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Comparative Study of Water Desalination using Reverse Osmosis (RO) and Electro-dialysis Systems (ED): Review

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ABSTRACT

The increasing drinking water demand in many countries leads to an increase in the use of desalination plants, which are considered a great solution for water treatment processes. Reverse osmosis (RO) and electro-dialysis (ED) systems are the most popular membrane processes used to desalinate water at high salinity. Both systems work by separating the ionic contaminates and disposing of them as a brine solution, but ED uses electrical current as a driving force while RO uses osmotic pressure. A direct comparison of reverse osmosis and electro-dialysis systems is needed to highlight process development similarities and variances. This work aims to provide an overview of previous studies on reverse osmosis and electro-dialysis systems related to membrane module and design processes; energy consumption; cost analysis; operational problems; efficiency of saline removal; and environmental impacts of brine disposal. RO system uses osmotic pressure as a driving force to force water through the membrane with less energy than other desalination systems. The enhancements in membrane materials and power recovery of the unit have massively decreased the price of RO units. ED system uses an electrical current to push dissolved ions across ion exchange membranes. The results of this review showed that desalination plants must be integrated with renewable energy to reduce power consumption and costs related to energy. Various technologies, including treatment processes and disposal methods, must be used to control concentrated solutions resulting from desalination processes because 5 to 33% of the total cost of the desalination process is associated with brine disposal.

Keywords: Electro-dialysis, Reverse osmosis, Brine solution, Desalination process, Water salinity.

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دراسة مقارنة لازالة الملوحه باستخدام منظومة التحلية ومنظومة التحلل الكهربائي

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الخلاصة

كثرة استهلاك مياه الشرب في العديد من البلدان أدت الى زيادة استخدام محطات تنقية المياه التي تعتبر من افضل الطرق لمعالجة مياه الصرف الصحي. تعد أنظمة التناضح العكسي (RO) والتحليل الكهربائي (ED) من اكثر التقنيات شيوعا والتي تستخدم لتنقية المياه التي يكون فيها تركيز الاملاح عالي. يعمل كلا النظامين على فصل الملوثات الأيونية والتخلص منها كمحلول ملحي ، ولكن ،نظام (ED) يستخدم التيار الكهربائي كقوة دافعة بينما يستخدم RO الضغط الأسموزي كطاقة خارجية. من الضروري إجراء مقارنة مباشرة بين أنظمة التناضح العكسي والتحليل الكهربائي لتسليط الضوء على أوجه التشابه والاختلاف بينهما لتطوير تقنيات تحلية المياه. الهدف من هذه الدراسة هو تقديم نظرة عامة على الدراسات السابقة حول أنظمة التناضح العكسي و التحليل الكهربائي المتعلقة بنظام (membrane) وعملية التصميم، واستهلاك الطاقة ، وتكلفة الانظمة ، وكفاءة إزالة الاملاح من المياه والآثار البيئية للمحلول الملحي الناتج من عملية التحلية. يستخدم نظام التناضح العكسي الضغط الاسموزي كقوة دافعة لمرور المياه من خلال (membrane) ومنع مرور بعض المواد مثل الاملاح والملوثات و يتطلب طاقة أقل من أنظمة تحلية المياه الأخرى ، وقد أدت التحسينات في الأغشية (membranes) وعملية حفظ الطاقة إلى خفض تكلفة تحلية مياه RO بشكل كبير. يطبق نظام التحلية الكهربائي تيارا كهربائيا كقوة دافعة لإزالة الأيونات الذائبة من خلال أغشية التبادل الأيوني (Ion exchange membranes). لهذا السبب, يجب دمج محطات تحلية المياه مع الطاقة المتجددة لتقليل استهلاك الطاقة والتكلفة المتعلقة بالطاقة.وايضا يجب استخدام تقنيات مختلفة لعمليات المعالجة والتخلص من المحلول الملحي المركز الناتج من عمليات تحلية المياه، لأن 5 إلى 33٪ من التكلفة الإجمالية للعملية عادة ما ترتبط بطريقة التخلص من المحلول الملحي.

الكلمات الرئيسية: التحليل الكهربائي ، التناضح العكسي، محلول ملحي مركز، ملوحة الماء، عمليه التحلية

