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Review on Technology-Based on Reverse Osmosis

Maha A. Faroon[a], Zainb A.A. Al Saad[b], Fatma A. J. Albadran[c], Lamia A. Ahmed[d]

[a,b,c,d] *Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq*

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ABSTRACT

Reverse osmosis (RO) is a membrane filtering system that uses a semipermeable membrane to remove contaminants from water before sending the purified water to be used in several settings, such as households and factories. The goal of this study is to investigate the process of reverse osmosis and the status of the membrane materials used in the process as advantages and disadvantages of Reverse osmosis. These membrane materials are the driving elements in the process. This review also discusses cleaning membranes, using RO systems for several applications, and new advancements in reverse osmosis. Traditional RO membranes for seawater desalination. This technique is regularly utilized to desalinate seawater for drinking, agricultural, and industrial applications. Reverse osmosis (RO) is a powerful method of purifying water that employs a semi-permeable membrane to filter out harmful bacteria and dissolved solids.

1. Introduction

This article serves as a resource for researchers and engineers interested in reverse osmosis technology's current state and future prospects by highlighting recent developments and identifying potential areas for future research and innovation.

Reverse osmosis (RO) is a remarkable water purification process that employs pressure to propel water molecules through a semipermeable membrane, thus excluding impurities. This method eliminates bacteria, viruses, and dissolved solids like salts and heavy metals. Households popularly use RO to refine tap water in various commercial and industrial applications, including laboratory and medical settings, where purified water is indispensable [1].

Reverse osmosis is a sophisticated and highly effective method of purifying water that utilizes a semipermeable membrane to eliminate impurities from the water. The process operates by subjecting the water to intense pressure, which compels it to pass through the membrane and separates the pollutants from the water. This is the opposite of osmosis, which happens when water flows through a semipermeable membrane from a place with fewer solutes to a place with more solutes [2].

RO systems consist of a membrane, a high-pressure pump, and a collection tank. Water is first filtered to remove large particles, and then passed through the RO membrane at high pressure. The membrane lets water molecules pass through but keeps out bacteria, viruses, and other harmful things and dissolved solids. The purified water is collected in the tank, while the contaminants are discarded [3].

* Corresponding author: Maha A. Faroon; maha.faroon@uobasrah.edu.iq ; +9647804179122

RO systems are incredibly efficient in eliminating diverse contaminants from water, including bacteria, viruses, and s dissolved solids such as salts and heavy metals. They are commonly used in households to purify tap water [4].

2. Reverse Osmosis Process

The reverse osmosis (RO) process typically involves several stages to purify water, including pre-treatment, membrane filtration, and post-treatment [5]. Fig 1. shows a Schematic representation of RO systems [4].

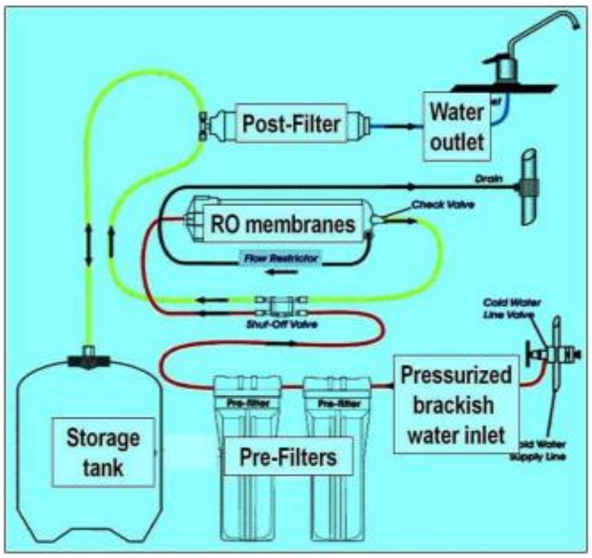

Figure 1. Schematic representation of RO systems [4].

