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MINI REVIEW

ROLE OF POLYMERIC MEMBRANE FOR WASTEWATER TREATMENT

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ABSTRACT

Hazardous water contamination is a rising concern for the provision of usable and drinkable water to the world. Innovative, economic, and renewable technologies are the need of the hour for wastewater treatment. Several technologies have been reported to encourage wastewater treatment, such as ion exchange, co-precipitation, adsorption, membrane separation, oxidation, biochemical processes, etc. Among them, membrane separation technology has been considered a promising approach due to its short route and viable economics. Polymeric membrane-based technology comes with ease of functionalization, high sustainability, excellent adsorption, economic advantage, and environmental friendliness. That's why, membrane processes were further developed to different separation mechanisms such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Herein, we report a mini review of polymeric membrane-based separation technology for wastewater treatment. The short communication includes the need for water purification and their purification by membrane technology, especially polymeric derived membranes. Besides, the state-of-art membrane and its utilization for the removal of various water contaminants were discussed. The proposed review would be helpful to provide a single platform to study about the role of polymeric membrane.

KEYWORDS

Wastewater treatment, Polymeric membrane, separation technology, hazards material

1. Introduction

The majestic demand for water and energy is undoubtedly increased worldwide. The companies are trying to overcome the challenges of combined future and current energy demand from new technology to be sustainable (Soltanieh et al., 1981; Punzi and Muldowney, 1987; Greenlee et al., 2009; Singh et al., 2018). On the other hand, as displayed less than one percent of fresh water on earth is useable by humans. As displayed in Figure 1, of the fresh water that humans consume, 70% is used for irrigation, 20% is allocated for industry, and only 10% finds domestic use (UNESCO, 2009). Various water resources are considered useless due to ineffective activities, so this plenty of water is appropriately inevitable for domestic propose and other beneficial needs. This devastating effect leads to severe disease; for example, due to the spread of diarrheal diseases, 1.8 million deaths result from unsanitary drinking water every year (Organization, 2004).

Among these deleterious trends, developing countries are expected to face alarming situations and the severe economic downfall of poor water quality. Fresh water need is the continuously growing demand as population has been approaching at an exceeding range. Water sources shortage ultimately results in the decline of lifestyle and development opportunities in water scares area. Water scarcity became a global concern as it is distinctly locked into polar icecaps. According to the Global Water Institute, around 700 million people in 43 countries suffer from water scarcity. Estimated report has been released by United Nations Educational, Scientific, and Cultural. Organization report, the unequal distribution of water leads to 1.8 billion people in the world to suffer from pure water sources, while 60% of the world population would be expected to bear physical water scarcity in 2025.

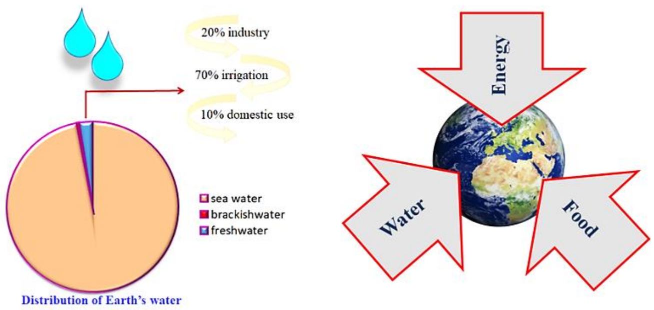

Figure 1: The utilization of fresh water for energy and food is subsequently alleviate the overall shortage of water resource

Freshwater accessibility is an ample means of sources in different application areas, such as in agriculture and energy production. For one megawatt-hour energy production, 21,000-25,000-gallon water is required, highly demanding, and cost-effective. Another hand, agriculture consumes 70% of all human freshwater, leading to water shortfall and

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high food prices according to a growing population (Waqas et al., 2021). Given all these considerations, the water supply should be clean and accessible through high-efficiency and low-cost technologies. Water sources worldwide are unhanded with inadequate equipment to be well treated in a safe and new methodology. The world ocean water could be helpful for pure water needs if proper routes of purification are adapted. Also, from petroleum refining residue, pure water can be generated (Puder et al., 2004).

