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A Mini Review on Treatment of Wastewater with Membrane Technology

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Abstract:

Wastewater treatment is a continuous environmental problem, which troubles human activities. Numerous efforts have been made over the years to develop newly efficient technologies, including traditional filtration, coagulation-flocculation, and biological treatment systems. Among which, membrane technology is proven to be a significant one. Membranes technology is divided into four categories based on pore size. The four types of membrane technology including micro-filtration, ultra-filtration, nano-filtration, and reverse osmosis. This paper focus on the introduction, advantages, disadvantages and protection of these four membrane processes.

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1. INTRODUCTION

The membrane technology has a low lab-experimental history before its first industrial application in 1960s [1-3]. In 1748, Abbe' Nollet makes an accidental discovery of the earliest known membrane phenomenon, which is called osmosis [4]. Between 1907 and 1920, Zsigmondy creates molecular filters which are the first microfilters and ultrafilters [1-3, 5]. Teorell and Meyer's (1930) study on transport over neutral and fixed-charge membranes provided the foundation for electrodialysis membranes and modern membrane electrodes [1-3, 6].

Since membrane technology inception in the 1960s, membrane technology has advanced significantly and is currently undergoing a blossoming that began in the early 1990s [6-8]. The use of membranes is generally recognized as the greatest technique currently available for the treatment of water and wastewater [9-11]. The use of membrane technology is primarily driven by growing fears about the world's population increase, the scarcity of freshwater supplies, and stricter rules governing water quality. Additionally, membranes are employed in the production of energy, the processing of food and beverages, the manufacturing of chemicals and pharmaceuticals, environmental monitoring, and quality control [12-14].

Human activities are entirely dependent on water. Numerous tons of wastewater are created each day in the home, industrial, and agricultural sectors as a result of the growing human population [15, 16]. However, freshwater resources are not renewed quickly enough to meet the needs of the growing population in terms of water use. Because of this, there is fierce competition and an unjust distribution of the few freshwater resources among the different industries. As a result, many people worldwide, particularly in poorer nations, lack access to clean water. Wastewater generation is unavoidable because it is a crucial link in the value chain of every aspect of life [17]. Around 10 barrels of wastewater are produced for every barrel of processed crude oil in the sector [18].

In keeping with this, numerous efforts have been made over the years to develop newly efficient technologies [10]. Studies have shown that membrane technology is one of the efficient wastewater treatment procedures. Membrane technology has expanded dramatically over the past couple of decades and offers several opportunities for wastewater treatment due to significant equipment size reduction, low energy requirements, and inexpensive capital costs [7]. Owing to little or no chemical use, environmental friendliness, and widespread accessibility, membrane technology has the potential to close the economic and sustainability gap.

Membranes technology is divided into four categories based on pore size. The four types of membrane technology include micro-filtration (MF), ultra-filtration (UF), nano filtration (NF) and reverse osmosis (RO) [6, 13, 19]. Micro-filtration membrane process is considered as a low-pressure membrane process [20]. Micro-filtration membrane are used for the retention of suspended material particles, which is similar to traditional coarse filtration [21]. Ultra-filtration membrane is one of the types of membrane technology, which pore size is about (2-100 nm) [22, 23]. It tosses off macro-molecular colloids and virus. Unfortunately, the membrane may allow almost more dissolved ionic species to flow through. It is also, considered an effective method for treating generated water and oily wastewater treatment. The key benefits of using it are its effectiveness in removing oil, lack of need for chemical additives, low energy cost, ability to function at low trans membrane pressures of 1 to 30 psi, and little space requirements [24, 25].

2. MEMBRANE TECHNOLOGY FOR WASTEWATER TREATMENT

Membranes are understood to be a designed barriers that filter out colloids, molecules, or salt utilizing a non-fibrous, engineered barrier and a size exclusion mechanism [26]. Membranes can separate different particles, based on their pore size, shape, and chemical or physical property. A membrane, in its simplest form, is a barrier that divides two phases by preventing certain components from passing through it [27]. The schematic diagram shows a summary of some of these techniques according to their driving forces below (Figure **1**).

