Materials Horizons: From Nature to Nanomaterials

Ashok Kumar Nadda
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Phuong Nguyen-Tri *Editors*

Membranes for Water Treatment and Remediation

Springer

Materials Horizons: From Nature to Nanomaterials

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Ashok Kumar Nadda · Priya Banerjee ·
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Membranes for Water Treatment and Remediation

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Preface

Crisis of fresh water resources has been intensified due to climate change, rapid population growth, and global increase in urbanization. Reclamation of wastewater has been considered crucial for reducing fresh water usage and achieving water sustainability. Reclaimed wastewater has been considered as an alternative water resource for non-potable or (indirect) potable use, especially in the counties or regions facing water scarcity. Various membrane-based techniques have been widely investigated for treatment of wastewater and production of treated water of superior quality. Over the last two decades, wastewater reclamation has received considerable attention as it offers an option to meet the requirements of the communities that are unable to access centralized wastewater facility; facilitate commercial buildings for achieving water sustainability; reduce water supply costs and decrease the load on centralized wastewater treatment systems; and spend less energy. It also releases lower CO_2 in comparison to centralized wastewater reuse systems as it does not need a higher degree of treatment in terms of wastewater characteristics. Reclaimed wastewater may have more public acceptance in comparison to municipal wastewater reuse due to cultural resistance and barriers in some countries.

In recent years, application of membrane-based techniques in wastewater treatment has been considered as a promising technique and has gained increasing scientific attention. Compared to other wastewater treatment technologies, membrane-based systems offer several advantages. Membranes provide a permanent barrier to suspended particles (including bacteria and virus) and macromolecules greater than the pore size of the membrane material, which result in an improved quality of treated wastewater. Decreased membrane price and development of new membrane materials facilitate membrane systems to achieve more efficient wastewater treatment with economic feasibility. Membrane systems exert less environmental footprint due to their compact nature. Despite more technical progress and practical applications of membrane-based wastewater treatment, a major challenge is membrane fouling, which inevitably occurs during wastewater treatment and leads to a higher energy demand and increased maintenance cost. Membrane-based separations are commonly performed with polymeric membranes due to their higher flexibility, easy pore forming mechanism, good film forming property, mechanical strength, chemical stability, high perm selectivity, selective transfer of chemical species, inexpensive materials for its fabrications required pore sizes for various filtration processes, low cost and smaller space for installation as compared to other membranes. Owing to these properties these membranes are widely applied in pressure driven processes such as ultrafiltration, nanofiltration and reverse osmosis for wastewater treatment.

This book aims to present comprehensive information on membrane-based techniques in wastewater treatment including direct pressure-driven and osmotic-driven membrane processes, hybrid membrane processes (such as membrane bioreactors and integrating membrane separation with other processes), and resource recovery-oriented membrane-based processes.

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Chapter 1
Polymeric Membranes for Water Treatment

Swati Sharma, Shreya Gupta, Sukhminderjit Kaur, Deepak Kumar, Priya Banerjee, and Ashok Kumar Nadda

1 Introduction

The most critical challenge faced by mankind nowadays is the shortage of fresh water caused by urbanization, industrial development, population growth, energy plant, and climate change [14, 62]. As the growing population and industrialization are increasing rapidly demand for safe, clean, and drinkable water is also increasing. In oceans, around 97% of water is stored as salty water that is not suitable for agricultural use or human consumption, only (>3%) of water on earth is available for agriculture and drinking purpose, and a large amount of this present is locked in the form of underground water, glaciers, and ice caps [86]. Various organic and inorganic contaminants are introduced into the water systems by the effluents from industrial and agricultural activity making them unsuitable for consumption. The main problem that needs to be solved is water quality, water quantity, and the removal of contaminants needed to avoid the side effects on human health and the environment. To produce clean water, many economical and multifunctional processes are developed.

