects. With a particular focus on reverse osmosis systems coupled with renewable energies.

2 Overview of Desalination technologies

Desalination of water is the process of removing salt and other impurities from seawater to make it suitable for human consumption, agriculture, and industrial use [7]. The most widely applied and commercially proven technologies can be divided into two types of processes, thermal and membrane. Other techniques have not seen

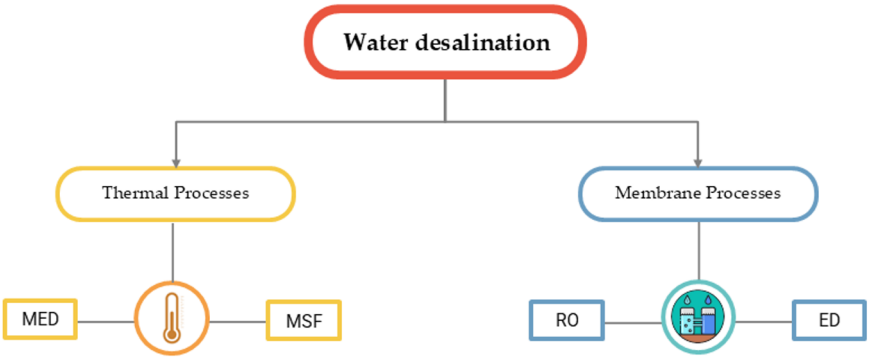

Fig. 1. Types of desalination process.

significant growth in the field due to issues generally related to energy consumption and/or the magnitude of the investments they require.
Whatever the method of separating salt and water considered, all desalination plants involve four steps: 1) A seawater intake with a pump and coarse filtration, 2) A pretreatment with finer filtration, the addition of biocidal compounds, and anti-scale products, 3) The desalination process itself and 4) The post-treatment with a possible remineralization of the produced water, the water must contain less than 0.5g of salt/l.

Desalting seawater is an expensive, energy-intensive process that emits significant amounts of greenhouse gases (GHGs) in most countries with a highly CO2-intensive electricity mix. The electricity consumption of the plants is high, varying according to the techniques in use; while thermal desalination processes, which are increasingly less used, consume more than 5 kilowatt-hours (kWh) of energy per cubic meter (m^3) of desalinated water, the reverse osmosis desalination process, now the most widespread, allows for the desalination of 1 cubic meter (m^3) of water with an average of between 2.5 and 3 kWh, with the record being set by a Saudi plant at 2.27 kWh [8].

2.1 Membrane Process

In membrane desalination processes, salts with larger radii cannot pass through the semi-permeable membranes. This results in fresh water with low TDS (Total Dissolved Solids) and the rejection of high-concentration brine. Reverse osmosis and electrodialysis are the main membrane desalination technologies. [9].

2.1.1 Reverse Osmosis (RO)

The RO process is relatively new compared to other technologies and was successfully commercialized in the early 1970s for desalinating water. RO is a membrane separation process in which water from a pressurized saline solution is separated from solutes (the dissolved matter) by passing through a membrane without the need to heat it or change its phase. The main energy required is the pressurization of the feed water [8]. It can also be described as a process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure greater than the osmotic pressure demonstrated in figure 2. Thus, the water flows in the opposite direction of the natural flow through

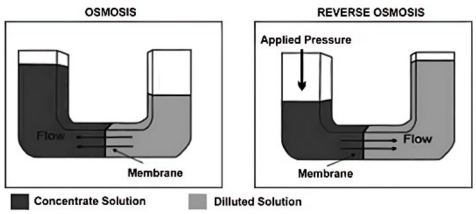

Fig. 2. Osmosis and RO process [14].

the membrane, leaving behind the dissolved salts with an increase in salt concentration [9]. A typical large-scale seawater RO plant includes five main components: a seawater supply system, a feed water pretreatment system, a high-pressure pumping system, RO modules (membrane separation), and a post-treatment system [10]. In recent years, the largest RO desalination plants have been built in Saudi Arabia. The Jeddah plant produces 15 million gallons per day (MGD), while the RO plants in Al Jubail and Yanbu have capacities of 24 and 33.8 MGD, respectively [11, 12]. As for Morocco, specifically the Agadir plant, it has a capacity of 275,000 m³/day (150,000 m³/day of drinking water and 125,000 m³/day for irrigation), with the possibility of expansion up to 400,000 m³/day [13].

