

## Water Filtration through Membrane Desalination Technology: A Review

Mohd Arsalan\*

Department of Applied Chemistry, Aligarh Muslim University, Aligarh, Uttar Pradesh, India

### ABSTRACT

Desalination is a technique where excess salts are removed from the sea or brackish water and converting into safe potable or usable purified water. It is a process that takes away mineral components from saline water. Therefore, the produced water will be most suitable for human consumption and irrigation purposes. The by-product of desalination process is brine (common salt). Desalination methods are primarily categorized into thermal distillation processes and membrane processes. The principle of desalination process is mainly depends on thermal, electrical, and pressure, where the thermal distillation is an oldest method and it may be nearly thousands of years old. In thermal distillation, the water is boiled and then the evolved steam is collected and cooled which turns into fresh water, and it leaves the dissolved salt behind in the vessel. While the membrane separation must requires driving forces such as applied and vapor pressure, electric potential and concentration to overcome the natural osmotic pressures, which results to force the water through membrane. It is apparent that this technology is much energy intensive and the qualitative research is continuously evolving to improve the separation efficiency and reduce the energy consumption. Reverse osmosis (RO) and Nanofiltration (NF) are the leading pressure driven membrane processes. Seawater desalination has the potential to reliably produce enough fresh water to support the large populations located near the coastal areas around the world.

**Key words:** Membrane technology, Thermal distillation process, Membrane desalination processes: Reverse osmosis, Nanofiltration, Microfiltration.

## 1. INTRODUCTION

### 1.1. Water Scarcity

Water is very essential for all living beings means that water is life; globally water covers nearly 70% area of earth's surface. It is appearing that the major portion of earth is covered by water body. Water scarcity or water stress is the lack of fresh water resources to meet the standard water demand. Humanity is facing water crisis due to the unequal distribution, that is, climatic changes, resulting in some very wet, and some very dry geographic locations. Water scarcity can also be caused by droughts, lack of rainfall, or pollution etc. The increasing world population, improving living standards, changing consumption patterns, and expansion of irrigated agriculture are the main basic factors for rising the global demand of water [1].

Across the world in most of the countries, there is severe shortage of drinking water found. In coming days, water shortages will be more prevalent among the poorer countries, where the resources are limited and population growth is rapid. Nowadays, around 700 million people in nearly 43 countries are suffering from water scarcity. By 2025, it is appearing that nearly 1.8 billion people will be living in countries or regions with absolute water scarcity, and also two-thirds of the world's population could be living under water stressed conditions [2]. Although, the seas/oceans covers earth's major portion and while there is severe shortage of potable water in mainly developing countries all around the world is found. The reason for this situation is that nearly 97.5% of earth's water is salty water and remaining 2.5% is fresh water which is in the form of ground water, ice-mountains, lakes, and rivers, etc. Therefore, to overcome the problems related to fresh water availability and consumption the novel desalination process of water purification indicating the most importance around the globe [3,4].

### 1.2. Water Purification Process

In countries, where waterborne diseases result in over 10,000 deaths each year and we do not need to emphasize why there is an urgent need for a water purification system in every household. While government might be doing their best to provide us with purified drinking water, but we must have a responsibility to ensure that our homes and workplaces are fitted with an electric water purifier for safe and clean water. Water purifiers are very essential to every home. With an increase in deadly diseases, it has become imperative to invest in a water purifier that ensures clean water for consumption [5].

The standards for drinking water quality are typically set by governments or by international standards. These standards usually include minimum and maximum concentrations of contaminants, depending on the intended use of water. Simple visual inspection cannot determine if water is inappropriate quality. Simple procedures such as boiling or distillation and the use of a household activated carbon filter are not sufficient for treating the all possible contaminants that may be present in water from an unknown source. There are some simple techniques may be used for treating the impure water at home, such as chlorination, filters, and solar disinfection, and for storing it in

### \*Corresponding author:

E-mail: mohdarsalan.chem@gmail.com

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safe containers could save a huge number of lives each year. Reducing deaths from waterborne diseases is a major public health goal in all the developing countries [6,7].

Municipal drinking water systems use various methods of water treatment to provide the safe drinking water for their society. Hence, water purification may be done by some physical processes such as coagulation and flocculation, filtration, sedimentation, disinfection and distillation, and by some biological processes such as slow sand filters or biologically active carbon, while chemical processes include flocculation and chlorination as well as the use of electromagnetic radiation (ultraviolet light).