2.1. Pre-treatment

The first stage in the RO process is pre-treatment, which is used to remove any large particles or debris from the water. This is typically done by passing the water through a sediment or sand filter. In some cases, additional pre-treatment steps, such as pH adjustment or aeration may be required to prepare the water for the membrane filtration stage [6].

2.2. Membrane filtration

The next stage is membrane filtration, where most contaminants are removed from the water. The water is passed through a semi-permeable membrane at high pressure using a high-pressure pump, typically around 60-70 psi. The membrane allows water molecules to pass through but blocks contaminants such as bacteria, viruses, and dissolved solids. This purified water is collected in the storage tank, while the contaminants are discarded [7].

2.3. Post-treatment

The final stage in the RO process is post-treatment, which is used to adjust the water's pH, add any essential minerals removed during the filtration process, and disinfect the water. This optional stage depends on the specific application or the desired final product quality [8].

The duration of the process can vary significantly, ranging from as little as half an hour to multiple hours, contingent upon the dimensions of the system, the velocity at which the water flows, and the composition of impurities present in the water.

It's important to note that the RO process can waste a good amount of water depending on the ratio of purified water to wastewater, which makes it less efficient for areas with water scarcity. To make it more efficient, many modern RO systems are coupled with membrane recovery systems or other technologies to increase water recovery and reduce waste.

3. Reverse Osmosis Mechanism and Operation

Reverse osmosis (RO) is a technique to purify water using a semipermeable membrane that can filter out ions, molecules, and larger particles. This membrane selectively permits water molecules to pass through, while preventing dissolved substances and other contaminants from passing through.

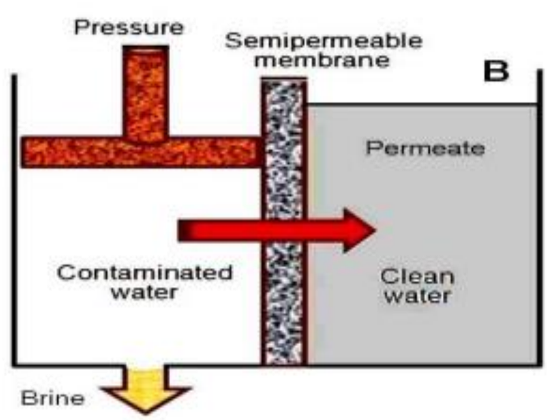

Figure 2. Reverse Osmosis [4].

The process involves applying pressure to contaminated water, which is then forced through the semipermeable membrane, leaving behind the impurities. Fig 2. can be consulted to visualize this process, while Fig 3. provides a schematic of how separation occurs via the reverse osmosis membrane.

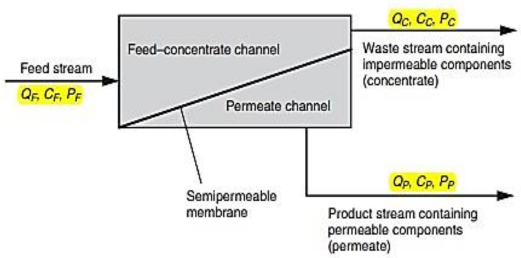

Figure 3. The schematic of separation process through reverse osmosis membrane [4].

The most important equations that govern the RO process are:

1. The osmotic pressure equation:

$$\pi = iCRT \quad (1)$$

The equation for calculating osmotic pressure is $\pi = iCRT$. Here, π represents the osmotic pressure, i is the can't Hoff factor (which denotes the number of ions produced when a solute dissolves in water), R is the universal gas constant, which is equal to 0.083145 Lbar/mol K, and T is the temperature.

2. The mass balance equation:

$$Qf = Qp + Qr \quad (2)$$

where Qf is the feed flow rate, Qp is the permeate flow rate, and Qr is the reject flow rate.

3. $$Jw = \frac{Qp}{A} \quad (3)$$

where Jw is the water flux, Qp is the flow rate permeate, and A is the effective membrane area.