2.1.2 Electrodialyse (ED)

ED was commercially introduced in the early 1960s, before RO. It was a cost-effective means of desalting brackish water, and it sparked considerable interest in desalination technologies to produce drinking water for municipal use [15]. It also has many other applications in the environmental and biochemical industries, as well as in table salt production [16, 17]. ED is an electrochemical separation process that uses electrically charged ion exchange membranes with a potential difference as the driving force. It is because most salts dissolved in water are ionic, meaning they are positively (cationic) or negatively (anionic) charged and migrate towards electrodes with opposite electrical charges. Membranes can be constructed to allow the selective passage of cations or anions. A schematic diagram of the process is illustrated in Figure 3.

2.2 Thermal Desalination Process

Thermal desalination methods are inspired by the natural hydrological cycle, where saltwater is first evaporated and then condensed to obtain freshwater with a low concentration of total dissolved solids (TDS). The main technologies in this category

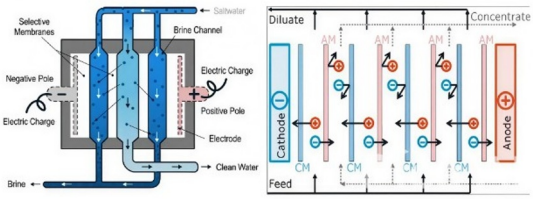

Fig. 3. Principe of desalination by electrodialysis [18]

are multi-effect distillation (MED) and multi-stage distillation (MSF). In the regions of North Africa and the Middle East (MENA), thermal processes such as MED and MSF dominate the desalination market, representing approximately 85% of the total water production capacity. This predominance is explained by the high salinity of seawater in the Gulf, the high frequency of algal blooms that can severely damage reverse osmosis (RO) membranes, as well as the presence of numerous large power plants, facilitating a cost-effective integration between energy production and desalination. [19].

2.2.1 Multi-stage flash distillation (MSF)

In the MSF process as shown in figure 4, the saline water passes through the tubes of the heat exchangers located in the different flashing stages, which preheats it before entering the brine heater. Although this system does not generate residual heat during distillation, it has high operating costs as well as increased risks of corrosion and scaling due to the high temperatures used. This process consists of two main parts: (i) the heating of the brine and (ii) the expansion stages [20]. The brine is heated in a specific heater using low-pressure steam, until it reaches a temperature between 90 and 110 °C, called the maximum brine temperature (MBT) [4, 21, 22]. Once heated, the brine enters the first stage, where the pressure is lower than in the heater, leading to rapid evaporation of the water (flashing phenomenon). Each stage of the MSF process operates at a temperature slightly lower than that of the previous stage, with pressure adjusted to the corresponding boiling point. During the condensation of the vapor produced by flashing on the tubes of the exchanger, the latent heat is transferred to the saline feed, which contributes to the overall process [20].

2.2.2 Multiple-effet distillation (MED)

The MED process, illustrated in Figure 5, is one of the most widespread desalination technologies today. However, the lost heat is not recoverable to power the distillation process [4]. This system has certain disadvantages, including high operating costs and operating temperatures that promote corrosion as well as the formation of deposits. The MED is mainly composed of a condenser and several compartments called effects. These effects operate at decreasing pressures and temperatures, generally between 65 and 90 °C [23]. Before reaching the condenser, the saline feedwater is preheated. It is then distributed in equal quantities to each effect. Inside each effect are bundles of evaporator tubes, onto which the saline water is sprayed. The low-pressure steam circulating through these tubes causes the initial evaporation of the feed water. In the subsequent effects, the steam produced in the

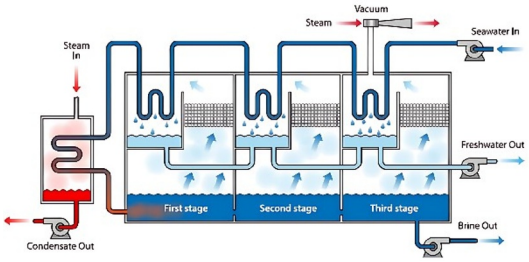

Fig. 4. Schematic diagram of an MSF unit [4]