Water purification has reduce the concentration of matter such as suspended particles, parasites, bacteria, algae, viruses, and fungi, and it reduces the concentration of a range of dissolved solids and particulate matter. The water found in the nature is never pure. The impurities come mainly in two states, that is, total suspended solids (TSS) and total dissolved solids (TDS). TSS are the particles that are larger than 2 microns and found naturally in the water body while the particles smaller than 2 microns (average filter size) are considered as dissolved solid. The more solids present in the water the less clear will be the water. Hence, it is very essential to drink the purified water because it has protected from harmful organisms as well as the toxic metals. There is some very important water purification processes used in present-day all around the world, these processes are mainly thermal distillation and membrane based techniques. Hence, the membrane based technology is clearly discussed in this review, where predominantly this technology is mostly used for the desalination process [8].

### 1.3. Thermal Distillation Process

Thermal distillation is an oldest and simplest method, where the seawater that has been drawn from the sea or ocean is filtered to remove the salts or impurities. The liquid is heated to produce vapor in a vessel that collects the salts. The evolved vapor is subsequently condensed into a container which then converted to a mineral-free liquid. While, the membrane distillation is relatively a new process and it has been commercially introduced only in the last few years. The process works using a specialized membrane which will pass water vapor but not liquid water. This membrane is placed over a moving stream of warm water, and as the water vapor passes through the membrane it is condensed on a second surface which is at a lower temperature than that of the feed water.

Power plants refineries and other valuable industries need high purified water for the processing. The thermal desalination process uses energy to evaporate water and subsequently condense it again. When there is waste heat or sufficient electricity available it can be properly used for distillation, as is often the case with refineries and power plants, the thermal desalination should be an efficient and viable solution [9,10].

Modern methods for the distillation of large quantities of salt water rely on the fact that the boiling temperature of water is lowered as air pressure drops, significantly reducing the amount of energy needed to vaporize the water. The three types of systems which found distillation processes are multistage flash distillation, multiple-effect distillation, and vapor-compression distillation. Distillation offers significant savings in operational and maintenance costs compared with other desalination technologies. In most cases, thermal distillation does not require the addition of chemicals or water softening agents to pre-treat feed water. The thermal distillation plants are much energy-efficient and cost-effective, and many plants are fully automated and require a limited number of personnel to operate. Thermal distillation has minimal environmental impacts, and this technology also produces

high quality water. The thermal distillation can be combined with other processes, such as using heat energy from an electric-power generation plant [11].

### 1.4. Desalination Processes

The main goal of the desalination process is to produce freshwater for the purpose of drinking, irrigation, or industrial usage. Desalination is the process by which minerals and salts are removed from seawater, brackish water, and it makes pure water for various domestic as well as industrial uses. Many industries need processed water for manufacturing, water treatment and other activities. Sometimes, the quality of water is not adequate or does not meet the quality standard for production purposes. In this regard, industries use the desalination plants to purify water for their best use. The growing need of safe, reliable, and consistent supply of water had made many manufacturing industries and water treatment plants to look for efficient desalination plants [10]. As the competition has increased, industries are trying to improve efficiency and quality of their products and services. To achieve their goals, the desalination plants are designed for providing better quality water for various industrial uses. Using a desalination plant for water purification is much more viable in terms of efficiency and cost. Advanced desalination technologies that are applied to seawater and brackish water proven to be an effective alternatives in a variety of situations. It is focuses on upcoming trends in modern desalination technologies and emphasizing the options offered by them. There are various thermal processes such as multistage flash distillation, multiple effect distillation, vapor compression evaporation, cogeneration, and solar water desalination. Membrane processes are also showing many categories such as reverse osmosis, electro dialysis, and membrane distillation methods [12].