1. INTRODUCTION

Potable water production has become a critical issue in many countries where there is an increase in population growth that leads to an increase in freshwater demand. The Middle East and North Africa (MENA) regions have recently been recognized as areas with water stress, as conventional water resources are insufficient to meet water demand. At least 12 countries in this region have severe difficulties with water scarcity, and only 500 m3 of renewable water resources are available per person **(Cherfane and Kim, 2012).** According to the World Health Organization, over 1.2 billion people do not have safe drinking water, and around 2.3 billion people, 41% of the Earth's population, are exposed to insufficient available water resources. By 2050, half of the world's population (about 3.5 billion) is predicted to live in regions with water scarcity **(WHO, 2018).** In 2018, the overall capacity of total operational desalination systems worldwide was (92.5 million) m^3/d, as reported by the International Desalination Association (IDA) **(Global Water Intelligence, 2018)**. Around 400 desalination projects were commissioned globally in July 2018. At the beginning of 2019, around 4 million m^3/d of the total capacity of desalination projects was committed, which equals the sum of 2015 and 2016 **(Global Water Intelligence, 2019)**. Desalination procedures separate soluble salts and minerals from salty water sources such as seawater, groundwater, and brackish water to provide freshwater for various sectors such as municipal, industrial, and agricultural irrigation. During the desalination process, the saline water is separated into product water (freshwater) and concentrated with a high concentration of salts and minerals. Membrane-based technologies like reverse osmosis and electro-dialysis have been used to make drinkable water from saltwater sources **(Kumar et al., 2018).** Therefore, water desalination plants are increasingly used to supply the depletion of water resources and meet drinking water demand worldwide. Water desalination technologies are used to increase water resources for some communities and large cities without clean water access **(Al-Kaabi et al., 2021).**

Today, reverse osmosis (RO) is the most widely used technique for new desalination installations; 44% of global desalination capacity and 80% of the total number of desalination units installed worldwide **(Greenlee, 2009).** In contrast, the increasing use of RO technology, which recovers large amounts of water while rejecting heavy residues back into the environment, has a strong impact and damages and harms both the physicochemical and ecological qualities of the receiving environment. Brine solutions also raise the salt content of groundwater and cause numerous issues in municipal wastewater drainage networks **(Morillo et al., 2014).** The RO has been developed to be the leading technology for water desalination, which treats a variety of saline water resources using pretreatment and membrane processes. It uses external forces to generate potable water from salty water and is the most popular membrane process used to desalinate water at high salinity **(Mengesha and Sahu, 2022)**.

Electro-dialysis (ED) is a membrane process of separation that employs an electrical field as a driving force to transport ions across ion exchange membranes. The ED is applied to concentrate dense brine solutions the same as effluent rejected from the desalination process of brackish and industrial water **(Korngold et al., 2009).** During desalination using ED technology, the major anions, such as chloride, sulfate, and nitrate, were gathered in the acid tank. The major cations, such as sodium and potassium were gathered in the base tank. Consequently, after the generation of concentrate and diluted solutions, the generated water may either be used immediately or treated again by RO for additional purification. The effectiveness of ED for brine conditioning for other industries is considered a great approach for brine management in different countries **(Morillo et al., 2014).**

The purpose of this work is to present a review of the principle of process design of desalination systems such as RO and ED. The main objective of the review is to reveal the feasibility of RO and ED units in terms of cost and energy consumption and the operational problems related to scale formation and membrane fouling. Additionally, the sustainability of the RO and ED units is investigated to reduce the environmental effects of desalination and meet the demand for clean water.

2. DESALINATION PROCESS

Desalination is the process of removing salts and dissolved solids and minerals from brackish water and seawater and is also used to increase water resources for mall communities and large cities and provide pure water for residential and industrial use. During the last 60 years, desalination was an effective method for supplying drinking water, evolving thermal and membrane desalination methods **(Greenlee, 2009).** Due to technological development, water desalination technology has become feasible and cost-effective for producing large amounts of high-quality water. Many factors affect the selection of desalination methods for sustainable water supply, such as energy consumption, performance and efficiency, affordability, and sustainability. The two main processes used for industrial desalination are thermal and membrane, as shown in **Fig. 1** (**Mujtaba et al., 2017).**

Thermal and membrane desalination procedures can be categorized as the major types of desalination technologies. The thermal desalination process is the oldest and still the leading process for large-scale freshwater production. The membrane-based RO process has been continuously increasing its market share and improving to be the controlling technology in producing clean water **(Mujtaba et al., 2017)**. In the thermal process, feed water is heated to a high temperature, and the vapour is condensed into pure water (distillate) in the membrane process, the feed water is pumped through semipermeable membranes to remove dissolved impurities. The primary thermal processes are MSF distillation (multistage flash) and MED (multi-effect distillation) with mechanical and thermal vapour compression (TVC and MVC). At the same time, reverse osmosis technology is the primary membrane process **(Alonso et al., 2020).** In addition, the membrane distillation process (MD) is a separation process that uses the vapour pressure difference as a driving force. Two types of MD were studied: direct contact membrane distillation (DCMD) and air gap membrane distillation (AGMD) related to the operation efficiency for desalinating saline water with different concentrations. Results showed that desalting using DCMD and AGMD has high-efficiency salt removal of about 99.99% **(Hassan and Reda, 2018**; **Khalaf and Hassan, 2019).** The study of membrane processes is consequently motivated by the necessity of a desalination technique that produces fresh, drinkable water at a reasonable cost. Membrane-based technologies, including reverse osmosis and electro-dialysis, have been used to generate potable water from salty sources **(Balcik-Canbolat, 2018).**