4. The salt rejection equation:

$$R = (1 - \frac{Cp}{Cf})) * 100\% \quad (4)$$

The salt rejection percentage (R) is a dimensionless value expressed as a fraction. It is calculated based on salt concentration in the permeate (CP) and the feed water (CF).

These equations help understand the basic principles of RO and can be used to design and optimize RO systems for various applications. It is important to note that the performance of the RO system depends on various factors such as membrane type, feed water quality, operating conditions, and system design [9].

4. Water Treatment Methods

Water treatment involves eliminating impurities from water to render it suitable for human consumption, industrial applications, or environmental release. Numerous water treatment techniques exist, each with its own set of advantages and disadvantages [10].

1. Filtration: The act of removing particles like sand, sediment, and debris from water by passing them through a filter is called filtration. Different filters, such as sand, activated carbon, and multimedia filters, can be used for this process.

2. Chemical treatment is adding various chemicals to water to eliminate impurities, such as viruses and bacteria. The chemicals commonly used in water treatment include hydrogen peroxide, ozone, and chlorine.

3. Distillation: Distillation involves boiling water and then collecting the steam as it condenses, leaving contaminants and dissolved solids behind. It is a highly effective method for water treatment, but it is also energy-intensive.

4. Coagulation and flocculation are used to remove suspended particles and pollutants. These mechanisms agglomerate particles into bigger, easier-to-remove bulk. Alum or ferric chloride is used to coagulate water. The suspended particles form flocs when the coagulant neutralizes their electrical charges. Flocculation follows coagulation in water treatment. Flocculation softly stirs water to generate bigger flocs. Filtration or sedimentation may remove the flocs. Mixers, paddle wheels, and other agitators may flocculate. Coagulation and flocculation remove suspended particles and pollutants from water but may not remove dissolved solids and other contaminants. These methods

may need costly and environmentally harmful chemicals.

5. Reverse osmosis is a process that uses a semi-permeable membrane to remove salts and minerals from water that have dissolved in it. It is often used to clean seawater or salty water for drinking or in industry.

5. Reverse osmosis Advantages

Reverse osmosis (RO) is a highly effective method for purifying water, and it offers several advantages over other water treatment methods. Some of the key advantages of the RO process include:

1. Reverse Osmosis (RO) is an exceedingly efficient method of purifying water. Its ability to remove a broad spectrum of contaminants from water, including bacteria, viruses, salts, and heavy metals, makes it one of the most effective water filtration solutions. RO's staunch performance can eradicate up to 99% of impurities from water, achieving purification at its zenith [11].

2. Versatility: RO systems offer versatility in terms of water purification. They can effectively purify water from various sources such as tap, well, and surface water. Additionally, they are suitable for treating water for various purposes, including household, industrial, laboratory, and medical use. [12]

3. Low maintenance: RO systems require minimal maintenance, making them a convenient and cost-effective option for households and businesses. The membrane should be replaced periodically to maintain optimal performance [12].

4. RO systems, known for their compact size, are versatile in terms of installation options - be it in homes, offices, or factories [8]

5. Durability: RO systems are built to last and can withstand the rigors of daily use. The high-pressure pump and the membrane are designed to be durable and long-lasting, thus making it a low-cost solution in the long run [13].

6. Environmental friendly: RO systems do not use chemicals in the purification process, making it a safe and environmentally friendly water treatment method [14].