Hence, seawater is pumped into the desalination plant and passes through pre-treatment filtration to remove most of the large and small particles, and filtered seawater is then forced under pressure through membranes which then the final filtration of potable water formed and is ready of the best use for the society. Hence, there are many advantages of desalination processes which reducing the scarcity of water in various areas, that is, desalination system provide a solution for the areas that have limited resources of fresh water and a reliable alternative source of water in times of severe drought. Progressive improvements in the performance of membranes have greatly enhanced the use of seawater desalination as an alternative for fresh and potable water production. As the freshwater supply is limited, so we should preserve its resources by utilizing the method of desalination to eliminate water shortage crisis that the world might be faces. It is almost an inexhaustible source to produce freshwater, so even in times of droughts, there will be sufficient access to fresh water supply. Membrane processes mainly show the following methods [13].

#### 1.4.1. Electro dialysis (ED)

Today conventional ED is commercially by far the most relevant of ion-exchange membrane separation process. By application, ED is replaced to some extent by other membrane processes such as reverse osmosis, microfiltration, and nanofiltration. ED is an electrochemical membrane separation process by which electrically charged membranes are used to separate the ions from an aqueous solution by the driving force of an electrical potential difference [14]. These days ED is used mainly for desalination of sea and brackish water. Electro dialysis reversal (EDR) was developed as an innovation to electro dialysis with the additional feature of polarity reversal of the electrodes, thereby switching the flow of ions. This reversal acts as a self-cleaning feature that minimizes the fouling and prolongs membrane life. ED is performed by an electro dialysis cell, which consist of a feed (dilute) compartment and a concentrate (brine) compartment formed by an anion exchange or a

cation exchange membrane placed between the two electrodes. ED processes are different from distillation and other membrane based processes such as reverse osmosis (RO) and nano filtration in that dissolved species are moved away from the feed stream rather than the reverse, because the quantity of dissolved species in the feed stream is far less than that of fluid. It offers the practical advantage of much higher feed recovery in many applications. The water desalination is still the most important large-scale application of electro dialysis. ED is very useful for water treatment, aiding in the removal of mineral salts, sulfate, nitrate, etc., from brackish or seawater. There are many applications, however, particularly in the industrial space, where brackish water desalination is integral to operations. It can also be used for the concentration of charged species in aqueous solutions. But other applications of electro dialysis in the food, the pharmaceutical and chemical industry as well as in wastewater treatment are gaining increasing importance. Another large-scale application of electro-dialysis is the pre concentration of seawater for the production of table salt. [15,16]

#### 1.4.2. Membrane distillation (MD)

MD is a phase separation method whereby saline water is heated to produce water vapor, which is then condensed to produce freshwater. It is a water desalination membrane process currently in limited commercial use. MD is a hybrid process of RO and distillation in which a hydrophobic synthetic membrane is used to permit the flow of water vapor through the membrane pores, but not the solution itself. A membrane used as a barrier for the liquid phase, allowing the vapor phase (e.g., water vapor) to pass through the membrane's pores. The driving force of the process is a partial vapor pressure difference commonly triggered by a temperature difference. It is a promising technology for treating saline and wastewater with high rejection factors, which cannot be accomplished by conventional technologies [17,18]. The processes of MD that uses a membrane to separate materials depend on static pressure difference as the driving force between two bounding surfaces such as reverse osmosis, or a difference in concentration such as dialysis or an electric field. Membranes used for membrane distillation (MD) inhibit passage of liquid water while allowing permeability for free water molecules and thus, for water vapor. These membranes offer pores with a standard diameter between 0.1 and 0.5  $\mu\text{m}$ .

MD indicated promising technology for separation processes due to its unique properties. Water which is a key component of chemical and physical processes and high separation factor are the most attractive characteristics of MD technology. Nowadays, it is predominantly used in environmental, food, pharmaceutical, and nanotechnology industries. It is used in desalination of sea water, brackish water, groundwater, and brines brought from other units. It is also used for the preparation of distilled water, pure water, and ultrapure water for medical and pharmaceutical purposes [19-21].