2.1. Micro-Filtration Membrane Technology

One of the membrane technology kinds that use membranes with highly open pore configurations in a low-pressure separation process is micro-filtration [29, 30]. Both organic and inorganic materials, including ceramic or stainless steel, can be used to create micro-filtration filters, such as polymer-based membranes. One of the most widely utilized membrane techniques for wastewater treatment is the micro-filtration membrane [19, 31]. Micro-filtration development started in the 1920s and 1930s, with the collision

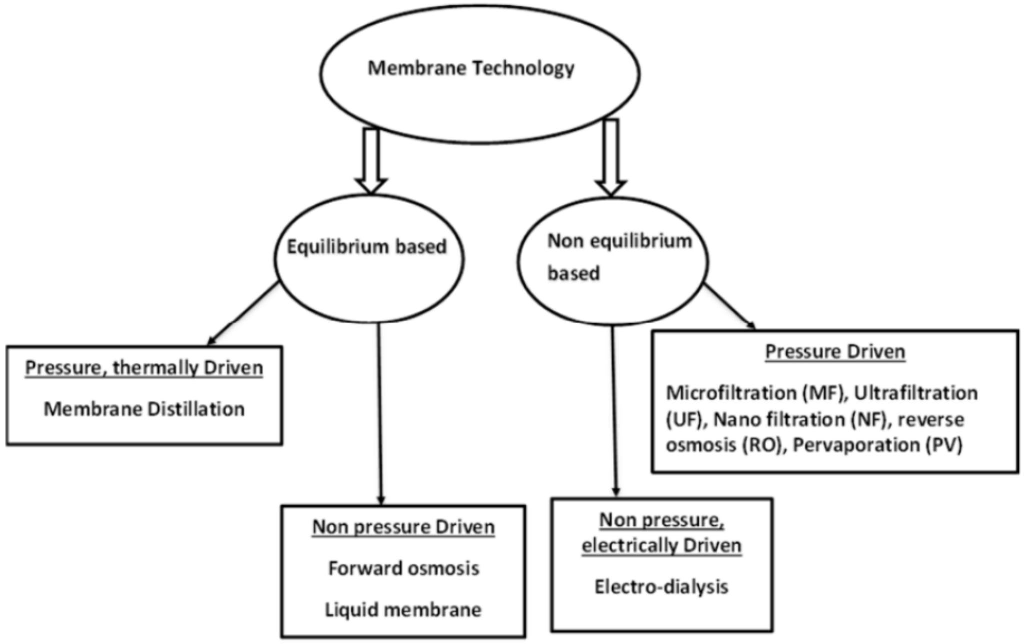

Figure 1: The schematic representation of some membrane processes [28].

(nitrocellulose) membranes are the first membranes to be made available for purchase commercially in 1926 [32]. Although there are more membrane manufacturers in the 1940s, until the middle of the 1960s, micro-filtration membranes are only used in laboratories and relatively small-scale companies. Dead-end or in-line filtration is the most popular method for micro-filtration. In the 1970s, cross-flow filtration, a substitute technology, and the use of membranes in large-scale enterprises both became feasible. Ceramic tubular cross-flow filters became on sale in the middle of the 1980s. The third type of micro-filtration to emerge in the following few years was semi-dead-end filtration [32, 33].

Micro-filtration membranes are frequently using in pharmaceutical, semiconductor industries, food and beverage [34]. To get rid of tiny particles, big bacteria, dangerous pathogens, and yeast cells, micro-filtration membrane technology employs the physical separation concept. For industrial applications where particles larger than 0.1 µm must be stayed in a mixed solution, micro-filtration is the preferred approach and a fairly well-established technology [21]. Micro-filtration membranes is making significant progress in the wastewater sector, concentrating on removing particles from wastewater, in sewage treatment, but also in a number of other types of industries like semiconductor fabrication that produce heavily polluted wastewater that requires extensive treatment due to toxic substances and metals [35].

Groundwater containing gaseous hydrogen sulfide (H_2S) has been assessed using micro-filtration membranes as an alternative treatment to the traditional method, which mostly involved air stripping to remove H_2S [36]. For the production of drinking water, filtering lake water through porous ceramic membranes has proven to be quite effective. The demand for chlorine, which is required to make a water transport and distribution network hygienically safe, was noticeably reduced as a result of the total removal of suspended particles, bacteria, and algae [37].

All process fluid travels through a micro-filtration membrane during dead-end filtration, and all patches that are larger than the membrane's severance compasses are stopped at the membrane's face. In order to help cutlet development, the entire feed water is treated all at formerly. The main operation of this system is batch or semi-continuous filtration of dilute results.