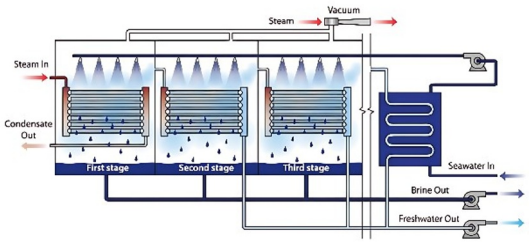

Fig. 5. Schematic diagram of an MED unit [4]

previous effect serves as a thermal source for the next evaporation. Moreover, this steam is also used to heat the saline water in the condenser. Given that the boiling point of water decreases with pressure, a reduction in pressure allows evaporation at lower temperatures [24]. Thus, external steam is only necessary in the first effect of the MED unit, while the heat recovered during cooling is reused as thermal energy in the subsequent effects [25].

2.3 Advantages & Disadvantages of technologies

This table allows for the comparison of the technical and economic performances of different desalination technologies. Membrane processes (RO, ED) are more economical and adaptable but limited by the quality of the produced water and technical constraints (membranes). Thermal processes (MSF, MED) produce better quality water, but at the cost of high energy consumption and more complex maintenance.

Table 1. Advantages and disadvantages of the main desalination processes.

Desalination Processes	Type of technologies	advantages	disadvantages
Membrane	Reverse osmosis (RO)	• Only electrical demand • Low investments • Coupled with many renewable energy sources • Modular structure of plant	• Lower water quality • High costs for membranes and chemicals • Subject to biofouling
	Electrodialysis (ED)	• High purity of Freshwater • Energy consumption proportional to salt concentration	• Only for brackish water (up to 2000 ppm) • Bacterial contaminants not removed by the system
Thermal	Multi-stage flash distillation (MSF)	• Maintenance operations to remove the scaling are simpler than in MED • High water quality • High-rated capacity	• High energy demand • Slow start-up • The entire plant is stopped for maintenance
	Multi-effect distillation (MED)	• High water quality • Low energy consumption	• Scaling on the pipes

2.4 Economic and Energy Aspects of Thermal vs. Membrane Desalination Technologies

The table 2 presents statistics on the state of the art of operational desalination plants [4, 26, 27, 28, 29], highlighting the energy and economic performance of the main desalination technologies, including membrane processes such as reverse osmosis (RO) and thermal processes like multi-effect distillation (MED) and multi-stage flash distillation (MSF). RO technology stands out for its low energy consumption (3 to 6 kWh/m³) and its competitive production cost (0.45 to 1.72 USD/m³), making it the most widely used solution globally, operating solely on electricity. In contrast, thermal processes require a significant amount of thermal energy (up to 390 kJ/kg), which results in a much higher total equivalent consumption (up to 25.5 kWh/m³ for MSF), as well as higher initial investment costs [4].

RO methods, which are becoming dominant in the desalination of brackish water and seawater, are currently the least expensive, mainly due to their low energy consumption, as well as recent advancements in membranes and energy recovery systems. In fact, RO technology accounts for approximately 69% of the world's installed desalination capacity, and it is favored in most new projects [5].

In addition to its energy efficiency, reverse osmosis produces water with a dissolved salt content between 400 and 500 ppm, suitable for both agricultural irrigation and human consumption. In contrast, the very pure water produced by the MED process (~10 ppm) requires remineralization before use, which adds complexity to the treatment steps [30].

Thus, thanks to its energy efficiency, economic viability, and the quality of the produced water, reverse osmosis has now become the most suitable technology for current desalination challenges, particularly in regions with high solar potential like Morocco.

Table 2. Energy and Economic Performance of Major Desalination Technologies.
Note: SW is the abbreviation of Seawater; BW brackish water.

Technology	**RO**		**ED**	**MED**	**MSF**
Input	SW	BW	BW	SW	SW
Average capacity [10^3 m^3/day]	1-320	UP to 98	Up to 145	0.6-30	50-70
Water quality ppm	400–500	200–500	150–500	10	10
Electrical Energy Consumption [KWH/m^3]	3 – 6	1.5-2.5	2.6 – 5.5	1.5 – 2.5	4-6
Thermal Energy Consumption [KJ/Kg]	None	None	None	230– 390	190 – 390
Electrical Equivalent for Thermal Energy (kWh/m^3)	None	None	None	5 – 8.5	9.5 – 19.5
Total Equivalent Energy Consumption (kWh/m^3)	3 – 6	1.5-2.5	2.6 – 5.5	6.5 – 11	13.5 – 25.5
Water Cost[$/$m^3$]	0.45-1.72	0.26-1.33	0.6–1.05	0.56-1.75	0.52-1.5