Industrially activity utilizes water resources which drained off large amount of contaminated water into social authorities. Due to fresh water inadequacy, population growth, development of industrial world contaminated water became an alternative attractive candidate of fresh water sources (Rizvi et al., 2021). It is deemed that water demand for different industrial area, agriculture, municipalities would raise 20-30% by 2050. The growing demand for water is due to generation of larger quantities, varieties of water contaminated with large range and concentration of chemicals (Hussain, et al., 2020). Therefore, for purification and separation techniques, Many techniques were introduced for wastewater treatment, such as reverse osmosis, ion exchange, adsorption, and so on (Kaplan et al., 2020; Ben et al., 2018; Huang et al., 2020; Hiller et al., 2019; Fazal et al., 2020; Li et al., 2019; Kahraman et al., 2020). The adsorption process is well recognized for its applications to remove organic pollutants, dyes, and heavy metals. Even though adsorption is an economical process, however, it faces significant challenges.

For example, the amount of time required for the operation is high, as well as the choice of proper adsorbent is also not standardized (Baltpurvins et al., 1997; Qdais et al., 2004; Huisman et al., 2006). Hereafter, there is a need for effective techniques such as membrane technology. Membrane technology can separate purify products from undesirable residue with high efficiency and low-cost energy. In the current advanced technologies, membrane technology is interestingly popular compared to other techniques due to low energy demand (Sirkar, 1997). Membrane technology involves polymers, so there are many membranes with different separation methods, which embodies a prospect for polymer science. Currently, in industrial processes, membranes are usually made of organic/inorganic material. However, the more dominating in the industry based on polymeric material. Choice of the membrane, which depends on membrane material, is critical for a particular application.

Pertaining a massive contribution in the purification process, the most commonly used organic polymer material are polyvinylidene fluoride (PVDF), nylon, polyethersulfone (PES), polysulfone (PS), and regenerated cellulose (RC). Reasons to gain more attention in purification applications include reduced nonspecific protein binding, broad pH compatibility, desirable wetting properties, high mechanical strength, high permeate flux, and high resistance to gamma radiation. In addition, PVDF polymer attained much attraction and rising demand by researchers and manufacturers currently. This short review article aimed to discuss the art of polymer-based membrane technology in wastewater treatment. In addition, the role of polymer sciences for improving water purification.

2. State and Art For Membrane Technology

Membrane technology accounts for two basic steps pre-treatment and reverses osmosis unit. During membrane technology operation, pressurized feed is applied to the membrane to produce permeate water. The membrane can function by two different fundamental mechanisms: pore flow and solution diffusion mechanism (Lonsdale, 1982; Baker, 2004). Various phenomena occur during membrane separation systems, which reduces the flux, for example, fouling, scaling, and concentration polarization. In general, the art of membrane separation follows three principles: adsorption, sieving, and electrostatic phenomenon. Based on pore and molecule size of material, membrane processes were further developed to different separation mechanisms such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) (Corporation, 2009). Molecules pass through RO membranes primarily by a solution-diffusion mechanism. Microfiltration (MF) and ultrafiltration (UF) membranes operate exclusively by pore-flow, whereas NF membranes show a combination of solution-diffusion and pore-flow character. The common characteristic of these membranes was tabulated in Table 1.