The most significant use of micro-filtration membrane technology is the filtration of aqueous solutions, particularly in the purification of drinking water and beverage [38]. In beverage production, industrial applications include the filtering wine and beer as well as the processing of milk and whey. Micro-filtration membrane is employed in biotechnology to keep biomass in the fermentation fluid. The separation of water and oil is the most crucial micro-filtration process in the metallurgical sector [34].

Membrane technology have numerous advantages such as, it does not need to change the pH of the solution and temperature during the micro filtration membrane separation. Without the use of chemicals, micro-filtration can also be accomplished, which lowers production costs, boosts product quality, and lowers labor expenses [39]. Unfortunately, membrane fouling or obstruction continues to be a major issue when using micro-filtration. In this scenario, micro-filtration membrane productivity is decreased, permeation flux is diminished, and the service life of filters is limited. The expansion of its applicability is unavoidably hampered by this circumstance.

2.2. Ultra-Filtration Membrane Technology

Ultra-filtration uses a finely porous membrane to separate water and micro solutes from macro-molecules and colloids [40, 41]. The membrane's pore size ranges from 10 to 1000 A on average. Bechhold creates the first artificial ultra-filtration membranes using collision (nitro cellulose). Other important early workers were Zsigmondy and Bachmann, Elford and Ferry. Colloid ultra-filtration and micro-filtration membranes are marketed for use in laboratories by the middle of the 20th century. Even though collodion membranes were frequently employed in scientific experiments, no industrial uses were known until the 1960s. The significant innovation came from Loeb and Sourirajan's creation of the an-isotropic cellulose acetate membrane in 1963.

The ultra-filtration membranes can be created from both the organic and the inorganic materials [23]. In order for the production of ultra-filtration membrane to be carried out, several other materials and polymers are used. A certain polymer is selected as a membrane material based on a number of extremely precise characteristics, including molecular weight, chain flexibility, chain interaction, etc. [42, 43]. The structure of ultra-filtration membrane is a symmetric or symmetric. Ultra-filtration membranes can have symmetrical or asymmetrical structures. The range of symmetric membrane thicknesses (porous and nonporous) is 10 to 200 μm. The asymmetrical structure of ultra-filtration membranes is made up of a highly dense outer layer or skin that ranges in thickness from 0.1 to 0.5 μm that is supported by a porous sub-layer that is between 50 and 150 μm thick. The size of the pore in porous membranes largely impacts the separation properties. In most circumstances, the kind of membrane material has little bearing on flux and rejection but is crucial for chemical, thermal, and mechanical stability [44-48].

The operation of ultra-filtration membrane can be achieved in two different service modes, which are dead-end flow and cross-flow [49-51]. The dead-end flow mode of ultra-filtration membrane operation is similar to a cartridge filter wherein there is only a filtrate flow and feed flow. The dead-end flow technique often limits itself to feed streams with low suspended particles but typically provides for optimal feed water recovery in the 95 to 98 percent range. The cross-flow mode of the ultra-filtration membrane operation different from that of the dead-end mode in which there is an extra flow aside from filtrate flow and feed flow. Typically, the cross-flow mode of operation yields a lower feed water recovery, i.e., 90 to 95% range.

The ultra-filtration membrane technology is recognized to be a competitive wastewater treatment technology as compare to the conventional wastewater treatment method. To ensure the whole process of the ultra-filtration membrane performs at its best, each stage of this process must be managed, creating a complicated control system. Modern water treatment plants use ultra-filtration membrane to replace the clarification process, which includes coagulation, sedimentation, and filtration and can be thought of as a membrane operation for clarity and disinfection Despite the fact that ultra-filtration membrane is permeable, all particle pollutants, including macro-molecules and viruses and bacteria, are rejected.

As previously stated, ultra-filtration membrane can be used for drinking water supply in a single operation, i.e., without any pre-treatment other than a standard screen filter. Ultra-filtration membrane can be used alone to treat wastewater when the feed water organic content level is not too high [52]. To eliminate water-borne pathogens when preparing drinking water, membrane filtration has replaced traditional technology as the preferable option. It has been discovered that ultra-filtration membrane technology can remove viruses, Giardia, and turbidity from water better than existing regulations allow. By utilizing ultra-filtration membrane, it is possible to eliminate 90-100% of viruses and bacteria [53, 54].