3 Coupling renewable energy with membrane processes:

In recent years, a considerable number of studies have highlighted the integration of reverse osmosis (RO) technology with renewable energy sources, and several desalination units powered by solar energy have been commissioned in different regions of the world. Photovoltaic (PV), solar thermal, and wind technologies are widely adopted to power the high-pressure pumps necessary for the operation of RO, thus offering an environmentally friendly solution, particularly suited for remote areas. Indeed, reverse osmosis, which only requires electricity, easily integrates with these energy sources, thereby reducing carbon emissions and operating costs. This section will successively present the principles, advantages, and limitations of reverse osmosis associated with photovoltaic, solar thermal, and wind energy.

3.1 Reverse osmosis process coupled with wind energy:

Reverse osmosis (WT-RO) is today the desalination process most associated with wind energy, mainly because the latter directly produces electricity. This coupling is generally achieved through an electrical conversion, as is the case with the unit developed by the wind turbine manufacturer ENERCON in Germany, capable of treating between 175 and 1,400 m³ of seawater per day, and up to 2,500 m³/day of brackish water, with an energy consumption of 2 to 2.25 kWh/m³ [31].

However, one of the major limitations of this combination lies in the intermittent nature of the wind. These fluctuations lead to variations in electricity production, which disrupt the stable operation of the pumps and expose the membranes to sudden pressure increases. To limit these undesirable effects, the use of energy storage batteries is often considered: they help smooth out the power supply and protect the membranes. The study by Parks et al. has also shown that such a system, if well regulated, can effectively mitigate these impacts [32].

In this regard, Richards and his colleagues designed a WT-RO system coupled with supercapacitors to desalinate brackish water. Result: a specific energy consumption (SEC) of 3.1 kWh/m³ for a daily production of 1.15 m³ [33].

But the addition of batteries remains costly, which calls into question the economic viability of these solutions. That is why Fadigas et al. proposed an alternative without electrical conversion, with direct pressure from the wind turbine. This system consumes approximately 2.8 kWh/m³ [34].

Finally, to better secure the energy supply, some systems combine wind energy with other sources such as photovoltaic panels or even conventional energies. This is the case, for example, with the compact unit developed by HatenboerWater, which uses both solar and wind energy to produce 7 m³/day with a consumption of approximately 4 kWh/m³ [35].

3.2 Reverse osmosis system powered by photovoltaic energy:

The Photovoltaic-Reverse Osmosis (PV–RO) system is particularly suitable for small installations, due to the flexibility of these two technologies and the significant decrease in the price of solar panels [36]. In most cases, these installations incorporate batteries to ensure energy storage, as demonstrated by the experiment conducted by Alghoul et al. Their device, dedicated to brackish water treatment, achieves a capacity

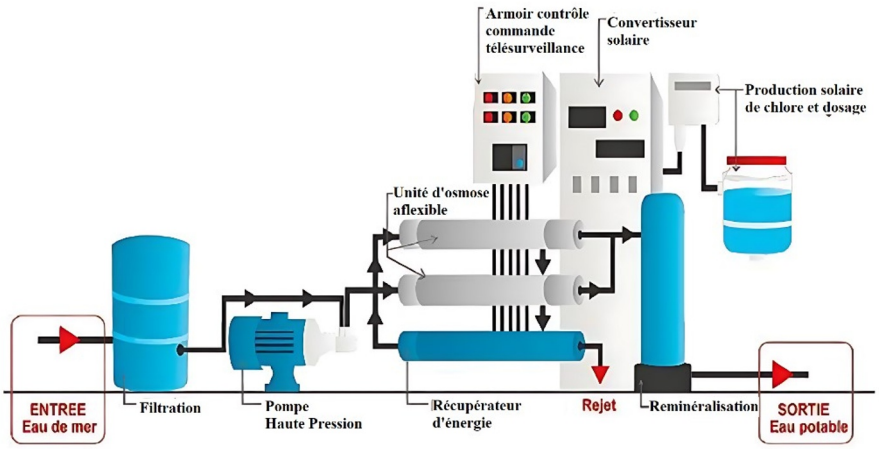

Fig. 6. Schematic diagram of Mascara's OSMOSUN [39].

of 5 m³/day with an energy consumption of 1.1 $kWh_{méc}/m^3$, with an investment cost of approximately 20 000 $, which corresponds to an estimated production cost of around 2 $/m3 [37].