#### 1.4.3. Reverse osmosis (RO)

RO is a technology that is used to remove a large majority of contaminants from water by pushing the water under pressure through

a semi-permeable or porous membrane. It is a special case of diffusion in which the molecules are water and the concentration gradient occurs across a membrane. RO occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration. This process leaves a higher concentration of solute (salt) on one side and only the solvent (fresh water) on the other. RO works using a high pressure pump to increase the pressure on the salt side of the RO and force the water across the semi-permeable membrane, leaving almost all the dissolved salts behind in the reject stream [22,23]. The amount of pressure required depends on the salt concentration of the feed water. The desalinated water that is deionized called permeate water, while the water stream that carries the concentrated contaminants which is not passed through the RO membrane is called the reject or concentrate stream. RO is capable of removing nearly more than 99% of the dissolved salts, particles, colloids, organics, bacteria, and pyrogens from the feed water. This membrane rejects contaminants based on their size and charge. RO is very effective in treating brackish, surface and ground water for both large and small flows applications. There are many industries that use RO water such as pharmaceutical, boiler feed water, food and beverage, metal finishing, and semiconductor manufacturing [24]. The schematic representation of RO membrane is indicated by following Figure 1.

If there is a semi-permeable barrier which allows the water to diffuse across the membrane from a lower to higher concentration so that both sides are at equilibrium which is called as osmosis or forward osmosis. While RO uses the semi-permeable barrier that allows the higher concentrated salt solution to the lower concentrated saline water solution side. When you think about RO, you think of high-pressure pumps, high-pressure vessels, stainless steel, and lots of energy; because you have to overcome that natural osmotic gradient and then have additional pressure to actually force water through. However, there is a drawback of RO, that is, it removes a number of healthy minerals from water along with the harmful minerals and particles. The removal of these minerals such as calcium and magnesium can actually make water unhealthy. Therefore, the addition of required calcium and magnesium ions into the pure drinking water can easily resolve these problems [10].

#### 1.4.4. Nanofiltration (NF) membrane

NF is a filtration technique where the size of the membrane pores is in nanometer. These membranes have pore sizes from 1–10 nanometre smaller than that used in microfiltration and ultra-filtration, but just larger than that in reverse osmosis technique. NF is a relatively recent membrane filtration process used most often with low total dissolved solids water such as surface as well as fresh groundwater, with the purpose of water softening and removal of disinfection by-product precursors such as natural plus synthetic organic matter. Devices of NF membranes are specifically designed to eliminate the viruses from contaminated sources. In most of the cases, the working parameters such as flow rate, temperature, nature of membrane, load of virus, and

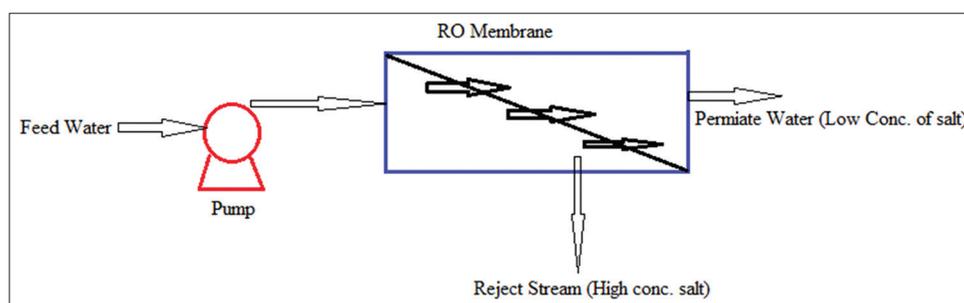


Figure 1: The schematic representation of RO membrane.

filter area are optimized for efficient and reproducible elimination of specialized virus. Polymer thin films are predominantly used for the NF membranes. The materials that commonly used are polyethylene terephthalate and metals such as aluminum and tungsten [25,26].

The main applications of NF are in water treatment for drinking water production as well as wastewater treatment and also its reuse. NF can be used to treat the all kinds of water including groundwater, surface water, and wastewater or as a pre-treatment for desalination process. NF membranes have ability to remove turbidity, microorganisms, and hardness of water. This process significantly shows lower operating pressure and provides a much more energy-efficient process compared with RO membranes. Nowadays, nanofiltration membrane is becoming more widely used in food processing applications. The research and development in solvent stable membranes have allowed the application for nanofiltration membranes to extend into new emerging areas such as pharmaceuticals, chemicals, flavor, and fragrance industries [27]. By Figure 2, the nanofiltration membrane is represented as follows.