For the treatment of wastewater, many technologies have been developed, including methods such as ion exchange [12], adsorption [35], reverse osmosis [110], and gravity [16], among these methods, adsorption is a widely used method for

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the removal of water contaminants because of its low cost, easy to use and availability of different adsorbents. The use of activated carbon, polymer composites, magnetic nanoparticles, and nanotubes are included in the different adsorbents, they can remove various types of contaminants including heavy metals [48, 54, 84, 85]. Despite being able to remove most of the water pollutants/contaminants, adsorption also shows some limitations like less use of these adsorbents commercially and a lack of appropriate adsorbents with high adsorption capacity [26]. Therefore, there was still a requirement for more efficient techniques/methods such as membrane technology. For wastewater treatments and desalination, membrane technologies are proving to be leading methods as membrane filtration presents some advantages such as maintenance and monitoring, a lower footprint, simple operation, lower mass storage tubes, compact modular design, and fewer flow rates of chemical sludges during the production of high-quality water from different sources [25, 46, 73]. This technology is known to be an effective water separation process because of its high contamination rejection of high-quality treated water yield [25]. The removal of soluble components and suspended particulate matter from the wastewater semi-permeable membranes is the general idea behind the membrane-based wastewater separation. The application of membrane technology especially in water treatment has been increasing rapidly over the past few decades, increasing the amount of efforts by membrane scientists/researchers [68]. The membrane is the functional component of a membrane filtration process. The separation of different materials through the membrane depends on molecular size and pore [122], therefore various membrane processes including nanofiltration (NF), microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO), and forward osmosis (FO) have been developed with different separation mechanisms (Fig. 1).

Both polymeric and inorganic materials can be used to prepare/form membranes, polymeric membranes are mainly organic in nature whereas inorganic membranes are mostly metals, oxides, and ceramics [70, 99, 114]. In comparison to membranes fabricated from inorganic materials, membranes prepared from the polymeric membrane are low-priced [70]. During fabrication, it is easy to handle polymeric membranes and can also be used for the high-water production capacity [51, 70, 99]. The aim of this chapter is to review the different polymeric membranes used for the treatment of wastewater and the fabrication of different polymers for the membrane technologies. The operating cost of water treatment along with permeate quality is determined by the type of polymer used for the filtration. To avoid the issues such as unwarranted energy consumption and frequent membrane replacement it is crucial to select the proper or most suitable type of polymer for a filtration process. The future work, applications, pros, and cons of polymeric membranes are also discussed briefly.

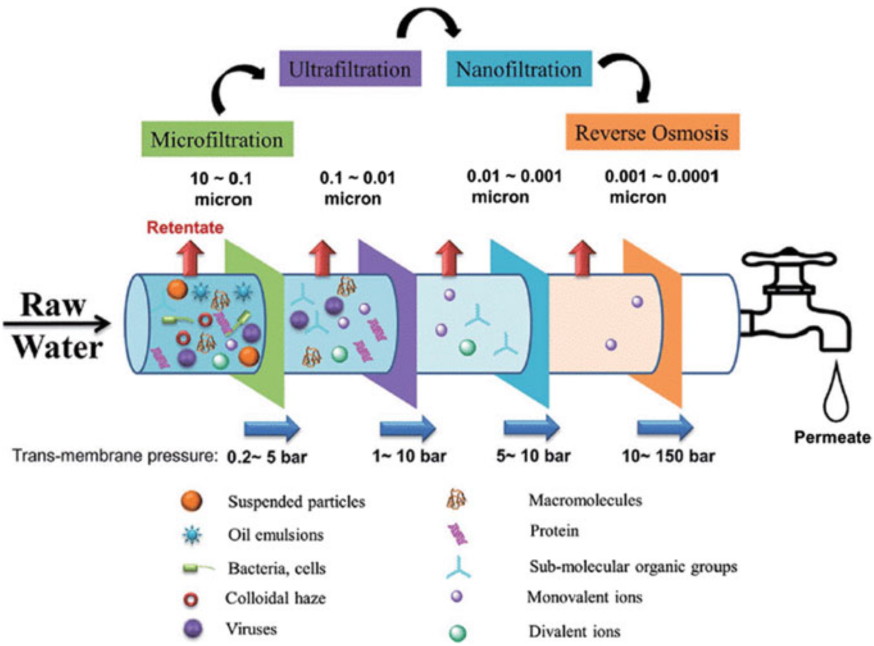

Fig. 1 Pressure-driven membrane processes for water treatment technologies, showing the particles effectively captured by each process along with the pore sizes of the membranes used for each process [53]

2 Polymers Used for Membrane Filtration (Water Treatment)

Polymers namely polyamide (PA), polysulfone (PSF), polyvinyl chloride (PVC), polyacrylonitrile (PAN), polyvinyl alcohol (PVA), poly (arylene ether ketone) (PAEK), poly (ether imide) (PEI), cellulose acetate (CA), polyvinylidene fluoride (PVDF), polyethersulfone (PES), polyaniline nanoparticles (PANI), polyimide (PI), polyethylene glycol (PEG), poly (methacrylic acid) (PMAA), and poly(arylene ether sulfone) (PAES) have been used in the fabrication of different membrane processes (NF, UF, MF, RO) [33].