2.3. Nano-Filtration Membrane Technology

In recent years, the development of nano-filtration membrane applications across all areas has been quite rapid [55, 56]. By the end of 1980, nano-filtration membrane was already being employed in filtration processes. Nano filtration characteristics are 7-30 operating pressure and 1-5 nm in pore size these are used to separate solutes with low molecular weight, and it's effective in rejecting hardness, heavy and dye metal [57, 58]. Nano-filtration membrane is a very promising membrane application for the future wastewater treatment technology, owing to low operating pressure, increased permeate flux, lower energy consumption and higher rejection. The nano-filtration membrane technology is one the types membrane technology that has been recently added to the wastewater treatment systems. Due to their unique properties, nano-filtration membranes are very effective at fractional and removing specific solutes from complicated process streams [59]. Recent years have seen a remarkable increase in the use of nanofiltration membrane technology, which has become a viable process [60, 61].

Nano-filtration membrane technology is becoming more predominant in pharmaceuticals, wastewater treatment, biotechnology, industry, brackish water desalination and water purification [62, 63]. Nano-filtration membrane method is used in industry for things like color separation in the textile industry, metal recovery, and olive mill wastewater treatment. Additionally, nano-filtration membrane is used to treat the wastewater from the coke industry, the pulp and paper industry, the oil and petroleum industry's greasy effluent, and to remove acid sulfate from wine water. There are numerous domestic sectors, in which nano-filtration applications has been used as well, such as the treatment of municipal wastewater, leachate, car wash effluent, and restaurant effluent. Additionally, nano-filtration membrane technology has been utilized to remove phenol chemicals from pomegranate juice as an alternative to separation in food processing. The combination of nano-filtration membrane and reverse osmosis with cascade operation in whey treatment produces the best results for recovering protein and lactose, during the treatment of instant tea powder effluent. Additionally, red wine and coffee extract are concentrated via nano-filtration membrane. The nano-filtration membrane technique is chosen in the pharmaceutical industry for the antibiotic separation process [64, 65].

2.4. Reverse Osmosis Process Membrane Technology

Reverse osmosis is considered to be a mechanism derived from the development of osmosis, that happens in nature, whereby may be a fashionable method technology to purify water for a large vary of applications, as well as semiconductors, food process, biotechnology, prescription drugs, power generation, brine desalting, and municipal beverage [66-71], clearly seen in Figure **2**.

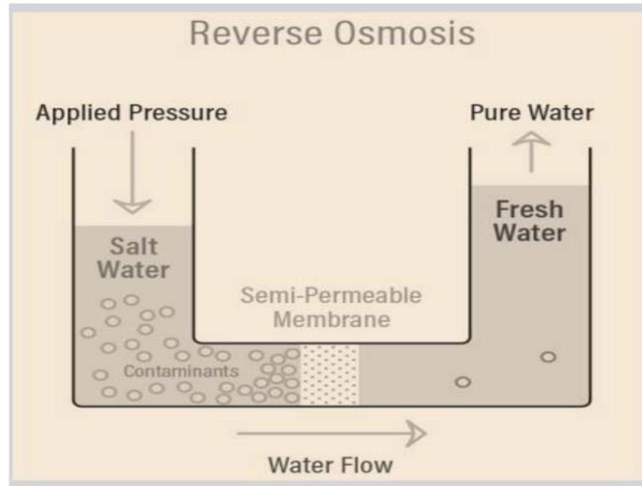

Figure 2: The general summary of reverse osmosis process.

Essentially, a RO desalination plant consists of four primary systems (shown in Figures **3** and **4**): (1) pre-treatment system, (2) high pressure pumps, (3) membrane systems, and (4) post-treatment system [72-77]. There is a pre-treatment system available to get rid of any suspended materials, preventing salt precipitation or microbiological growth on the membranes. A chemical feed followed by coagulation, flocculation, and sedimentation, as well as sand filtration or membrane processes like micro-filtration and ultra-filtration, are examples of standard pre-treatment techniques. A water pump is necessary to apply pressure to waste water or a saline solution in order to create the reverse osmosis pressure. The solvent will not flow when the pressure is equal to the solution's natural osmotic pressure. The solvent flows through the reverse osmosis membrane, forming a concentrated solution on the pressure side and a more diluted solution on the opposite side if the pressure is greater than the natural osmotic pressure of the solution. If the pressure is lower, the solvent flows from the diluted solution to the concentrated solution. All of these will successfully separate the solute and eliminate contaminants such salt, colloid, microorganisms, heat source, organic debris, and others. To put it another way, the idea behind desalination using a reverse osmosis membrane is to exert higher pressure than natural osmosis pressure on water that has been salted. This will force the water