The performance under natural conditions of a membrane is based on the ratio of solute retained/permeated percentage through membrane. Retention of both the charged and uncharged solutes and permeation measurements can be categorized into their performance parameters. For charged solutes, the ionic distribution of salts near the membrane-solution interface plays an important role in determining the retention characteristic of a membrane. If the charge of the membrane and the composition plus concentration of the solution to be filtered is known, the distribution of various salts can be found. While uncharged solutes cannot be characterized simply, although in general an increase in molecular weight or solute size leads to an increase in retention. The valence charge, chemical structure, functional groups as well as pH of the solute may play an important role in determining the retention characteristics of membrane [27-31].

#### 1.4.5. Ultrafiltration (UF) membrane

UF is a type of membrane filtration in which forces such as pressure and concentration gradients lead to a separation through semi permeable membrane. Suspended solids and solutes of high molecular weight are retained by the membrane, while water and low molecular weight solutes pass through the membrane in the form of filtrate. This separation process is used in industries as well as in research for purifying and concentrating macromolecular such as protein solutions. In other words, UF is a low pressure membrane process used for water treatment which particularly designed to remove the turbidity causing particles including those comprised of suspended solids, bacteria, colloidal matter, and proteins. UF can also remove protozoa and some viruses from the water. A UF system may be selected over an RO

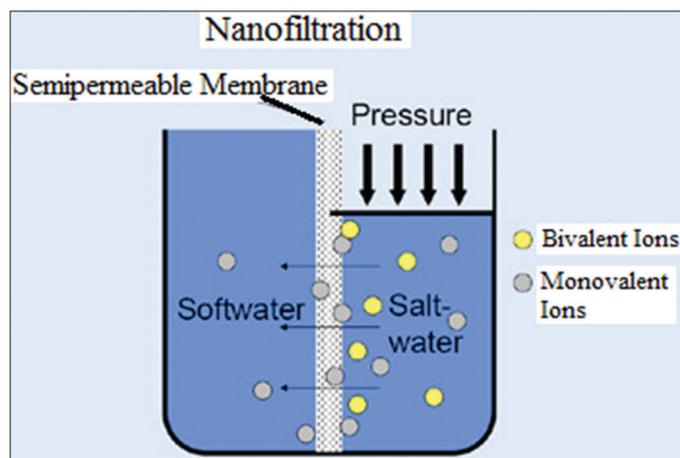


Figure 2: Indicated the activity of nanofiltration membrane.

system because it wastes less water to the drain. UF is frequently used to pre-treat surface water, seawater, and biologically treated municipal water for upstream of the reverse osmosis unit [32,33]. Following Figure 3 shows the representation of UF membrane.

UF is not fundamentally different from microfiltration. Both of these separate the molecules based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate the substances based on the process of absorption and the rates of diffusion. UF system uses standard home water pressure to push water through a semi-permeable membrane and remove any contaminants. Unlike reverse osmosis, ultrafiltration retains desirable minerals in the water body. UF systems use a hollow fiber membrane, which filters water from the inside out. UF provides a large surface area for particles to adhere while the other membranes like the spiral wound RO membrane filter from the outside in. The hollow fiber membrane has a high chemical resistance to oxidants and chlorine and other RO membranes do not show such chemical stability and resistance. A RO system provides the most extensive filtration because this membrane has the smallest pore size. A UF system retains beneficial minerals while an RO system removes the important salts. However, this means that an ultrafiltration system does not remove salts, fluoride, or TDS dissolved in water. An ultrafiltration system also operates on low water pressure, but a reverse osmosis system needs a booster pump to increase water flow for operation. Industries such as chemical and pharmaceutical manufacturing, food and beverage processing, and waste water treatment, make use of ultrafiltration to recycle flow or add value to later products and blood dialysis also utilizes ultrafiltration membranes [34].

#### 1.4.6. Microfiltration membrane

Microfiltration is a type of filtration process where the contaminated water is passed through a porous membrane to separate microorganisms and suspended solids from the liquid. Microfiltration may also be used in combination with other membrane technologies such as reverse osmosis, nanofiltration, and ultrafiltration [35,36]. Microfiltration filters can be made with both organic materials, such as polymer based membranes, as well as inorganic materials, such as ceramic or stainless steel. Microfiltration membranes have the most open pore sizes of all polymeric membranes. With a pore size range of 0.1–10  $\mu\text{m}$ , microfiltration membranes are capable of separating large suspended solids such as colloids, particulates, fat, and bacteria, while allowing sugars, proteins, salts, and low molecular weight molecules pass through the membrane [37,38]. Figure 4 shows the transportation of various ions through microfiltration membrane.