3 Membrane Processes and Polymers Used

3.1 Nanofiltration

In recent decades, NF membranes have attracted attention as a potential for water treatment/filtration because of their advantageous properties like low energy consumption in comparison to RO and high retention of neutral molecules (low molecular weight) and divalent salts [28, 60, 124]. For some highly polluted waters, NF is pre-treated to make it more effective, also because of their moderate stability these membranes can only endure an aqueous solution having a pH range of 2–11. In a study, textile wastewater is treated with NF membrane and it was reported that the prepared membrane exhibited decent removal of common salts and dyes and heavy metal ions, displaying high removal efficiency toward cationic dyes and metal ions. Nowadays, most available NF membranes are consisting of different polymers such as PA, PAN, PI, and PVA in TFCs [4, 94, 98, 102–105, 115, 121]. Though, when in contact with a few amines PIs are not stable, and also in polar solvents they display very poor stability and performance, therefore, in aqueous solutions having strong acids/bases, strong amines, and chlorinated solvents these PIs are not favored, but through the crosslinking process they can be modified and better resistance against such chemicals can be obtained. In a study, PEEK is used as a material for NF membrane, and it was reported that PEEK membranes are highly resistant against different acids, bases, and solvents and have a low degree of sulfonation, but these membranes show low water permeability. These membranes demonstrated water permeance of 0.7–0.21 and 0.2–0.8 L/h m^2 bar when tested for their separation performance in dimethylformamide (DMF) and tetrahydrofuran (THF), respectively [18]. Yang and co-workers, reported the use of PMIA/GO composite NF membranes for the treatment of water. In comparison to the pure PMIA, the fabricated composite membranes exhibited a better/larger hydrophilic surface that as a result gave rise to pure water flux, and also high dye rejection, and increased fouling resistance to BSA (bovine serum albumin) were achieved [111, 112].

3.2 Microfiltration (MF) and Ultrafiltration (UF)

(A) **Microfiltration**

In microfiltration, separation mainly occurs through sieving because of its large pore size (approx. 0.1–1.0 m), and removes little or no organic matter, MF mainly removes the suspended solids or particles, bacteria [20]. However, when pre-treatment is applied then maybe there is an increase in organic matter removal. MF can be used as a pre-treatment to reduce fouling potential in RO and NF [96]. MFs main drawback is that they cannot remove contaminants such as dissolved solids (<1 mm in size), and it does not act as a barrier to viruses. Microfiltration membranes have been mainly utilized in wastewater treatment, membrane bioreactor, and membrane distillation [1, 9, 30–32, 102–105].

A membrane bioreactor (MBR) is an active sludge process in which MF and UF membranes are combined together for wastewater treatment in different industries. In the configuration of MBR, the membrane is submerged into the bioreactor, and treated water is permeated using a vacuum whereas solids are reserved in the bioreactor. In comparison to a traditional side stream configuration, the current MBR configuration lowers energy consumption and also reduces the membrane fouling amount [52]. Polyvinylidene fluoride (PVDF), polyacrylonitrile (PAN), polyethylene (PE), and polyethersulfonate (PES) are mostly used as polymeric membrane materials for applications of MBR. Among these PVDF accounts for about 45% of MBR polymeric membranes and because of PAN's lower affinity to extracellular polymeric material it is most likely the most fouling-resistant one [59].

Normally, MBR membranes have a pore size between 0.03 and 0.4 m, PES and PE membranes are mostly available with a pore size of 0.03 and 0.2–0.4 m respectively, while PVDF membranes are available in the whole range of pore sizes due to their versatile manufacturing [41]. Compared to UF membranes the integrity of MBR membranes is less [1].

The two-stage process of CAS (conventional activated sludge) including biotreatment and clarification is replaced by MBR a single integrated process. Some advantages such as reduced footprint, nearly complete separation of suspended solids from the effluents, product consistency, and reduced sludge production make MBR superior to conventional treatment [91]. Because MBR systems operate at a higher concentration of mixed liquor suspended solids (MLSS) they remove a large range of biodegradable and hydrophobic trace organics more efficiently than CAS processes, MBR systems also offer a definitive boundary layer proving a complete suspended solid retention [40]. Consequently, MBR effluent has the potential to be used as process water, irrigation water, also as feed to potable reuse applications [50].