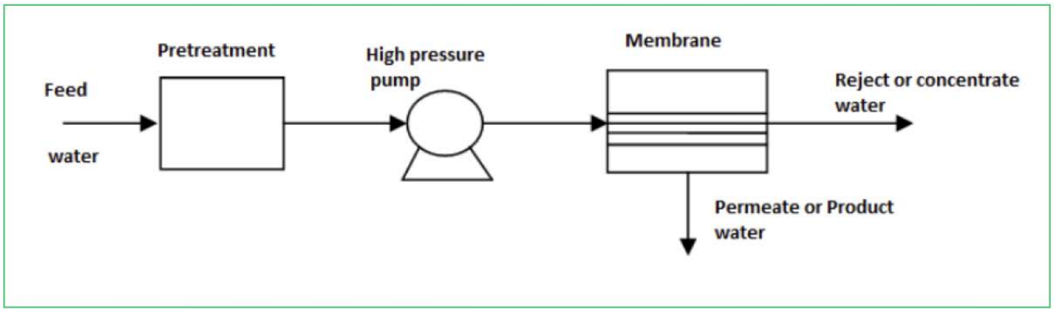

Figure 3: Schematic diagram of the RO process.

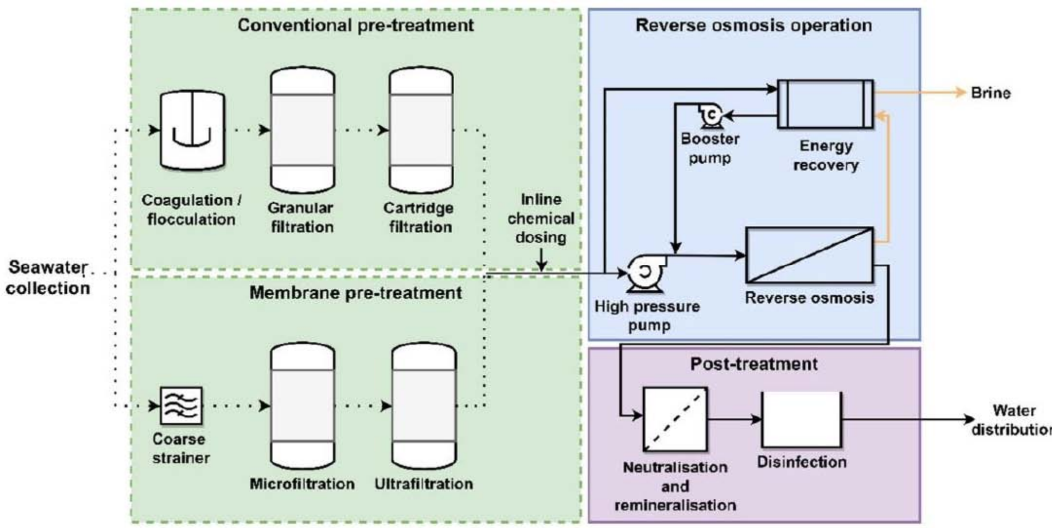

Figure 4: The reverse osmosis process utilizing either conventional or membrane pre-treatment, as indicated by the dotted lines [78, 79].

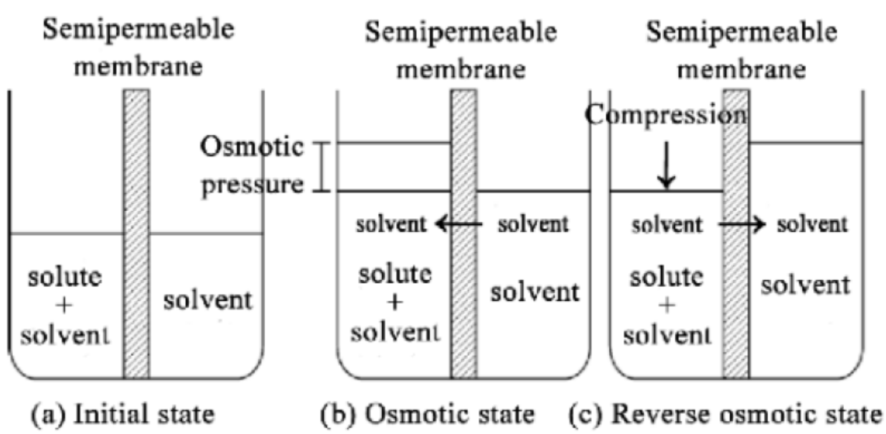

Figure 5: Principle of reverse osmosis.