Table 1: Comparison Among Different Types of Membrane Process

Membrane Process	Pore Size	Membrane Type	Driving Force	Main Application	Reference
MF	50nm-5μm	Symmetric and Asymmetric Microporous	Hydrostatic pressure 0.5-5 bars	Clarification, sterile filtration	(Pal et al., 2020)
UF	5-100nm	Asymmetric Microporous	Hydrostatic pressure 1-9bars	Separation of macromolecular solutions	(Siagian et al., 2021)
NF	1-5nm	Asymmetric	Hydrostatic pressure 4-20bars	Separation of small organic compounds and multivalent ions	(Pal et al., 2020)
RO	Dense	Asymmetric Composite with Homogenous Layer	Hydrostatic pressure >20 bars	Production of pure water	(Heo et al., 2020)

3. Current Typical Polymeric Membrane

The high amount of seawater could be treated and separated by membrane technology. The membrane rejects seawater about >98%, but the efficiency could be 99.1% (Fritzmann, Löwenberg et al., 2007). However, the more dominating in the industry based on polymeric material. Choice of the membrane, which depends on membrane material, is critical for a particular application. Pertaining a massive contribution in the purification process, the most commonly used organic polymer material are polyvinylidene fluoride (PVDF), nylon, polyethersulfone (PES), polysulfone (PS), and regenerated cellulose (RC). Figure 2 illustrates components of a typical polyamide membrane, including the cross section of a 34 nm polyamide discriminating layer obtained from Dow's NF200 membrane. Cellulose acetate membranes are resistant to the chlorine added to disinfect the feed water, and some other polymers such as poly (vinyl alcohol), postpolymerization sulfonated polysulfone have found some desalination applications.

Among them, thin film composite (TFC) made of aromatic polyamides showed the best desalination applications. TFC comprises three layers: ultrathin barrier layer, microporous polysulfones, and reinforcing fabric imposing; the significant advantages of a TFC system are the ease of achieving optimal separation performance by tailoring each layer (Desai et al., 1991). However, TFC faces considerable performance degradation when exposed to trace amount of chlorine, literature study methods for chlorine resistant membrane only with 50% improvement still in this prospect no favorable chlorine resistant process have adopted. Besides, FT-30 dominated the desalination industry for 30 years due to higher flux and salt rejection, a wide pH range, and higher operational temperature (Vos et al., 1966).

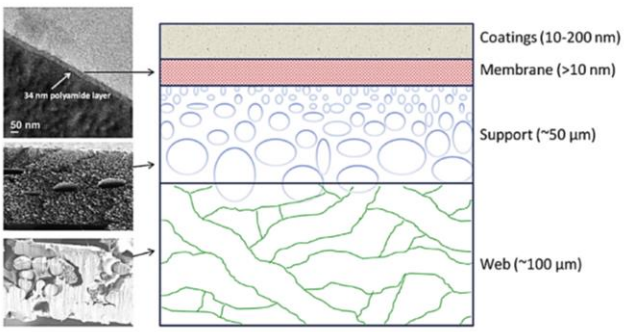

Figure 2: Comment layers of NF polymerized membrane. Data extracted by permission from ref. (Paul and Jons, 2016)

Due to amide linkage in the TFC membrane, it has drawn some drawbacks in desalination, so a growing method of developing a polymer with a robust backbone actively resists chlorine attack. Many polymer platforms, including polysulfones, polyimides, polymethacrylates, and styrenics have been explored (Brousse et al., 1976; Zschocke et al., 1978; Davis 1987; Gao et al., 2012). Among them, TFC membranes have been prepared from direct copolymerized sulfonated polysulfone materials; these membranes have been evaluated as potential water purification materials, as they exhibit high tolerance to chlorine over a wide pH range (from pH 4 to pH 10) (Park et al., 2008). Another commercially available sulfonated polymer proves best for desalination, named Nexar TM. Nexar TM incorporates polystyrene sulfonate in a unique pentablock copolymer architecture, which interestingly increases the water permeability directly proportional to the degree of sulfonation in the backbone (Helfferich 1995).