(B) **Ultrafiltration**

In ultrafiltration, compounds can be separated between 0.005–10 μm, these membranes are highly water filters with less consumption of energy in the removal of suspended matters, macromolecules, and pathogenic microorganisms [47, 80]. UF has some drawbacks such as maintaining high-pressure water flow regular cleaning required and any dissolved inorganic substances in water can't be removed [120].

In UF membranes as polymeric materials mainly PS and PES are used due to their strong chemical stability, wide pH operation range, and good mechanical properties [22, 61, 76, 87, 90, 100, 108]. But the applications of these membranes in the treatment of water are limited because of their hydrophobicity that leads to decreased permeability of the membrane, also mostly polymeric materials of UF membrane show hydrophobic properties. Recently for the UF membranes fabrication, some other natural hydrophobic polymeric materials such as PMAA, PVC, and PVDF are also used [11, 38, 58, 102–105, 111, 112, 123].

During the operation there can be a decline in water flux because of membrane hydrophobicity as organic compounds get accumulated favoring the attachment and growth of microorganisms onto the surface of the membrane, leading to fouling and failure of the membrane [102–105]. It is important to modify these polymeric materials to improve their properties and increase their applications in the treatment of water. The main motive to modify these membranes is to increase the hydrophilicity of the membrane, enhancement in the membrane hydrophilicity also increases the antifouling properties of the membrane for liquid water-based filtration.

Some polymeric materials such as PSF, PVC, PMMA, and PES are incorporated with different types of particles or nanoparticles (TiO_2, MSP-1, ZnO, silica) to improve their properties mainly hydrophilicity [24, 33, 70, 81, 118].

3.3 Reverse Osmosis (RO)

RO technology (Fig. 2) is used for the removal of smaller particles and dissolved solids, this method is only permeable to molecules of water [72]. To make water overcome the osmotic pressure enough/high pressure should be applied to RO. In comparison to UF, the pore size of RO membranes is tighter, these membranes are able to convert hard water to soft water and require low maintenance [107]. They have extremely small pores and have the potential to remove all particles smaller than 0.1 nm including bacteria and organics [109]. The main disadvantages of RO membranes are the high-pressure use, prone to fouling, and being expensive in comparison to other membranes. Desalinating of water through RO is considered the most efficient and popular method as it is appropriate for potable and near-to-potable water production [45, 55].

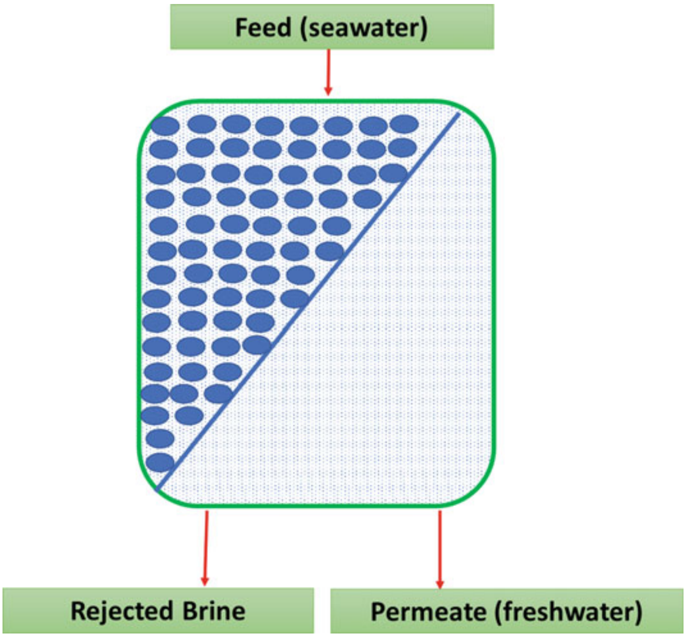

Fig. 2 Reverse osmosis process showing the separation of salt from water

Commercially available RO membranes consist of polymeric materials like PA and CA [15, 31, 32]. CA is a natural polymer mainly obtained through the esterification of wood, recycled paper, bagasse, and cotton, CA is eco-friendly, renewable, and biodegradable and also known for its high potential flux and hydrophilicity, biocompatibility [21, 29, 66, 79]. PA membranes have the ability to withstand higher temperatures and operate under a wider pH range making it more preferable over CA [113].