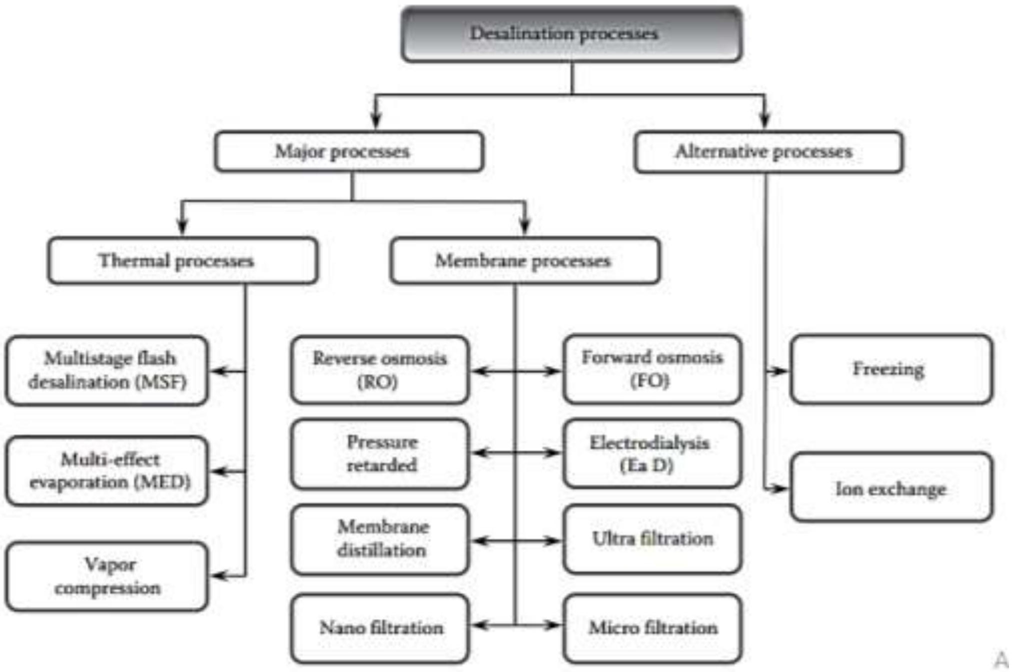

Figure 1. Various types of desalination processes (**Mujtaba et al., 2017).**

2.1 Principle of RO Process

The main concept of RO desalination based on the membrane process method is the movement of saline water across a partially permeable membrane from a higher to a lower salt concentration solution by applying osmotic pressure. When pressure is applied, water particles are passed through a membrane, and dissolved salts are trapped behind the membrane. According to the mass balance of flow around the RO unit, the inlet flow of saline water is divided into two discharges; the produced water (permeate) and the concentrate (brine). The operating pressure should equalize the osmotic pressure of the solution at the outlet of the membrane in the RO system with a single stage **(Zarzo and Prats, 2018)**. Osmosis is the natural flow of water through the membrane from a less concentrated solution to the most concentrated solution to equalize the chemical potential of the water, as shown in **Fig. 2.** The force that results from the separation of two liquids with different concentrations by a membrane is known as osmotic pressure. It can be estimated using mass balance equations with specific energy consumption and production capacity. In reverse osmosis, an external pressure greater than the osmotic pressure is applied to the saline solution, causing the water to flow in the reverse direction through the membrane **(Syed et al., 2000). Fig. 3** shows that the RO system produces two solutions: the dilute or pure solvent, also known as permeate, and the reject or concentrate**.** The concentrate is a brine solution that contains different particles, such as sediments, microorganisms, and minerals, which cause numerous effects on the environment associated with discharge into receiving water bodies and groundwater **(Ben and Roboam, 2015).**

RO units are installed and arranged in a package that consists of a sediment pre-filter, a carbon filter to control odour and taste, and a mineral adjustment unit for post-treatment. Ro membranes are constructed from polymeric materials with varying pore diameters and thicknesses. Cellulose acetate and polyamide are polymeric materials used to create semipermeable RO membranes. Significant progress has been made in producing membranes and modules over the past few decades, including creating thin-film membranes with great mechanical strength and chemical resistance **(Wan et al., 2021)**. Additionally, the RO plant's capacity (or unit volume of water production) and salt retention rate improved due to the rapid decrease in membrane pore size. The pore size of an RO membrane is typically between 0.1 and 1 nm, which is smaller than the size of an ion. The amount of water per area of membrane elements has increased due to great improvements in membrane technology **(Lee et al., 2020).** The efficiency of a RO membrane is described using important parameters such as **(Alonso et al., 2020)**:

a. Permeate flux is the permeate generated per unit of time and membrane area during separation. Volume per square meter per hour is used to measure the flux. It is calculated by using this equation:

$$Pv = \frac{Fp}{S} \tag{1}$$

where:
Pv, permeate flux
Fp, permeate flow rate
S, the membrane area

b. Salt rejection: is the amount of solute that the RO membrane retains. The ratio of the retention rate is measured by:

$$R = \left[1 - \frac{Cp}{Cave}\right] * 100 \tag{2}$$

$$Cave = \left(\frac{Cf - Cc}{2}\right) \tag{3}$$

where:
Cave, the average feed concentration
R, rejection

Cp, permeate concentration
Cf, feed concentration
Cc, concentrate concentration

c. Recovery rate: is the percentage of feed flow that across through the membrane. It is expressed as a percentage:

$$Qr = \frac{Qp}{Qf} \quad (4)$$

where:
Qr, recovery rate
Qp, permeate flow rate
Qf, feed flow rate.