molecules in the raw water to the other side of the membrane and cause the permeation to go in the other direction, achieving the goal of eliminating the salt from the water. Reverse osmosis technology is one of the most cutting-edge membrane separation techniques used in treatment wastewater in the world. Other way, the basic principle is shown in Figure **5**.

3. MEMBRANE FOULING AND CLEANING

The foremost hindrance to the prevalent of membranes technology is the existence of fouling phenomenon on the membrane process. Membrane fouling is the cause of the deteriorating of permeate quality and the decline in permeate flux [80]. Fouling in membrane can also be

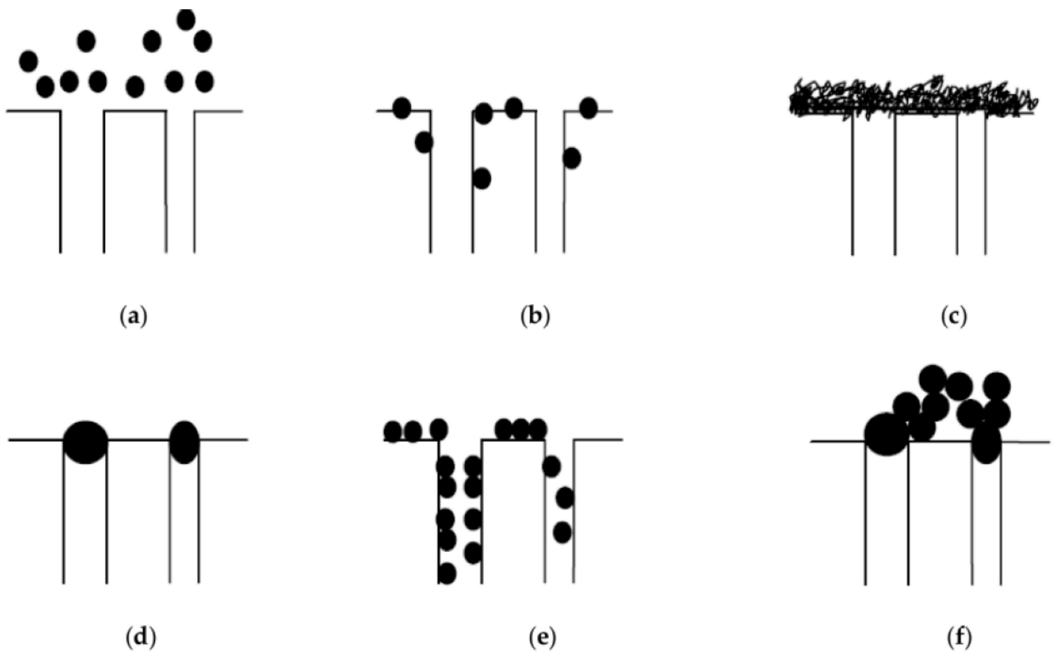

Figure 6: Mechanisms of membrane fouling [85]. (**a**) Concentration polarization; (**b**) Adsorption; (**c**) Gel layer formation; (**d**) Complete blocking; (**e**) Standard blocking; (**f**) Intermediate blocking.

motivated by the hydrodynamics of the filtration process. Fouling in membrane is generally classified as reversible and irreversible [81]. It is simpler to deal with the reversible fouling phenomenon than the irreversible fouling. The cake layer formation, adsorption, and pore blocking are examples of the irreversible fouling (Figure **6**) [82]. Complete, standard, and intermediate pore blocking are the three different forms of pore blocking [83, 84].

The degree of flux recovery reveals the degree of fouling as well as the efficiency of the cleaning technique. Concentration polarization and fouling are direct link to flux decline in membrane. Concentration polarization takes place when dissolved and colloidal substances gather on or very close to the membrane surface, whereas fouling is the progressive accumulation of pollutants on the membrane surface [86]. The interactions between the foulants in the feed stream, the fouling layer, and the filtration process hydrodynamics all have an impact on membrane fouling [87, 88]. Various efforts are being tried by organizations and businesses to address this issue of flux drop during membrane processes, particularly the micro-filtration membrane, can have a negative impact on the economics of a given membrane operation [89, 90].