However, as PA membranes have continuous exposure to chlorine and some oxidizing substances, so their practical application is limited [119]. The amide group present in the membranes of PA is sensitive to attacks of chlorine during chemical cleaning [31, 32, 101]. So, to prevent the PA membranes degradation, the concentration of chlorine is reduced by an additional step of de-chlorination. Also, Poly (arylene ether) copolymers, especially poly (arylene ether sulfone) have been used to overcome this problem, as these polymers are highly resistant to chlorine attacks due to the absence of susceptible amide linkages [74, 75].

Nebipasagil and coworkers, prepared photo cross-linkable disulfonated PAES copolymers for the applications of RO, initially they synthesized PAES oligomers with controlled molecular weights and degrees of sulfonation by nucleophilic aromatic substitution. The molecular weight of the PAES was controlled by using Meta-aminophenol and thamtelechelic amine end groups were installed. The novel cross-linkable PAES oligomers with acrylamide groups presence on both ends were obtained by reacting meta-aminophenol end-capped oligomers with acryloyl chloride. In order to obtain, PAES copolymer thin films, UV radiation is used in the presence of a UV photoinitiator and a multifunctional acrylate to cross-link the acrylamide-terminated oligomers. It was observed that the smooth surfaces of cross-linked disulfonated PAES films had improved high water passage and also there was a reduction in water uptake [69].

PVC can also be used as polymeric material for RO membranes, due to its durability and flexibility, and also with better biological and chemical resistance. PVC/CA polymers are used as membrane binders to achieve enhanced separation properties and special selective characteristics in membranes. Hydrophilic characteristics of the membrane can be improved by increasing the concentration of CA in the PVC/CA polymers solution and rejection capabilities of the fabricated membrane can be improved by increasing the CA concentration by around 10% [3, 29, 77].

4 Types of Polymeric Membrane

The polymeric membranes are classified broadly into two categories; porous and non-porous. The two are each categorized into two subcategories.

4.1 Porous Membrane

The porous membranes are used for microfiltration and ultrafiltration purposes. Microfiltration entails membranes whose pore sizes are expressed in terms of micrometers. The pore sizes range from about 0.1 μm and above. These membranes are often used as the first step of filtration before the water progresses to the other stages. Among the materials removed by this type of membrane are suspended solids, micelles protein, bacteria, and fats. Ultrafiltration membrane also falls under the porous category. The average pore size is between 0.001 and 0.1 μm [8]. The membranes operate based on the principle of molecular exclusion. They remove macromolecules, protein, and enzymes, as well as starch from the solution. The membranes are in most cases made of polyethersulfone or polysulfone molecules [92].

4.2 Nonporous Membrane

Non-porous polymer membranes are another main category. The membrane is relatively dense compared to the porous membranes and water diffuses through the membrane only by the application of pressure, concentration, or electrical potential gradient [49]. Non-porous membrane falls under nanofiltration or the reverse osmosis technique [49]. The type of polymeric material used in both categories makes the difference in the permeability and selectivity of the membrane. In most cases, organic nanofiltration membranes are made by applying a thin film of a polymer to a polyethersulfone or polysulfone ultrafiltration substrate. Those in the nanofiltration category mainly remove amino acids, multivalent salts, and polysaccharides. The reverse osmosis membrane filters out salts and other minerals leaving only clean water for consumption. Separation occurs through the diffusion of dissolved species through the membrane and overcoming the osmotic pressure of the process fluid [99].

5 Polymer Membrane Filtration Process

As noted, [33], the use of polymer membranes to treat water is also referred to as reverse osmosis. In its simplest form, the process entails pressuring water through a semipermeable membrane to remove impurities and contaminants. The membrane is made of polymer materials that distill or remove the dissolved organic solids, including salts, from the water to make it clean for consumption. The process is as demonstrated below in Fig. 3.

The process has three main stages. The first stage is the Pre-filtering stage. Here, the water from the supply line enters the reverse osmosis pre-filter first. Herein,