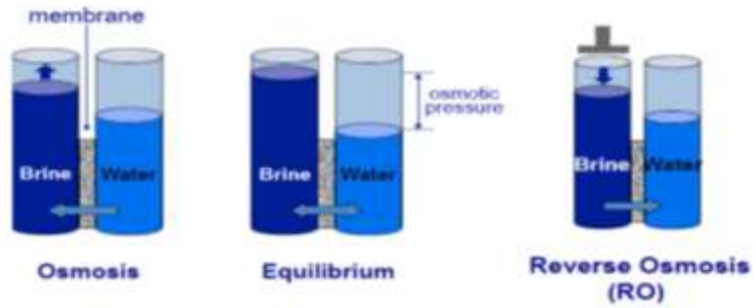

Figure 2. Principle of RO system **(Mengesha and Sahu, 2022)**.

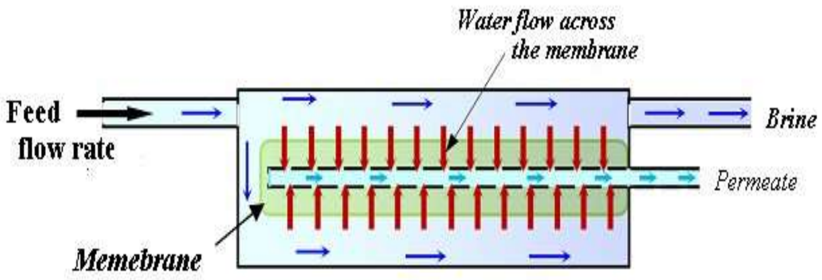

Figure 3. Discharge water through the RO system **(Ben and Roboam, 2015)**.

2.2 Principle of the ED Process

Electro-dialysis is a membrane process used to demineralize saline water. In this process, an electrical field is used as a driving force to transfer ions across ion-selective membranes. ED process is developed to concentrate brine solution using electrical energy and is reliable for industrial applications. Photovoltaic panels could deliver energy that makes this technology consume less electrical power and be appropriate for places with high insolation. The energy requirement is directly related to the amount of salt in the treated water. A direct electric current is supplied across the stacks as an ionic current, as shown in **Fig. 4**. The stacks include a cation and anion-permeable membranes arranged in series between two electrodes to allow the cations and anions in the feed liquid to migrate toward the cathode and anode. After the passage of ions through selective membranes, clean water and brine solutions are produced and flow through the space between membranes, as shown in **Fig. 5 (Syed et al., 2000; Banasiak et al., 2007).** However, when the brine is highly concentrated, the ED process performs worse than other technologies because of the formation of scale on the membranes and the lower income of electric energy. Further research is related to developing the permeability of membranes and finding solutions to avoid scale forming, such as using chemical components and pretreatment as is done in reverse osmosis **(Korngold et al., 2005).** ED technology can be employed experimentally to concentrate brine solutions like effluents from brackish and industrial water desalination. The experimental results showed that ED could concentrate saline water from 0.2–2% to 12–20% **(Oren et al., 2010).** In a process known as AquaSel, ED is employed to concentrate brine water rejected from the RO unit. According to GE Water, AquaSel was successfully used at a Coca-Cola bottling facility in Asia in 2011. ED system, with a capacity of about 136 m^3 per day, was in use for over 1000 hours and recovered over 99% of the RO concentrate from the ingredient-quality water treatment system used to make soft drinks **(Pankratz, 2012).** In addition, many properties make ED technology suitable for water desalination and treatments, such as high separation, selectivity, and using fewer chemical treatments. ED technology can be used in several aspects, such as concentration and desalination processes, dilution and regeneration to recover and restore water and other products, such as heavy metal ions, salts, acids or bases, nutrients, and nutrients organics **(Gurreri et al., 2020)**.

RO brine solution concentration may be increased from 1.5% to 10% by using an ED pilot plant at an energy cost of 7.0-8.0 kWh/m^3. ED was used to dilute the RO brine to a more manageable 18-20 mN before combining it with RO permeate. The recovery rate was between 97% and 98% **(Korngold et al., 2009).** Furthermore, ED successfully treats reverse osmosis concentrate (ROC), boosts total RO water recovery to over 90%, and achieves a "near-zero liquid discharge approach. There are several advantages of employing electro-dialysis to treat ROC, such as lower residual, less sensitivity to suspended particles, longer membrane life compared to other applications (such as RO), simple operation, no complex pretreatment needed, and less power consumption **(Balcik-Canbolat, 2018).**