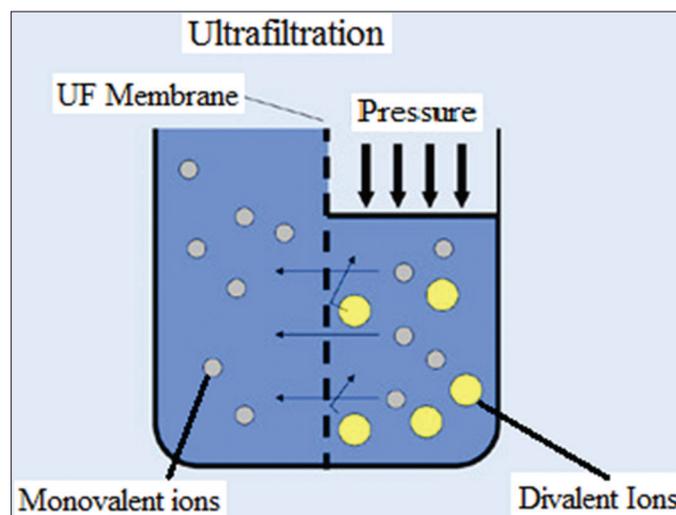
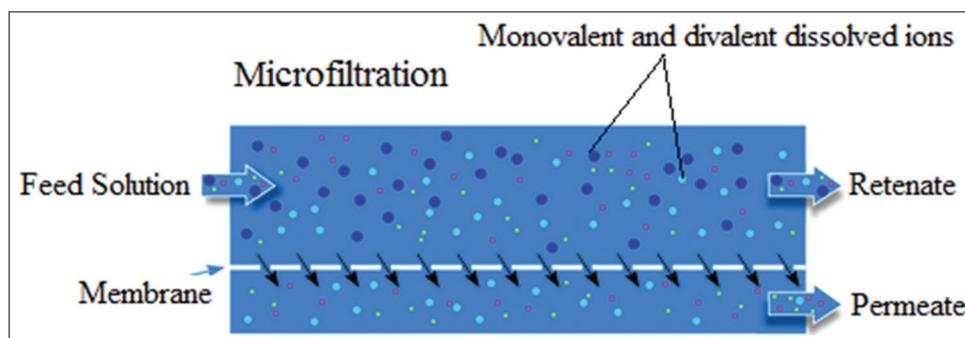


Figure 3: Schematic representation of UF membrane and their activity with different ions.



**Figure 4:** The transportation of various dissolved ions through microfiltration membrane.

The principle of micro filtration is a physical separation in which the dissolved solids, turbidity and microorganisms can remove by determining the size of the pores in membranes. Substances that are larger than the pores are fully removed while the smaller one can partially remove that depends on the presence of a refuse layer on membrane. The micro and ultrafiltration are the pressure dependent processes, which remove dissolved solids and substances from water to a lesser extent than nano filtration and reverse osmosis. MF processing is widely used in the food industry for applications such as wine, juice, and beer clarification, for wastewater treatment, and plasma separation from blood for therapeutic and commercial uses. In biotechnology industries, MF shows applications such as cell recycle and harvesting, separation of recombinant proteins from cell debris, and purification of process streams. These microfiltration membrane filters are showing to sustain excellent chemical and heat resistance, and also available in maximum configurations, to provide the flexibility for customization around the specific process applications [37,39].

## 2. CONCLUSIONS

Water scarcity or water stress is the lack of fresh water resources that should meet the standard water demand and it caused mainly by the droughts, lack of rainfall, or pollution, etc. Desalination is an important process, where the salts are removed from sea or brackish water and converted into fresh water. The water impurities are mainly in two states, the total suspended solids and total dissolved solids. Total suspended solids are the particles that are larger than 2 microns and found naturally in the water body while the particles smaller than 2 microns are considered as dissolved solid. There are some water purification processes such as thermal distillation and membrane based techniques which are used in present-day all around the world. The principle of desalination process is mainly depends on thermal, electrical, and pressure, where the thermal distillation is much oldest method. Membrane technology constitutes diverse applications in the field of water filtration, especially for the desalination processes. This review summarizes the fundamental aspects and applications of processes such as reverse osmosis, ultrafiltration, microfiltration, nanofiltration, and ED. At present, reverse osmosis and nanofiltration are the most leading pressure driven membrane technology, and it is much energy intensive and cost effective processes which continuously growing to improve the separation efficiency of saline water. Hence, seawater desalination has the potential to consistently produce enough fresh water to support the large populations located near the coastal areas all around the world.