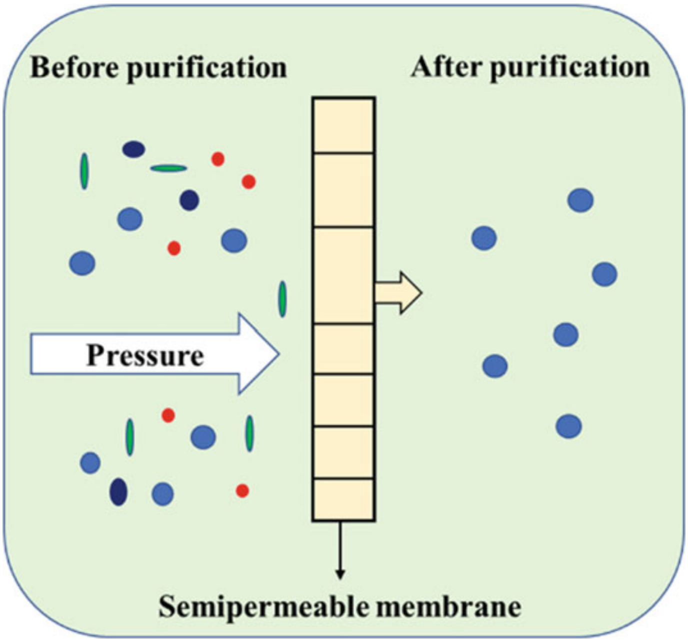

Fig. 3 Reverse osmosis: a water purification process

sediments and carbon filters remove the sand, silt, dirt, and other sediments that may potentially clog the system. Chlorine and phenol, which can cause major damage to the polymer membranes used in the reverse osmosis process, are also removed using carbon filters [97]. The second stage is the reverse osmosis membrane, which in this case is a semipermeable polymer membrane. The membrane removes dissolved salts, aesthetic contaminants, and health-related contaminants. Once the water is filtered through the membrane, it enters the pressurized storage tank for storage. There is a final post-filter stage that removes any remaining odors or tastes using the same polymer membrane. The water is then ready for distribution [57].

6 Membrane Fouling

The polymeric membrane is also used for the treatment of produced water. In industrial waste treatment, membrane-based separation plays an important role which comprises Produced water treatment. For industrial separation using membrane have many advantages including simple operation, no phase change, ease to scale up, cost-efficient, and less area occupied [43]. In layer filtration, the membrane has a particular barrier in the middle of two phases of perfuse matters. The particular transport is attained based on differences in physical or chemical properties of perfusing matter to the other side of the membrane. In porous membranes (microfiltration, ultrafiltration) separation rate of particles is based on sieving, size exclusion, and on the other hand in the case of the nonporous membrane (nanofiltration, reverse osmosis) separation is based on the solution–diffusion mechanism of solutes and solvent. The polymeric membrane show utility to form better filtration membranes is low cost, flexible, and has a border spectrum to be utilized in desirable separation techniques [63]. The high salinity of PW restricts its beneficial uses. Membrane mainly reverses osmosis and selective nanofiltration lessens the high salinity of produced water (PW). Some RO and NF membranes are used in PW treatment are NF1, polyethersulfone, NF90, and polyamide [6, 64].

Mainly the membranes which are used in PW treatment are NF and RO that are thin-film composite (TFC) membranes. TFC consists of three layers, the upper dense layer is made up of polyamide compound, and the middle layer is composed of polysulfone which is supported by the third layer of polyester microporous compound [65]. The membrane separation processes of NF and RO are determined by water-possessed pressure and depend on diffusive-based mass transfer. Membrane fouling increases the flux or increases the transmembrane pressure (TMP). Factors that cause fouling are depositions of inorganic components, because of this the pores of the membrane block [125] and result in reversible and irreversible membrane fouling [23]. When there is an attachment of particles on the surface of the membrane called reversible fouling and when the attachment of particles on the surface of the membrane which is cannot be removed by physical cleaning called irreversible fouling.

6.1 Fouling Control

It is controlled by ultrasonic cleaning, membrane cleaning using chemical agents, and membrane modification.

(A) **Ultrasonic treatment**

The process involves the removal of thick foulant originating from the surface of the membrane. The fouling of polymeric membranes by various pollutants between the active layer surface of the membrane and foulant molecules needs harsh thermal or chemical treatment to remove but this gives damage to the original membrane which is impossible to recover. To control the membrane fouling uses cleaning strategies such as a designed process, membrane cleaning by ultrasonic techniques, and hydraulic cleaning [17, 36].

(B) **Fouling control by chemical cleaning**

The ideal chemical cleaning agents have the following properties:

a. Solubilized foulant.
b. Hydrolyzed foulant.

c. The agent should not damage the membrane or system.
d. Avoid new fouling while in solution [82].

Chemicals that we used are to clean the foulant from the surface of the fouled membrane and the selection of chemicals is based on the components which cause fouling are:

- **Sodium dodecyl sulfate (SDS)**: It is a surfactant that contains hydrophilic as well as hydrophobic components and forms micelles with fats and oils which helps in ameliorate fouled cleaning [106].
- **Disodium ethylenediaminetetraacetate (EDTA)**: Known as a chelating agent used to remove metal ions and foulant from the fouling layer [7].
- **Sodium hydroxide (NaOH)**: In comparison with SDS and EDTA, sodium hydroxide is a more effective cleaning agent. In a study, SDS was found more efficient when applied for 5 min and it restores permeability completely. Both disodium ethylenediaminetetraacetate and sodium hydroxide have a similar range of cleaning efficiency and both are inferior to SDS [5].