Nevertheless, to reduce the economic and environmental impacts associated with the use of batteries, numerous studies are exploring configurations without electrical storage. This is the case of the numerical study conducted by Thomson et al., focusing on a seawater desalination unit equipped with a Clark pump. This system offers an average production of 3 m³/day, with a specific energy consumption of 3.5 kWh_{el}/m^3 (or 1.8 $kWh_{méc}/m^3$), for a production cost estimated at 2.8/m³ [38].

In this same vein, the French company Mascara-NT has developed a PV–RO system that does not require batteries, as shown in Figure 6. The generated electricity is directly used to power a high-pressure pump that operates in synchronization with sunlight. This solution shows a consumption of 2.5 kWhel/m³ and a production cost of less than 2$/m³ [39].

PV-RO systems without batteries, however, have a significant limitation: their operation is restricted to periods of the day when solar irradiation is sufficient to exceed the startup threshold of the high-pressure pumps. In addition, there is an increased risk of membrane fouling related to biofouling, that is, the proliferation of organisms such as microalgae during the system's shutdown phases. This situation necessitates the recirculation of fresh water through the membranes to limit fouling.

3.3 Reverse osmosis process coupled with solar thermal collectors:

Low-temperature solar thermal energy (ST) represents a promising alternative to address the intermittency issues encountered in systems operating from photovoltaic panels or wind turbines. Thanks to the thermal inertia of solar collectors and their association with a motorcycle, ST technologies are less sensitive to variations in solar resources.

The most widespread conversion cycle to harness this energy is the Organic Rankine Cycle (ORC), mainly composed of an evaporator, a condenser, a pump, and a turbine, as illustrated in Figure 7. An organic working fluid circulates throughout

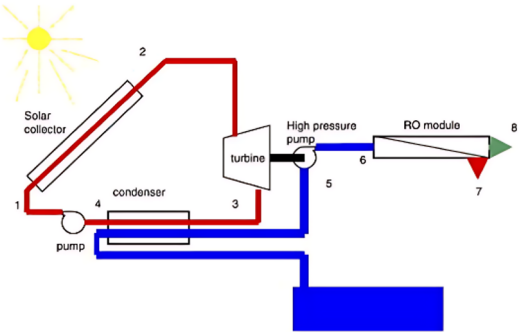

Fig. 7. Reverse osmosis fed by an ORC connected to a high-pressure pump [40]. 1: Working fluid entering the heat exchanger, 2: Working fluid at maximum pressure and temperature, 3: Expanded steam, 4: Condensed working fluid, 5-6: Water to be treated, 7: Retentate, 8: Permeate.

the system, and its expansion in the turbine, coupled with a motor pump, generates the hydraulic power required for the pressurization of the water supplying the reverse osmosis module. This type of OI-ORC coupling is the subject of increasing research, with several experimental prototypes deployed notably in Greece, the United States, France, and Egypt [40, 41].

A seawater desalination process based on the ORC-RO coupling, with a production capacity ranging from 1.3 to 2.55 m³/day, was tested by Manolakos et al., with a specific energy consumption (SEC) of approximately 2.35 kWh_{mec}/m^3 and an estimated cost of \$0.6/m³ [40].

This type of coupling, however, raises the issue of efficiency losses associated with the multiple conversion steps required to transform thermal energy into useful hydraulic energy. Indeed, this transformation chain successively goes through the thermal-mechanical-electrical phases, then the electrical-mechanical-hydraulic phases.

To circumvent these losses, A. Attia explored an alternative approach, illustrated in Figure 8, consisting of directly supplying the reverse osmosis module via a piston pressurization system. This is powered by an organic fluid, heated and evaporated in a solar concentrator [42].

According to a theoretical study, this type of system could generate up to 55 L/m²/day from seawater, and between 200 and 1800 L/m²/day from brackish water, with respective energy consumptions of 204 kWhméc/m³ and 2 to 37 kWhméc/m³ [42].