## 3. REFERENCES

1. C. J. Vörösmarty, P. Green, J. Salisbury, R. B. Lammers, (2000) Global water resources: Vulnerability from climate change and population growth, *Science*, **289**: 284-288.
2. World Economic Forum, (2019) *Global Risks Report (2019)*, Cologny: World Economic Forum.
3. D. Colombo, D. M. Gerloni, M. Reali, (1999) An energy-efficient submarine desalination plant, *Desalination*, **122**: 171-176.
4. M. Eyvaz, E. Yüksel, (2018) *Desalination and Water Treatment*, London: Intech Open.
5. Narayana Health, (2019) *Effects of Water Borne Disease in Health and its Prevention*, Bengaluru: Narayana Health.
6. A. Malik, A. Yasar, A. B. Tabinda, M. Abubakar, (2012) Water-borne diseases, cost of illness and willingness to pay for diseases interventions in rural communities of developing countries, *Iranian Journal of Public Health*, **41**: 39-49.
7. WHO/UNICEF Joint Monitoring Programme, (2005) *Water for Life: Making it Happen*, Geneva: World Health Organization and UNICEF.
8. P. J. Michaud, (1994) Measuring total suspended solids and turbidity in lakes and streams. In: *A Citizen's Guide to Understanding and Monitoring Lakes and Streams*. Washington, DC: Puget Sound Water Quality Authority.
9. Desalination, (2007) *The American Heritage Science Dictionary*, Boston: Houghton Mifflin Company.
10. A. Panagopoulos, K. J. Haralambous, M. Loizidou, (2019) Desalination brine disposal methods and treatment technologies - A review, *Science of the Total Environment*, **693**: 133545.
11. S. Khan, A. Nakhbov, (2020) *Nuclear Reactor Technology Development and Utilization*, Cambridge, UK: Woodhead Publishing.
12. T. A. Davis, M. C. Porter, (1990) Electrodialysis. In: *Handbook of Industrial Membrane Technology*, New Jersey: Noyes Publications.
13. A. D. Khawaji, I. K. Kutubkhanah, J. M. Wie, (2008) Advances in seawater desalination technologies, *Desalination*, **221**: 47-69.
14. H. Strathmann, (2010) Electrodialysis, a mature technology with a multitude of new applications, *Desalination*, **264**: 268-288.
15. J. B. Tonner, J. Tonner, (2004) Desalination and energy use. In: *Encyclopedia of Energy*, Amsterdam, Netherlands: Elsevier Science.
16. S. Khan, S. Haider, (2018) Nuclear energy powered seawater desalination. In: *Renewable Energy Powered Desalination Handbook: Application and Thermodynamics*, Oxford: Butterworth-Heinemann.
17. D. M. Warsinger, A. Servi, G. B. Connors, J. H. Lienhard, (2017) Reversing membrane wetting in membrane distillation: Comparing dryout to backwashing with pressurized air, *Environmental science, Water Research and Technology*, **3**: 930-939.
18. A. Deshmukh, B. Chanhee, V. Karanikola, S. Lin, A. P. Straub,