(C) **Fouling control by surface modifications**

By transforming, the surface properties of membrane fouling can be managed. The degree of fouling is influenced by the roughness of the surface [71] charge of the surface hydrophilicity, and hydrophobicity. The membranes which are more susceptible to fouling are rough membranes although the smooth and neutral surface of the membrane is less prone [67]. Membrane surface hydrophilicity is the main criterion for the antifouling property of polymeric membranes [63]. To fouling, surface modification is very important for polymeric membranes. The surface modification includes grafting blending, and incorporation of nanomaterial such as carbon nanotubes [95], TiO_2-based polymeric membrane [13], ZnO-based polymeric membrane [89].

(D) **Removal of membrane fouling using nanoparticles**

In polymeric material, researchers concentrated on integrating inorganic nanoparticles resulting in the development of a Nanocomposite membrane, and because of this physiochemical and mechanical properties were enhanced. Nanomaterials are used as fillers for example carbon nanotubes (CNTs), nanosized TiO_2, and nanosilver.

Carbon nanotubes (CNT): It is a single-wall carbon tube made up of carbon with a diameter in the range of nanometers. Carbon nanotubes have various properties like carbon nanotubes have high hydrophilicity and good chemical stability. Carbon nanotubes with properties of antibacterial, high centralized strength, and improved porosity it has been ideally utilized in membrane augmentation [19]. There are many methods utilized to manufacture inorganic polymer membranes based on Carbon nanotubes which involve blending, direct coating, in-situ polymerization CVD, and CVD template [56]. In a process of polymer membrane formation, CNT is used as a substrate to intercalate with polymerization [83].

Silver nanoparticles: Silver nanoparticles (SNP) have properties of bactericidal, increased oxidative stress, and high-affinity silver ions because of this it is drawn into the field of mixed matrix membrane [10, 93]. Silver is a non-allergic, non-toxic, and eco-friendly metal, so it has fewer hazards toward human cells [2]. Also, it is efficient when the bacterial solution is incorporated into the matrix of the membrane [117] because of this antibacterial ability and low toxicity apropos humans, silver ions take on in membrane fabrication. It was found that the Ag-containing membranes have unique antifouling properties [37].

7 Future Research

Recent decades of research and developments in this field have concentrated on appropriate techniques to procure clean water by filtering and reutilizing water to support human health and water scarcity. The process of removing impurities and pollutants from water to procure suitable water is called water purification. Due to its high efficiency and low cost, water purification technologies are dominated by membrane technology. In comparison with other types of membranes, membrane separation industries are led by polymeric membranes as they are economical and practically favorable. But the membrane use has less chemically and thermally divergent which reduces their utility. A major area that required more research to enhance flux, selectively, and reduce membrane fouling is a crucial barrier in the utilization of membranes for water purifications. Currently, research is focused on the addition of Nano-filters and polymers in the second phase of membrane preparations to enhance the selectivity and pursuance of the membrane.

8 Pros and Cons of Polymeric Membranes

The first major advantage of polymeric membranes over other membranes, such as the use of ceramics is the fact that the membranes are cheaper to use. The materials are not only affordable to use but have low associated costs, especially in terms of energy use. While noting that in some cases polymeric membranes cannot withstand high temperatures and some chemicals, cost-effective polymeric membranes are cost-effective and offered businesses a major cost advantage in large-scale water purification [34].

The other advantage of polymeric membranes pertains to effectiveness. Compared to other traditional mechanisms, polymeric membranes have proven to be reliable over long periods. This is coupled with the fact that the membranes can continuously be improved so that the quality of the filtration becomes even higher. Such improvements have seen the production of membranes that are even more chemically stable and thus removing high chemical reactions at the surface of the membrane. The chances of growth in this area mean that the effectiveness of the membranes even in the future is going to surpass other mechanisms that could be in use today. The other advantage that the membranes have is energy efficiency. One of the biggest challenges that have existed about water filtration has revolved around energy efficiency. This is especially the case of desalination of salty water covers the largest portion of the earth's population. The energy that has been required in the past to make the water suitable for drinking has resulted in major conflicts, especially balancing between non-renewable energy sources that cause pollution and the need for clean water. However, polymeric membranes have provided cheaper energy alternatives, especially for commercial use. The idea that there is room for improvement promises that the energy efficiency may improve even in the future making it possible to provide the world with enough water for drinking especially from salty water.