To limit the efficiency losses associated with successive conversions, Igobo et al. proposed a particular configuration of the ORC cycle. In this approach, the expansion of the working fluid directly drives a piston intended to pressurize the water. The

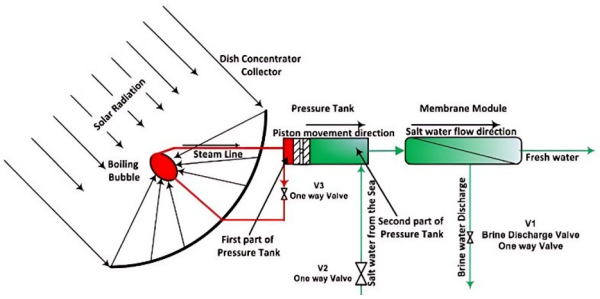

Fig. 8. Reverse osmosis process directly fed by a concentrating solar collector [42].

system uses a low-temperature thermal source (90–70 °C) and could produce up to 13 m³/day of brackish water, with a specific energy consumption estimated at 0.34 $kWh_{méc}/m^3$, a cycle efficiency of 7.7%, or 4.85 kWh_{th}/m^3 [43].

These studies are focused on utilizing industrial waste heat, as an alternative to solar thermal energy.

A similar study reports a process in which the expansion of the working fluid is directly utilized in a cylinder with a moving piston. The experiment showed a specific energy consumption (SEC) of 45 kWhth.m-3 for a productivity of 1.27 L.h-1 at a salinity of 1.1 g.L-1 (high pressure of 2.2 bars) [44].

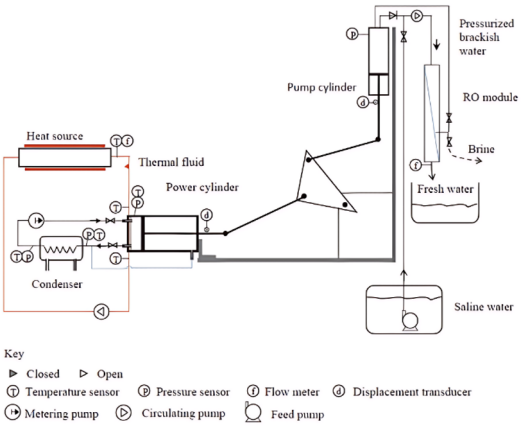

Fig. 9. ORC-RO process powered by low-temperature heat [43].

4 Conclusion

This study highlights the superiority of reverse osmosis, which is distinguished by its high energy efficiency (3 to 6 kWh/m³), its economic competitiveness (between $0.45 and .72/m³), and its great operational flexibility. In contrast, thermal processes, although producing higher quality water, are hindered by their high energy consumption, reaching up to 25.5 kWh/m³ in the case of the MSF process.

The integration of renewable energies represents a promising path: PV-RO systems without batteries show costs below 2$/m³, wind configurations exhibit consumption around 2.8 kWh/m³, while systems using solar thermal reveal their potential with an estimated cost of $0.6/m³ [40].

Nevertheless, some challenges persist, particularly the management of the intermittency of renewable sources, membrane biofouling, and the optimization of energy storage solutions. The future of desalination relies on the refinement of membrane technologies coupled with renewable energies, supported by appropriate policies to make this approach a sustainable lever for global water security.

Acknowledgment

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References

1. Food and Agriculture Organization of the United Nations. (n.d.). AQUASTAT – Water use methodology. Retrieved from https://www.fao.org/aquastat/en/overview/methodology/water-use
2. A. El-Aabssi and A. Assir, "Modern Irrigation Systems Adoption in Morocco: Problems and Development Directions," 2025 5th International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET), Fez, Morocco, 2025, pp. 1-6, doi: 10.1109/IRASET64571.2025.11007971
3. Colombo D, De Gerloni M, Reali M. An energy-efficient submarine desalination plant. Desalination 1999;122:171– 6.
4. WDI. Water Desalination International: Introduction. Published by WDI. http://www.aterdesalination.com/introduction.htm (21 April 2008).
5. Gleick PH (ed.). The World's Water: The Biennial Report of Fresh Water Resources 1998 – 1999. Island Press, 1998.
6. Al-Kharabsheh S, Yogi Goswami D. Analysis of an innovative water desalination system using low-grade solar heat. Desalination 2003; 156:323–32.
7. Bouramdane, A.-A. (2023). Optimal Water Management Strategies: Paving the Way for Sustainability in Smart Cities. Smart Cities, 6(5), 2849-2882. https://doi.org/10.3390/smartcities6050128
8. Eyl-Mazzega, M. A. (2023). L'essor de l'industrie du dessalement d'eau de mer. Études, (10), 19-30.; Marc-Antoine Eyl-Mazzega et Élise Cassignol, « Géopolitique du dessalement d'eau de mer », Études de l'Ifri, Ifri, septembre 2022.
9. Gohil, P.P.; Desai, H.; Kumar, A.; Kumar, R. Current Status and Advancement in Thermal and Membrane-Based Hybrid Seawater Desalination Technologies. Water 2023, 15, 2274. https://doi.org/10.3390/w15122274
10. Ayyash, Y., Imai, H., Yamada, T., Fukuda, T., Yanaga, Y., and Taniyama, T., "Performance of reverse osmosis membrane in Jeddah Phase I plant", Desalination, vol. 96, no. 1, pp. 215–224, 1994. doi: 10.1016/0011-9164(94)85173-5.