- T. Tong, D. M. Warsinger, M. Elimelech, (2018) Membrane distillation at the water-energy nexus: Limits, opportunities, and challenges, *Energy and Environmental Science*, **11**; 1177-1196.
19. A. Alkhdhiri, N. Hilal, (2018) Membrane distillation-principles, applications, configurations, design, and implementation. In: *Emerging Technologies for Sustainable Desalination Handbook*, Oxford: Butterworth-Heinemann, p55-106.
20. K. Karakulski, M. Gryta, A. Morawski, (2002) Membrane processes used for potable water quality improvement, *Desalination*, **145**: 315-319.
21. V. Bruggen, (2013) Integrated membrane separation processes for recycling of valuable wastewater streams: Nanofiltration, membrane distillation, and membrane crystallizers revisited, *Industrial and Engineering Chemistry Research*, **52**: 10335-10341.
22. D. M. Warsinger, E. W. Tow, K. G. Nayar, L. A. Maswadeh, J. H. Lienhard, (2016) Energy efficiency of batch and semi-batch (CCRO) reverse osmosis desalination, *Water Research*, **106**: 272-282.
23. J. Balster, (2005) Preparation and characterisation of monovalent ion selective cation exchange membranes based on sulphonated poly(ether ether ketone), *Journal of Membrane Science*, **263**: 137-145.
24. J. Crittenden, T. Rhodes, H. David, H. Kerry, T. George, (2005) *Water Treatment Principles and Design*, 2<sup>nd</sup> ed. New Jersey: John Wiley and Sons.
25. R. Yagnaseni, W. David, L. H. John, (2017) Effect of temperature on ion transport in nanofiltration membranes: Diffusion, convection and electromigration, *Desalination*, **420**: 241-257.
26. L. A. Baker, C. Martin, (2007) Nanotechnology in biology and medicine: Methods, devices and applications, *Nanomedicine: Nanotechnology, Biology and Medicine*, **9**: 1-24.
27. A. Rahimpour, (2010) Preparation and characterization of asymmetric polyethersulfone and thin-film composite polyamide nanofiltration membranes for water softening, *Applied Surface Science*, **256**: 1657-1663.
28. V. K. Shahi, (2003) Studies on the electrochemical and permeation characteristics of asymmetric charged porous membranes, *Journal of Colloid and Interface Science*, **262**: 566-573.
29. R. D. Letterman, (1999) *Water Quality and Treatment*, 5<sup>th</sup> ed. New York: American Water Works Association and McGraw-Hill.
30. V. Souza, M. Quadri, (2013) Organic-inorganic hybrid membranes in separation processes: A 10-year review, *Brazilian Journal of Chemical Engineering*, **30**: 683-700.
31. P. Y. Apel, (2006) Structure of polycarbonate track-etch: Origin of the "Paradoxical" pore shape, *Journal of Membrane Science*, **282**: 393-400.
32. M. Clever, F. Jordt, R. Knauf, N. Rübiger, M. Rüdibusch, R. H. Scheibel, (2000) Process water production from river water by ultrafiltration and reverse osmosis, *Desalination*, **131**: 138-145.
33. J. M. Laine, D. Vial, M. Pierre, (2000) Status after 10 years of operation — overview of UF technology today, *Desalination*, **131**: 17-25.
34. A. Y. Tamime, (2012) *Membrane Processing Dairy and Beverage Applications*, Chichester: Wiley.
35. C. Charcosset, (2012) *Membrane Processes in Biotechnology and Pharmaceuticals*, Amsterdam, Netherlands: Elsevier.
36. K. Scott, (1995) *Handbook of Industrial Membranes*, 2<sup>nd</sup> ed. Amsterdam, Netherlands: Elsevier Science.
37. R. Baker, (2012) Microfiltration. In: *Membrane Technology and Applications*, 3<sup>rd</sup> ed. California: John Wiley and Sons Limited, p303-324.
38. J. Crittenden, R. R. Trussell, D. Hand, K. Howe, G. Tchobanoglous, (2012) *Principles of Water Treatment*, 2<sup>nd</sup> ed. New Jersey: John Wiley and Sons.
39. R. H. Perry, D. W. Green, (2007) *Perry's Chemical Engineers' Handbook*, 8<sup>th</sup> ed. New York: McGraw-Hill Professional, p2072.

#### \*Bibliographical Sketch



Dr. Mohd Arsalan has completed their M.Phil and Ph.D from Aligarh Muslim University Aligarh-India and he was an Assistant Professor in Department of Applied Chemistry Aligarh Muslim University Aligarh. He has nearly four years of teaching experiences as an Assistant Professor in the Department of Applied Chemistry, Dept of Chemistry and University Polytechnic, AMU, Aligarh. He has published more than 18 reputed research papers in the field of fabrication and characterization of composite membrane as well as synthesis of composite materials. His fields of research are Polymeric-Inorganic Composite Materials, Water Resources, Membrane Technology, and Wastewater Engineering. He has also visited some others countries for attending the International Conferences in the field of Desalination using Membrane Technology.