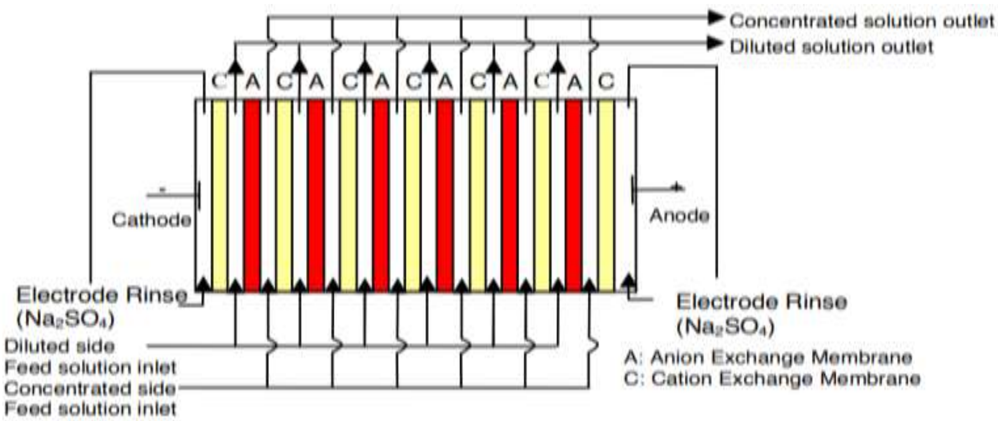

Figure 4. Electro-dialysis system layout **(Banasiak et al., 2007).**

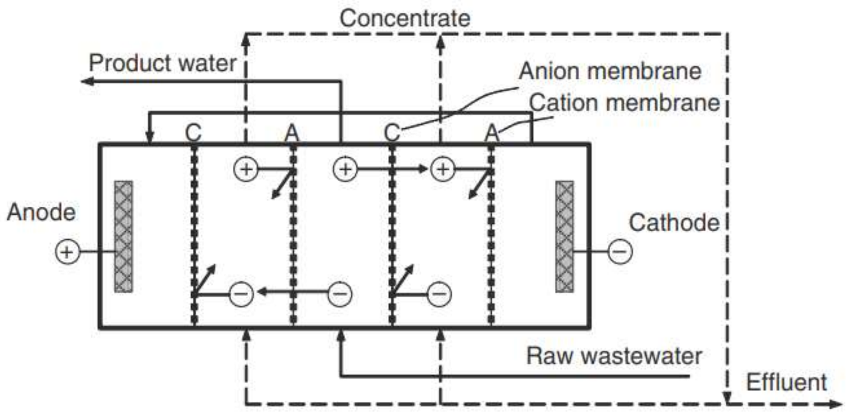

Figure 5. Operating principle of ED process **(Chaoa and Liang, 2008).**

3. ENERGY CONSUMPTION

The level of power required for a desalination system depends on the quality of feed water, the effectiveness of the water treatment, the technology used by the resource, and the size of the plant. Both RO and ED are widely used in the membrane desalination process. However, RO requires energy injection, while ED requires current delivery between electrodes to achieve ion separation **(Nassrullahm, 2020).** Compared to RO, ED can concentrate inlet water to a higher salinity than 100 000 mg/l. ED process consumes more power, about 7 to 15 kWh/m^3 of energy for feed water during concentrating brines to such high salinities (**Korngold et al., 2009).** The salinity of effluent from the ED process is much higher (e.g., TDS > 10 000 mg/l) compared to effluent from brine concentrators and RO, which produce water with very low TDS, which indicates a balance between the quality of produced water and total energy consumption and capital cost **(Loganathan et al., 2015)**. A typical RO plant used for seawater destination consumes 1.5 to 2.5 kWh of energy to produce 1 m^3 of water, while a thermal distillation system consumes around 10 times that value. Many countries, such as Saudi Arabia, can afford to develop and use desalination technologies; otherwise, the cost is already high for most other countries **(Robert, 2006).** RO has primarily increased in use because of its reduced particular investment costs and lower electrical energy usage (4-5 kWh/m^3 versus 13 kWh/m^3 for MSF), the possibility for developments in pretreatment techniques, system designs, and membrane materials that might lead to further cost reductions **(Banat, 2007).** By providing the consistent feed water quality necessary for effective RO plant operation, pretreatment alters seawater's properties and enhances SWRO performance. It also eliminates the possibility of RO membrane fouling, which lowers the cost of membrane replacement and cleaning frequency. Recently, numerous conventional and non-traditional RO pretreatment techniques have been used for this purpose, such as coagulation/flocculation, acidification, disinfection, microfiltration, ultrafiltration, and nanofiltration **(Blandin et al., 2016).** A comparison was carried out between RO, ED, and crystallizer systems in terms of energy consumption for each system under conventional operating conditions, as shown in **Fig. 6.** The results showed that the amount of electrical energy consumed by RO units is about 2.0 kWh/m^3 of total water produced. In comparison, ED units consume 1.9 times that energy at 3.7 kWh/m^3 of total water produced. Therefore, the RO system is more energy efficient than ED and crystallizer systems **(Nayar et al., 2019).**