One of the biggest challenges facing the use of polymeric membranes is the problem of fouling [78] defines fouling as the process through which colloidal or particulate matter deposits itself in the pores of the membrane or on the surface, which adversely affects the effectiveness of the membrane in water filtration. The continuous movement of water that contains microbes, macromolecules, colloids, and particulates over the membrane leads to the accumulation of the materials on the surface of the membrane meaning that the water flux is reduced. In addition to that, the cake layer formed on the top of the membrane also affects the overall rejection performance of the membrane [39]. To deal with the fouling problem, the membrane needs to be constantly cleaned, which increases the cost In addition to that, the membrane must also be continually replaced, which raises the cost. More energy is also required to move the water across the membrane, thus increasing the cost as well.

The weakening of the membranes presents a major risk, especially in the case of water filtration. According to Praneeth et al. [78] sometimes the duration of use for the polymeric membranes may be shorter than expected. In that regard, their use may be extended to a time in which they have already become weak. During such a time, the selectivity of the membranes becomes unacceptably low. This means that some of the materials that need to be filtered out pass through the membranes. Among them could be health contaminants that pose a major risk to the health of the individuals who rely on the water from the system. Water is used for industrial processes; the presence of some materials can result in major losses as a result of poor product quality. This is especially the case when the water that passes still has some odor or dissolved salts. And polymeric membranes cannot resist high temperature because at that temperature membrane plasticizes which results in a loss of flux [44].

9 Applications

Polymeric membranes are engaged in applications such as desalination, removal of water hardening, municipal wastewater treatment, production of potable water, and industrial and household water treatment. It offers a simple technique to be used widely, cost-effective, environmentally friendly, stable, and divergent applicable in a range of temperature, pressure, and pH. Membrane fouling and membrane sensitivity to toxicity are the main extremities and problems of membrane technology. For this reason, Researchers have established several ways to overcome membrane technology. These ways consist of the amalgamation of nanomaterial such as graphene oxide and nanometer-sized metal oxides (zinc oxide), among others [88]. Overall, it can be concluded that membrane technology is a very advantageous technique for wastewater treatment. Many research approaches are focused on having efficient solutions and approaches to prolong its lifetime [42, 56, 116].

10 Discussion

The chapter identifies why water purification through polymeric membranes is critical in today's world. The process of water filtration using the polymeric membrane is also explained. The various types of polymeric membranes are identified and so are the advantages and disadvantages. And why do we need this treatment?

As identified, the world's freshwater sources are currently under pressure to meet the demand for freshwater by the growing global population. According to [27], less than 1% of the world's water sources are freshwater. 97% of the sources are salty and 2% of them are already contaminated by human activities. The competition for the available water is shared between three major areas. 70% of the freshwater is used for irrigation to feed the growing population in the age of major pollution effects. 20% of the water is used for industrial processes that are also critical for human existence [27]. Only 10% of the water is allocated to human consumption. Globally, more than 1.2 billion people do not have access to fresh water while another 2.6 billion have contaminated freshwater [27]. Poor access to clean fresh water, especially for developing countries is devastating. To bridge the gap between supply and demand for freshwater, it is evident that mechanisms need to be put in place that makes both the salty and contaminated water safe for consumption. Since the pressure on water demand will most likely increase in the future, there needs to be low-cost, highly efficient methods of water purification that can be relied on to meet the growing need. Polymeric membranes thus present a major opportunity for water filtration to meet the demand in a low-cost and energy-efficient way.

11 Conclusion

One of the most critical threats facing the world in this century is the supply of clean water with satisfactory quality from water resources. Polymeric membranes are a critical part of water purification today. The membranes offer a chance to bridge the gap between the supply and demand for fresh water at home and in industries. The biggest advantage of the membrane is the fact that they are energy-efficient and also low-cost compared to other mechanisms. That area continues to grow for even more efficiency in the future. Therefore, it concluded that prolonged studies are required for optimizing the characteristics properties, and performance of membranes. It includes such as antifouling, increased durability, impaired energy consumption, improved selective permeability, and enhanced thermal, mechanical, and chemical stability. The membrane which is used in water treatment has higher flux, is less selective and less prone to various types of fouling, and is more resistant to the chemical environment.

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