11. Khawaji, A. D., Kutubkhanah, I. K., & Wie, J. (2007). A 13.3 MGD seawater RO desalination plant for Yanbu Industrial City. Desalination, 203(1–3), 176–188. https://doi.org/10.1016/j.desal.2006.02.018
12. AL Mobayed AA, Balaji S. Successful Operation of Pretreatment in Al-Jubail SWRO Plant. Paper presented at IDA World Congress on Desalination & Water Reuse Conference. 11– 16 September 2005. pp. 12.
13. Zaoui, N. (2022, June 8). Usine de dessalement d'Agadir : tous les tests contractuels ont été passés avec un succès. Le 360 Français. https://fr.le360.ma/economie/usine-de-dessalement-dagadir-tous-les-tests-contractuels-ont-ete-passes-avec-un-succes-261535
14. Fritzmann C, Lo¨wenberg J, Wintgens T, et al. State-of-the-art of reverse osmosis desalination. Desalination 2007; 216:1– 76.
15. Buros OK. The ABCs of Desalting, 2nd edn. ASIN: B0006S2DHY, International Desalination Association, 2000, 30.
16. Water Desalination Technologies in the ESCWA Member Countries. UN-ESSWA, ASIN: E/ESCWA/TECH/2001/3. United Nations, 2001, 172.
17. Strathmann H, Winston WS, Sirkar KK. Membrane Handbook, ISBN-0-442-23747-2. Van Nostrand Reinhold, 1992, 246 – 54.
18. Abdalla, S., Khalla, S. A., & Suss, M. E. (2023). Desalination fuel cell stacks: scaling up the Co-Production of electricity and clean water. Meeting Abstracts/Meeting Abstracts (Electrochemical Society. CD-ROM), MA2023-02(25), 1347. https://doi.org/10.1149/ma2023-02251347mtgabs
19. Thu, K.; Kim, Y.D.; Amy, G.; Chun, W.G.; Ng, K.C. A hybrid multi-effect distillation and adsorption cycle. Appl. Energy 2013, 104, 810–821.
20. Nassrullah, H.; Anis, S.F.; Hashaikeh, R.; Hilal, N. Energy for desalination: A state-of-the-art review. Desalination 2020, 491, 114569.
21. Hanshik, C.; Jeong, H.; Jeong, K.W.; Choi, S.H. Improved productivity of the MSF (multi-stage flashing) desalination plant by increasing the TBT (top brine temperature). Energy 2016, 107, 683–692.
22. Shahzad, M.W.; Burhan, M.; Ang, L.; Ng, K.C. Energy-water-environment nexus underpinning future desalination sustainability. Desalination 2017, 413, 52–64.
23. Wang, X.; Christ, A.; Regenauer-Lieb, K.; Hooman, K.; Chua, H.T. Low grade heat driven multi-effect distillation technology. Int. J. Heat Mass Transf. 2011, 54, 5497–5503.
24. Fleck, J.A. The influence of pressure on boiling water reactor dynamic behaviour at atmospheric pressure. Nucl. Sci. Eng. 1961, 9, 271–280.
25. Ghalavand, A.R.Y.; Hatamipour, M.S. A review on energy consumption of desalination processes. Desalin. Water Treat. 2015, 54, 1526–1541.
26. Cipollina, A.; Micale, G.; Rizzuti, L. A critical assessment of desalination operations in Sicily. Desalination 2005
27. Jones, E.; Qadir, M.; van Vliet, M.T.H.; Smakhtin, V.; Kang, S.M. The state of desalination and brine production: A global outlook. Sci. Total Environ. 2019, 657, 1343–1356.