The amount of energy consumed by RO units for a given amount of product water is considered the most critical problem in desalination technologies. The RO system used to desalinate seawater and produce freshwater is the most energy-efficient **(Choi et al., 2019).** RO consumes the least energy compared to the ED process, as shown in **Table 1**. There are many essential components related to the total energy consumption of the entire RO process, such as the amount of energy used for pushing the inlet water from the source, for pressurization of saline water, for pretreatment which includes microfiltration and pumping, for post-treatment (pumping the product water and flushing the membranes), and for reversing the flow direction of raw water across the membrane **(Rajaeifar et al., 2019**). In addition, desalination systems that use high-pressure processes for desalinating saltwater consume much energy to perform efficiently. Billions of saline water are required through pressure treatment processes, consuming an average energy of 10–13 kWh/per kgal (**Ghaffour et al., 2014).** Different feed water types, primarily seawater SW and brackish water BW, are treated with RO. Between 2015 and June 2018, 57.5% of the total desalination capacity's feed water came from SW, while 18.5% came from BW. This indicates that SW is the primary source of feed water for RO. However, desalting SW requires more energy than desalting BW. This is because SW has more salinity than BW, which results in higher osmotic pressure **(Global Water Intelligence, 2018)**. Energy Recovery Devices (ERD) devices are a feature of modern RO desalination facilities, allowing energy to be recovered from the brine effluent. ERDs can be used in place of the RO system's throttle valve to expand the concentrated stream and generate boosting pressure. Energy usage can also be reduced by combining a RO system with various energy recovery technologies and off-grid power supplies such as photovoltaic and wind power **(Hube et al., 2020).** The RO plants become more cost-effective with increased capacity in terms of production and energy recovery through the use of various types of turbines, such as Pelton turbines, which can reduce energy consumption in plants with a capacity of less than 5000 m^3/d by 35–42%. Whereas, isobaric energy recovery devices can significantly reduce energy consumption with a capacity of more than 5000 m^3/d by 55–60% **(Voutchkov, 2018).**

Table 1. Comparison between RO and ED systems
(Shahzad et al., 2017; Mayor, 2019; Schunke et al., 2020)

Properties	SWRO	BWRO	ED
Typical plant size (x 1000 m^3/day)	Up to 624	Up to 98	2-145
Recovery ratio (%)	35-50	50-90	50-90
Tolerated feed salinity (ppm)	30,000-60,000	500-10,000	< 5000
Brine temperature (^oC)	Same as inlet	Same as inlet	< 45
Electrical energy (kWh/m^3)	4-6 with ERO 7-13 without ERO	0.5-2.5	0.7-5.5
Thermal energy (MJ/m^3)	None	None	None
Total energy (kWh/m^3)	4-6	1.5-2.5	2.64-7 0.7-2.5 at low TDS
Product water quality (ppm)	300-500 for a single pass	200-500	150-500

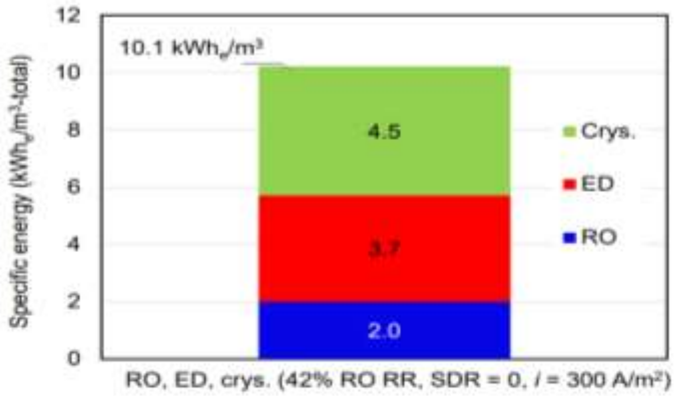

Figure 6. Comparison of energy consumption between RO, ED, and crystallizer **(Nayar et al., 2019).**