6. Reverse osmosis Disadvantages

While reverse osmosis (RO) is a highly effective method for purifying water, it does have some disadvantages that should be considered. Some of the key disadvantages of the RO process include [15]:

1. High initial and operational costs: Reverse osmosis (RO) systems can be a costly investment in purchase and installation expenses and the energy required for operation. Furthermore, the membranes used in the process must be replaced periodically, which can add to the operational costs.[16]

2. Water waste: RO systems can produce a significant amount of waste water, with up to 80% of the water going to waste. This can be a problem in areas with water scarcity and high-water costs [17]

3. Membrane clogging: RO membranes can become clogged over time due to the presence of certain dissolved solids, such as calcium and magnesium. This can lead to reduced water flow and decreased performance, and the membranes may need to be cleaned or replaced more frequently.[18]

4. Removal of essential minerals: RO systems can remove essential minerals from the water, such as calcium and magnesium. This can make the water less palatable and can also have an impact on human health. Some RO systems have an option of remineralization or you can add mineral drops to the purified water [19]

5. Limited application: RO systems are less effective when treating water with high levels of dissolved gases, such as hydrogen sulfide and carbon dioxide. Additionally, RO is not effective for treating water with high levels of organics, colloids, and bacteria [20]

6. High-pressure requirement: To force water across the membrane during the RO process, high pressure is required, which can be problem in certain areas where water pressure is low [20]

7. Slow water production: The RO process can be relatively slow in producing purified water, depending on the membrane's size and the pressure applied to the water [20].

7. Reverse Osmosis Applications

The water purification method reverse osmosis (RO) has several potential uses. The following are some of the most typical uses of RO [21]:

1. Household use: households widely use RO systems to purify tap water. They can effectively remove many contaminants, including bacteria, viruses, and dissolved solids, making the water safe to drink.
2. Industrial use: Reverse osmosis is a process that uses a semi-permeable membrane to remove salts and minerals from water that have dissolved in it. It is often used to clean seawater or salty water for drinking or in industry.
3. Laboratory and medical use: RO systems are used to produce high-purity water for laboratory and medical applications, including the preparation of reagents, media, and buffers.
4. Desalination: One of the most well-known applications of RO is the desalination of seawater, which can be used to produce freshwater in coastal and island communities where freshwater resources are limited.
5. Food and beverage industry: RO is used in the food and beverage industry to purify water used in the production of drinks, such as soft drinks, and for cleaning and sanitizing equipment.
6. Pharmaceutical industry: RO produces high-purity water for the pharmaceutical industry to produce drugs and clean and sanitise equipment.
7. Power generation: RO is used to purify water for power generation, including removing dissolved solids and impurities from the feedwater used in boilers and steam production.
8. Aquaculture: RO systems, such as fish and shrimp farms, can provide high-quality water for aquaculture systems. Top of Form.

8. Utilization of Membrane Technology in Water Treatment

Scientists and engineers are exploring membrane technology to provide ample high-quality water to meet human, environmental, and industrial demands. This groundbreaking technology utilizes selectively permeable membranes that replace or enhance standard water treatment methods. By applying membrane filtration, undesirable particles, dissolved salts, and organics are selectively removed, significantly improving effluent quality. The retained particle sizes depend on the membrane's pore diameters during filtration. Not only is membrane filtration an effective method for producing clean drinking and process water, it can also be used for industrial processes and treating wastewater, treating sewage in cities, getting products out of water streams, closing water loops., treating groundwater, agricultural waste streams, and percolation waters. A specific type of membrane filtration called membrane bioreactors (MBRs) treat industrial wastewater and municipal sewage by retaining biomass via biologically activated sludge and microfiltration/ultrafiltration (MF/UF) membrane separation. MBRs can effectively replace secondary clarifying and tertiary sand filtration by blocking suspended particles. Membrane distillation (MD) applies a hydrophobic membrane to separate water from other compounds by utilizing vapor pressure. As a result of the development of better membrane materials, forward osmosis, and membrane distillation, membrane separation growth is expected to rise even further. As such, membrane technology has a significant role to play in improving water quality and sustainability, and will become increasingly vital in the global water cycle as research into this area continues. [21]

9. Traditional RO Membranes for Seawater Desalination

Traditional desalination facilities employ reverse osmosis (RO) membranes to extract dissolved salts from seawater. These membranes typically have a pore size of less than 0.1 microns, which is small enough to effectively remove dissolved salts and other impurities from the water [21]