The abecedarian handicap to effective chemical cleaning, which is the second of the two defining cleaning mechanisms, is allowed to be mass transfer. The first stage in chemical cleaning is to identify composites that can be employed as drawing agents [91]. The selection of the applicable accoutrements is grounded on the feed composition and the layers that have rained on the membrane face, and is generally done by trial and error. The membrane's performance may be negatively impacted by the unhappy cleaning agent selection. The chosen cleaning agent needs to be affordable, washable with water, chemically stable, safe, and suitable to dissolve the maturity of the rained fouling rudiments without causing any detriment to the membrane [92]. Cleaning agents often fall under the categories of bases, acids, enzymes, surfactant, and disinfectants, as well as combinations of these categories.

Unless sufficiently large concentrations are utilized to overcome the forces of attraction, the chemical agent cannot reach the foulants. To describe the membrane chemical cleaning process, several researchers recommended the following six steps:

1. Bulk response of cleaning reagent as the cleaning in place is introduced;
2. Cleaning agent is transported to membrane face;
3. Cleaning agent transportation through foulants layers to membrane surface;

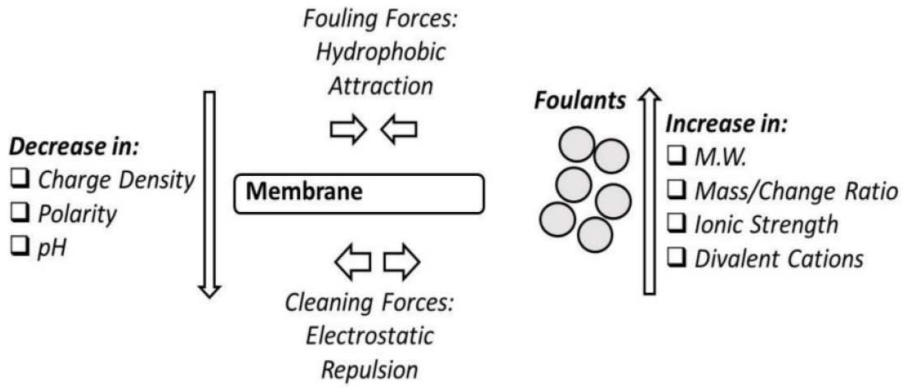

Figure 7: Schematic stage model for solution transport.

4. Waste cleaning agent with suspended foulants transported to interface;

5. Cleaning responses solubilize and detach foulants;

6. Eventually, transport of waste matter to the bulk result from forgetful side of membrane.

According to the electrostatic equilibrium model (Figure **7**), the foulants is physically removed from the membrane surface by minimizing forces that keep it there during cleaning. Whether the foulants is organic, inorganic, acidic, or basic, as well as the charge state, should all be taken into consideration when choosing the cleaning agent. Solutions containing sodium hydroxide (NaOH) are employed where membrane chemical resistance is a concern. Increased mass transfer and transport of the cleaning agent to the membrane surface are made possible by its ability to enlarge NOM molecules. Using NaOH at the threshold value concentration, which varies for different foulants and membrane materials and degree of fouling, could increase the amount of permeate that is recovered [93]. This may explain why oxidants work better when paired with alkaline cleaning solutions, especially in areas where organic foulants are prevalent [94]. Acids are used more frequently to remove mineral scaling because they are efficient for cleaning in place and chemical enhanced back flush at pH levels as low as 1.0.

4. CONCLUSIONS

In general, research has shown that several membrane technologies, including micro-filtration, ultra-filtration, nano-filtration, and reverse osmosis, are employed to effectively treat wastewater from various activities. However, improvements in membrane fouling and membranes sensitivity to harmfulness are the key constraints of the membrane technology, which must be addressed in order to address specific particle limitations and increase membrane usage in various kinds of wastewater. The cleaning method with less secondary waste liquid caused by membrane cleaning and easy to deal with the waste liquid should be chosen, because it is dangerous to consider the secondary waste liquid produced by membrane cleaning. For this reason, researchers have developed many ways to improved membrane technology in wastewater treatment. Overall, it can be said that wastewater treatment using membrane technology has been proven to be quite promising.

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CONFLICTS OF INTEREST

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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