4. COST ANALYSIS

In 2014, desalination was considered the most energy-intensive water treatment method, consuming 75.2 TWh of energy annually. Therefore, the high cost of energy consumption for this process is not surprising **(Shahzad et al., 2017)**. Desalination has been recognized as an important source of clean water. However, one of the biggest obstacles to expanding it is its high cost of operation. As reported by the Global Water Intelligence (GWI) Desal-Data, desalination projects are expected to cost $93,700 million over the next four years. Only operating expenses cost about $5.1,6*10^{10}$ **(GWI, 2020 Cited in Nassrullah et al., 2020).**
Fig. 7 shows that energy, labor, replacements, and chemicals are the four main services that make up operational costs **(Karaghouli and Kazmerski, 2013).**
Electricity for desalination, electricity for pumps, and chemicals for membrane cleaning (chlorine acid) are the three factors contributing to an ED system's operating costs. The operation cost of the ED system was estimated to be about $0.146 per cubic meter of treated water **(Chao and Liang, 2008).** Ion exchange membranes (IEMs) are used in ED to remove ionic species from aqueous solutions by passing a current through them (IEMs). The amount of salt in the feed water significantly impacts ED unit costs. Therefore, the ED process is more practical for desalting BW. Expanding the ED process is limited because RO membranes are less expensive than IEMs, and the capacity of global ED is just 3% **(Shatat and Riffat, 2014; Takagi et al., 2014)**. According to (**Morillo et al., 2014**), the cost of an ED system with a membrane surface of about 80% and used for seawater desalination was estimated. The energy cost was expected to be about $0.06/kWh, the pump efficiency to be 0.85, the life of the membrane to be 10 years, and the cost of rejected salt was $30/t while the recovered salt was about 80%. The result showed that using this method, the product water cost was about $0.44/m^{3,} and the produced salt was 23.7 kg/m^3 of total generated water.
Technological advancements in RO units result in cost savings due to various factors such as lower membrane replacement costs, fewer chemical treatments required, process automation, reduced labor requirements, and effective pretreatment of inlet water **(Al-Bazedi et al., 2016). Fig. 8** shows the measured specific costs of RO, ED, and crystallizer systems related to the total water produced under conventional operating conditions. The cost of an RO unit was about 0.7 \$/m^3 of total water produced, while the cost of an ED unit was about 1.8 \$/m^3. A comparison between the cost ratio of ED and crystallizer and RO unit costs showed that the cost of an ED unit was 2.5 times that of an RO unit **(Nayar et al., 2019).**

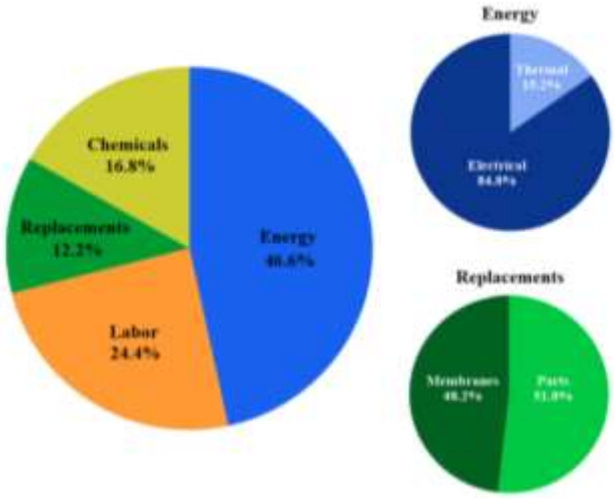

Figure 7. Operating cost of desalination systems **(Karaghouli and Kazmerski, 2013).**

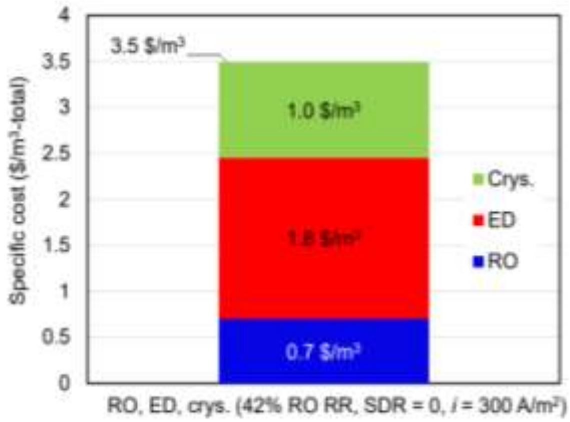

Figure 8. Comparison of specific cost between RO, ED, and crystallizer **(Nayar et al., 2019).**

5. OPERATIONAL PROBLEMS OF ED AND RO SYSTEMS

In an ED system, the force that drives particles to the anion exchange membrane at which a deposit may develop. The driving force for deposition is changed into a driving force for deposit removal by the periodic reversal of the supplied power. ED can operate for a short time at higher turbidities before fouling, but not for very long, and the stacks can be dismantled for maintenance and cleaning. In contrast to the RO system, extreme deposits are particularly challenging to remove with a chemical cleaning solution **(Allison, 2001).** ED with reversal polarity is one of the techniques used in industry to control fouling problems. The electrode polarities and the hydraulic flow streams are periodically reversed in this ED mode. Dilute compartments turn into concentrated compartments quickly when the polarity is reversed, and vice versa. Hence, a particular piece of equipment prevents membrane fouling, dissolves scale seeds, and does not require chemical additions **(Mikhaylin and Bazinet, 2016).** The regular reverse polarity provides a self-cleaning technique to minimize ion exchange membrane surface fouling in the ED process. As a result, the ED system can maintain a steady flow without being affected by membrane fouling. Compared to RO, ED systems are stronger physically and chemically needed to switch between the dilute and concentrate streams. Foulants attached to the membrane surface and travelling in one direction were released when the polarity of the electrodes was reversed. As a result, ED with reversal polarity can handle wastewater with a higher level of organic solutes, colloidal particles, and microbes **(Liang, 2003; Hansima et al., 2021).**