The most common type of membrane used in Traditional desalination RO systems is the thin-film-composite (TFC) membrane. TFC membranes are made from multiple layers of material and are highly effective at removing a wide range of dissolved salts and impurities from water. These membranes can be made from various materials like cellulose acetate, polyamide, and others [21]

Traditional desalination RO membranes are typically made of a highly crosslinked polymer matrix, with a very thin active layer that is typically less than 1 micron thick. The active layer is responsible for the separation of dissolved salts and other impurities, while the polymer matrix provides mechanical strength and durability [21]

The performance of Traditional desalination RO membranes can be affected by several factors, including the temperature and pH of the water, the pressure applied to the water, and the presence of dissolved gases, organics, colloids, and bacteria in the water. Adding chemicals such as chlorine, hydrochloric acid or sodium hydroxide to the feed water is common to control the pH, temperature, and bacteria levels to prevent fouling.

Traditional desalination RO systems are efficient in removing dissolved solids. Still, they can be less efficient in removing other impurities such as dissolved gases, organics, and bacteria, and thus often require pre-treatment stages to remove those. The membranes can also be sensitive to high pressure, temperature, and chemicals, so operating and maintaining them properly is important [21].

10. Membrane Characteristics

Membranes used in reverse osmosis (RO) systems have several characteristics that affect their performance and suitability for a particular application. These characteristics include pore size, permeability, selectivity, durability and chemical resistance, temperature and pressure tolerance, operating flux and fouling resistance. The membrane's pore size determines its ability to remove dissolved solids and other impurities from the water. Permeability and selectivity determine the ease with which water molecules pass through the membrane and how effectively it separates different types of molecules. Durability and chemical resistance, temperature and pressure tolerance, operating flux, and fouling resistance are all important factors that affect the lifespan and maintenance requirements of the membrane. The appropriate membrane characteristics for a specific application will depend on the source water quality and the contaminants that must be removed [21].

11. Cleaning of a Membrane Used in a RO System

The frequency of cleaning reverse osmosis (RO) system membranes depends on several factors, including the source water quality, the system's operating conditions, and the specific contaminants that need removal. In general, it's recommended to schedule regular cleaning of the membrane at intervals that are based on the following criteria:

1. Water quality: The quality of the source water will affect the rate of fouling and the need for cleaning. High dissolved solids, organic matter, microorganisms, and other contaminants require more frequent cleaning.
2. System operating conditions: Factors such as the temperature, pressure, and pH of the source water can affect the rate of fouling and the need for cleaning. Systems that operate at higher temperatures and pressures, or with higher pH levels, will generally require more frequent cleaning.
3. Membrane type: Different membranes have varying resistance to fouling and different cleaning requirements. Polyamide membrane typically require more frequent cleaning than TFC or CA membrane
4. Water production rate: High water production rates will require more frequent membrane cleaning to maintain optimal performance.
5. Conductivity or TDS measurement: Continuously monitoring the conductivity or Total Dissolved Solids (TDS) in the permeate water, is a positive sign of the fouling of the membrane and the need for cleaning. As the membrane becomes fouled, the conductivity of the permeate water will increase.

In general, a routine membrane cleaning schedule should be established, to ensure that the membrane is cleaned regularly, before fouling becomes severe and causes a significant reduction in water production. It's important to consult with a water treatment professional to determine the appropriate cleaning schedule for your specific system and water source [22].

12. Insights from Recent Research Studies

Hailemariam et al. (2020) examined the materials commonly used in reverse osmosis membrane fabrication and the advancements in reverse osmosis technologies. The study analyzed the benefits and drawbacks of using reverse osmosis for water treatment and desalination, and found that polyamide thin-film composite (PA-TFC) is the most frequently used material for RO membrane synthesis. Significant advancements in material science, process optimisation, system optimisation, membrane synthesis techniques, and reverse osmosis adaptations were also emphasised in the review. Furthermore, the study noted that polyamide (PA) is commonly used to fabricate RO membranes and that numerous research works have been conducted for their development [23].