28. Zimerman, Z. Development of large capacity high efficiency mechanical vapor compression (MVC) units. Desalination 1994, 96, 51–58.
29. Al-Karaghouli, A.; Kazmerski, L.L. Comparisons of Technical and Economic Performance of the Main Desalination Processes with and without Renewable Energy Coupling. In World Renewable Energy Forum; ASES: Boulder, CO, USA, 2012. 88. Lindemann, J.H. Wind and solar powered seawater desalination. Applied solutions for the Mediterranean, the Middle East and the Gulf countries. Desalination 2004, 168, 73–80
30. Curto, D.; Franzitta, V.; Guercio, A. A Review of the Water Desalination Technologies. Appl. Sci. 2021, 11, 670. https://doi.org/10.3390/app11020670; Mahmoud Shatat* and Saffa B. Riffat Institute of Sustainable Energy Technology, University of Nottingham, Nottingham NG7 2RD, UK
31. Enercon, "Enercon Desalination Systems -Sustainable solutions for drinking water production," Enercon energy for the world, pp. 1–4.
32. G. L. Park, A. I. Schäfer, and B. S. Richards, "Renewable energy powered membrane technology: The effect of wind speed fluctuations on the performance of a wind-powered membrane system for brackish water desalination," J. Memb. Sci., vol. 370, no. 1–2, pp. 34–44, 2011.
33. B. S. Richards, G. L. Park, T. Pietzsch, and A. I. Schäfer, "Renewable energy powered membrane technology: Brackish water desalination system operated using real wind fluctuations and energy buffering," J. Memb. Sci., vol. 468, pp. 224–232, 2014.
34. E. A. F. A. Fadigas and J. R. Dias, "Desalination of water by reverse osmosis using gravitational potential energy and wind energy," Desalination, Elsevier, vol. 237, no. 1–3, pp. 140–146, 2009.
35. E. Rabinovitch, "Drinking with the wind," Novembre, 2008.
36. M. Abutayeh, C. Li, D. Y. Goswami, and E. K. Stefanakos, "Solar Desalination," in Desalination: Water from water, 2014, pp. 551–581.
37. M. A. Alghoul et al., "Design and experimental performance of brackish water reverse osmosis desalination unit powered by 2 kW photovoltaic system," Renew. Energy, vol. 93, pp. 101–114, 2016.
38. S. M. Shalaby, "Reverse osmosis desalination powered by photovoltaic and solar Rankine cycle power systems: A review," Renew. Sustain. Energy Rev., vol. 73, no. March 2016, pp. 789–797, 2017.
39. Clément Lacroix. Procédé thermo-hydraulique solaire pour le dessalement par osmose inverse. Thermique [physics.class-ph]. Université de Perpignan, 2020. Français. NNT : 2020PERP0001. tel03532375
40. D. Manolakos, G. Kosmadakis, S. Kyritsis, and G. Papadakis, "On site experimental evaluation of a low-temperature solar organic Rankine cycle system for RO desalination," Sol. Energy, vol. 83, no. 5, pp. 646–656, 2009.
41. L. García-Rodríguez and A. M. Delgado-Torres, "Solar-powered Rankine cycles for fresh water production," Desalination, vol. 212, no. 1, pp. 319–327, 2007.

42. A. A. A. Attia, “Thermal analysis for system uses solar energy as a pressure source for reverse osmosis (RO) water desalination,” Sol. Energy, vol. 86, no. 9, pp. 2486–2493, 2012.
43. O. N. Igobo and P. A. Davies, “Isothermal Organic Rankine Cycle (ORC) driving Reverse Osmosis (RO) desalination: Experimental investigation and case study using R245fa working fluid,” Appl. Therm. Eng., vol. 136, no. January, pp. 740–746, 2018.
44. J. Nihill, A. Date, P. Lappas, and J. Velardo, “Investigating the prospects of water desalination using a thermal water pump coupled with reverse osmosis membrane,” Desalination, vol. 445, no. August, pp. 256–265, 2018.