In Taiwan, the RO technique is the most widely used method for wastewater desalination due to its high production rate (over 95%). The applicability of the membrane for large-volume wastewater desalination is uncertain because of membrane fouling and high operating costs. In contrast, the ED technique has recently become more prevalent in field tests since it can offer a higher rate of water reclamation and has less fouling **(Chao, 2005)**. The permeability of the RO membrane decreases if the solubility is exceeded and the flow passages clog. These salts may also scale or precipitate on the surface of the membrane. The four most prevalent scale components are calcium carbonate ($CaCO_3$), calcium sulfate (CASO4), barium sulfate (BaSO4), and strontium sulfate ($SrSO_4$). Lowering the water's tendency to foul in the RO membrane is the main objective of any RO pretreatment system (for SW or BW) **(Yin et al., 2020).** An automatic flush system that automatically flushes membrane components before and after an operation may be used on the RO plant to reduce scaling and membrane fouling. Fouling is often managed using built-in membrane flushing devices, such as flowmeters, pressure sensors, and flow timers **(Hao et al., 2021).**

6. SUSTAINABLE ENVIRONMENT

The use of desalination processes has increased globally, which raises concern about environmentally sustainable concentrate management techniques. To reduce the environmental effects of desalination and meet the clean water demand with high operating efficiency, some factors must be considered as integrating desalination with renewable energy sources, using low-grade heat to power thermal desalination, Desalination technologies lead to various environmental problems, such as climate change due to high energy consumption and environmental destruction because of the disruption of large parts of the ocean and harmfully affect the surrounding environment due to brine disposal **(Herrero-Gonzalez et al., 2020).** One method of lowering the salinity of the waste residuals being discharged is to dilute it with municipal wastewater or normal SW before releasing it into the marine environment. According to research, very little harm is done when dilution and quick mixing are employed carefully to reduce brine content **(Meneses et al., 2010)**. In addition, the cost of brine disposal depends on brine volume and features, disposal method, and the required brine treatment before being disposed of. It takes about 5 to 33% of the total cost of the desalination process **(Pramanik et al., 2017)**.

Desalination technologies can be powered by different renewable energy sources, especially in remote areas with many available renewable energy sources. Renewable energy is an attractive substitute to the source of energy for desalination systems replacing conventional sources. RO units powered by a hybrid energy system (photovoltaic wind) without battery storage can be a possible application to produce clean water for small remote communities suffering from poor fresh water and energy supplies **(Ben and Roboam, 2015).** ED process fed by photovoltaic (PV) solar energy can overcome the challenges that arise in SWRO desalination regarding energy consumption. Furthermore, HCl and NaOH, employed in the desalination industry, can be produced from the brines. Therefore, environmental advantages related to the energy supply can be achieved **(Herrero-Gonzalez et al., 2020).**

The main environmental impacts associated with reverse osmosis concentrate (ROC) composition are biofilm formation, changes in seafloor bathymetry, changes in water circulation patterns and local habitat, and changes in sediment transport patterns. More effects are associated with ROC composition, such as salinity, temperature, pH, residual chemicals, reaction byproducts, and heavy metals **(Kress, 2019).**
The increase in salt concentrations of water bodies that are receivers of disposed brine is associated with brine disposal. Brine disposal, which contains high TDS value, adversely affects the marine communities living in surrounding areas and is also esthetically unpleasing and affects soil properties and groundwater. Additionally, the existence of chemical materials used for pretreatment and membrane cleaning and corrosive metals in brine solutions is a critical concern. Due to salinity, temperature, and chemical composition, brine disposal greatly threatens our environment. The salinity and temperatures of brine depend entirely on the unit treatment processes employed. Therefore, new technologies must be studied, including treatment operations and disposal options to manage concentrated solutions from desalination plants **(Katal et al., 2020).**

7. CONCLUSIONS

This work reviews the principle of desalination systems such as reverse osmosis (RO) and electro-dialysis (ED). In addition, the cost and energy consumption, the operational problems, and the sustainability of the RO and ED units are studied to reduce the environmental effects of the desalination process. The main conclusions derived from this review are:

- The RO system used to desalinate seawater and produce freshwater is the most energy efficient. Also, ED technology is suitable for water desalination and treatment with significant environmental benefits, such as high separation efficiency, selectivity, and fewer chemical treatments needed.
- The cost of brine disposal depends on brine volume and features, disposal method, and the required brine treatment before being disposed of, and it takes about 5 to 33% of the total cost of the desalination process.
- RO process showed significantly lower power consumption and operating cost than the EDR process. The studies show that the RO process could be economical for water desalinating when proper development is employed.
- To minimize ion exchange membrane surface fouling in ED unite, a self-cleaning technique is provided by the regular reverse polarity in the ED process.
- RO membrane fouling and scaling could be controlled using various methods, such as automatic flush and RO pretreatment systems.
- Brine solution contains all the sediments, microorganisms, and minerals which severally affect the environment due to discharging into receiving water bodies.
- Different conventional brine disposal methods are the best option to reduce the environmental impacts of brine effluent from RO and ED processes.
- Using renewable energy, such as solar energy, is a nature-based option and the most favourable research and innovation method for decreasing energy consumption associated with desalination systems by generating thermal or electrical energy for desalination technologies.

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