Burlace and colleagues, in their 2022 publication, delve into fouling and its prevention in batch reverse osmosis. They aim to assess the progress made in reverse osmosis technology and gain insight into the fouling and scaling phenomena. Batch reverse osmosis features unique flow characteristics not seen in traditional reverse osmosis, such as osmotic backwashing, feed flow reversal, salinity cycling, and water hammer/pulse flow. The authors also examine the latest developments in reverse osmosis technology to enhance its efficiency and longevity [24].

In their 2022 review, Rashidi and colleagues examine research on desalination systems that utilize wind energy. They suggest that incorporating hybrid systems, which combine wind turbines with other technologies, can enhance the reliability of these systems and help address the intermittent nature of wind. However, the cost-effectiveness of using hybrid energy depends on the particular case study and the availability of other renewable energy sources. Depending on the hybrid energy system's structure and components, the price of generating freshwater might range widely [25].

In conclusion, reverse osmosis (RO) membrane technology has changed significantly over the years and is now a common way to purify and desalinate water. New materials and ways to change them have improved RO membrane performance, such as better selectivity, durability, and resistance to clogging. Renewable energy sources, such as wind energy, could also power RO systems cleanly and sustainably. RO membrane technology will keep improving and more useful as more research and development is done in these areas, especially where getting clean water is hard.

13. Recent Advances in Reverse Osmosis

Several new developments in reverse osmosis (RO) technology aim to improve water treatment systems' efficiency, cost-effectiveness, and sustainability. Some of the most notable developments include:

1. Membrane materials: Researchers are developing new types of membrane materials that can improve the performance and durability of RO systems. For example, some researchers are exploring ceramic membranes and others are developing new types of polymer membranes that can withstand higher temperatures and pressures, and are more resistant to fouling [26].
2. Energy recovery devices: Energy recovery devices (ERDs) are designed to reduce the energy consumption of RO systems by recovering some of the energy lost during the desalination process. This can include using pumps to recover energy from the brine stream or devices that convert pressure into electrical energy [26].
3. Advanced pretreatment: Pretreatment is an important step in the RO process, it is used to remove particles, dissolved solids, and other impurities that can foul the membrane. Researchers are developing new methods for pretreatment, such as biofiltration and membrane bioreactors to remove dissolved organics, and more advanced methods for particle removal, such as ceramic ultrafiltration [27].
4. Forward osmosis: (FO) is a relatively new technology in which osmotic pressure separates dissolved solids from water. It can be more energy-efficient than traditional RO systems and can be used to desalinate seawater and treat municipal and industrial wastewater [27].
5. Integrated systems: Integrated systems combine different desalination technologies to produce high-quality water with lower energy consumption and costs [28].

These new developments in RO technology can potentially improve the efficiency and sustainability of water treatment systems and make desalination more cost-effective. However, it's important to note that while some of these developments are in the advanced stages of research and development, others are still in the early stages.

14. Conclusion

RO is an effective technique for water purification. water that employs a semi-permeable membrane to filter out harmful bacteria and dissolved solids. The method is used to desalinate seawater for potable, agricultural, and industrial applications. There are a few issues with the system, including its high energy consumption, the need for regular cleaning and maintenance, and membrane fouling. Technology advancements are being made to increase water quality and make the systems more efficient and sustainable.

Overall, RO technology is a reliable and effective way to make good drinking water. It has a lot of advantages over other ways to treat water, such as getting rid of a wide range of contaminants, having low operating costs, and using less energy. But there are also some problems with RO technology, such as the need for regular maintenance, the fact that it creates wastewater as a byproduct, and the chance that the membrane will get clogged or scaled. Even with these problems, RO technology is likely to remain an important part of water treatment and desalination for the foreseeable future. This is especially true as water scarcity becomes a bigger problem in many parts of the world.

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