Irrespective of desalination application, membrane technology found another scope of interest in various fields such as in pharmaceutical/chemical manufacturing plants, involve the removal of biological/organic contaminant before disposal. However, presences of organic pollutants (As, B) in the environment even at lower concentrations, lead to reduced rejection, which can be harmful to human health (Oo et al., 2009). One possible solution is to remove these toxic particles (As, B) by the solution of a weak acid or base molecule to modify the charge of the molecule (Park et al., 2008). Boron rejection is achieved (75-80%) by single pass reverse osmosis, and this could be highly rejected by applying multiple passes to reduce the boron concentration in the permeate to acceptable levels. As oxidizing this regent can lower concentration, the oxidation state changed from (III) to (V) (Kartinen et al., 1995). The development of membrane for virus filtration by different manufacturer are illustrated in Figure 3.

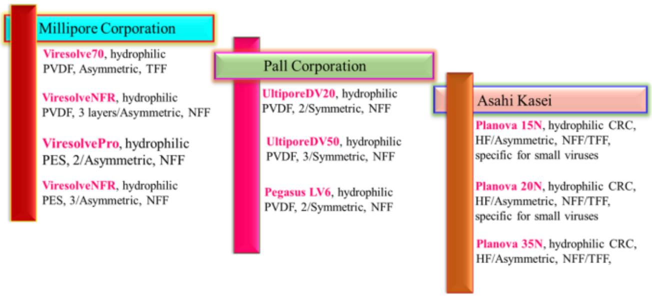

Figure 3: Virus filtration membrane developed by different manufacturer.

3. Challenges

Concerning enlarged membrane technology methods, forward osmosis has been deliberate and utilized in water purification. The driving force for the separation is an osmotic pressure gradient, such that a "draw" solution of high concentration (relative to that of the feed solution) is used to induce a net flow of water through the membrane into the draw solution, thus effectively separating the feed water from its solutes. This method found application in different fields like food processing, controlled drug release devices, and water treatment (Childress et al., 2006). Few research challenges associated with purification of water are displayed in Figure 4.

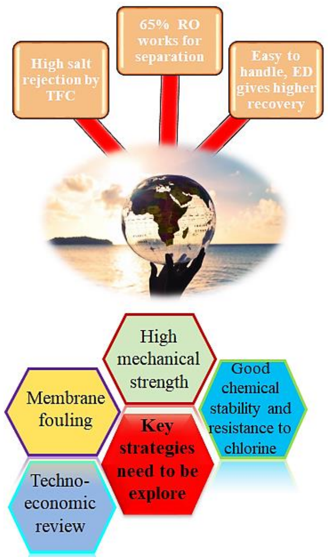

Figure 4: Few research challenges associated with purification of water.

Less attention has been paid to this methodology during the forward osmosis process, and the internal concentration polarization could be reduced the critical problem (McCutcheon et al., 2006). Purification of water can be achieved by membrane generated power supply by the difference of salinity of two bodies (Mehta et al., 1978). In another desalination application field, a method is used to combine desalination and power generation known as electrodialysis or reverse electrodialysis. This method includes the cation and anion membrane; upon passing the salinity solution, cation pass through the cation membrane, and anion pass through the anion membrane. This phenomenon creates electroneutrality on the membrane; brings more benefit than other technology such as reverse osmosis due to less sensitivity of feed water quality results for reduced pre-treatment process (Nagarale et al., 2006). In reverse electrodialysis, electroneutrality is maintained by charge collectors on either side of the system. Moreover, the membrane for these applications is advantageous should be robust and relatively easy. But it still met the same issues concerning fouling, scaling, and chemical resistance.

4. Conclusion

Polymeric membrane-based technology comes with ease of functionalization, high sustainability, excellent adsorption, economic advantage, and environmental friendliness. This technology has shown tremendous potential in wastewater treatment. The treatment capabilities of these membrane and related hybrids have been explored for diverse waste removal applications. Unlike conventional technology, e.g., absorption and ion exchange, the polymer type membrane technology offers abundant advantages in good surface chemistry, allowing easy surface-sorption of toxins. The short communication includes the need for water purification and their purification by membrane technology, especially polymeric derived membranes. Besides, the state-of-art membrane and its utilization for the removal of various water contaminants were discussed. The proposed review would be helpful to provide a single platform to study about the role of polymeric membrane.

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