

APPLICATION OF NOVEL MEMBRANE TECHNOLOGIES FOR INDUSTRIAL WASTEWATER TREATMENT

Abstract

Industrial wastewater reuse must undergo radical adjustments to account for factors. Which include rapidly dwindling resources, public concern, environmental degradation, and health dangers to consumers and workers? A desirable economic alternative is wastewater reuse. Particularly when discussing vital preservation for future generations, it can be a beneficial tactic. The amount of waste diverted to treatment facilities is decreased by prudent use as well, and reduces the overall cost of treatment. Possible future roles of membrane technology in water sustainability are discussed in this paper by examining their potential uses and present state. It also includes the role of cutting-edge technologies and examining the difficulties in the study and development of membrane materials in this area.

Keywords: Water sustainability; Membrane technologies; Novel materials; Fouling; Scaling.

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APPLICATION OF NOVEL MEMBRANE
TECHNOLOGIES FOR INDUSTRIAL WASTEWATER TREATMENT

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I. INTRODUCTION

Water scarcity has been caused by global urbanization and population growth. One of the major issues of the twenty-first century is the water crisis[1,2]. According to published data, 4 trillion cubic meters of water are used annually by industrial sectors, while the estimated volume of clean water needed for daily human consumption is 0.01 trillion cubic meters[3–5]. Finding new clean water supply sources from various industries, such as wastewater, saline water, and rainwater, is urgently needed. Significant amounts of industrial wastewater are discharged directly into the environment, which poses serious risks to both the ecosystem and human health [6–8]. Consequently, treating industrial wastewater would be a practical way to address the freshwater shortage and aid in keeping our environment sustainable. Due to the rising industrialization, the available freshwater supply is becoming a severe threat to the living communities around the world. Groundwater depletion brought on by excessive water withdrawal and reduced recharge and the water situation is additionally exacerbated by pollution of the water sources. The use of treated wastewater as an alternative resource is encouraged by the growing demand on water supplies[9].

Food, pharmaceuticals, steel, pulp and paper, power, as well as other industries, have all been identified as some of the high-volume users and producers. Industrial wastewater can be treated using a variety of techniques, such as physical-chemical systems (gravity concentration, evaporation, coagulation, filtration, and centrifugation) [10], adsorption[11], Fenton oxidation[12,13], ozone[14], microalgae cultivation[15], constructed wetlands[16], UV disinfection[17], plasma[18], microbial fuel cells (MFCs)[19]. However, their limited use is due to their high operating costs and production of secondary pollutants [20–22]. There has recently been an increase in interest in creating environmentally sustainable, cost-effective, and technologies for treating industrial wastewater that are effective. Membrane processes have a lot of potential because of their distinctive benefits, such as superior effluent performance, low energy consumption, and simplicity of use [23]. Membrane processes encompass a wide range of technologies, such as membrane bioreactors (MBRs), pressure-driven membrane filtration (microfiltration, ultra filtration, nanofiltration), reverse osmosis, forward osmosis, electro dialysis, membrane contactors, and membrane distillation (MD)[24]. Membrane technologies satisfy environmental impact standards for sustainability, land use, usability, adaptability, and simplicity. However, they still require cost-saving improvements and affordability, energy consumption and expertise. These improvements require advancements in membrane materials. A new chance for membrane development has recently arisen with the appearance of novel two-dimensional (2D) materials like grapheme.

As a result, this study combines and evaluates the most recent research on mixing grapheme materials with other materials in polymer phases, such as grapheme oxide and reduced grapheme oxide with an aim toward using them in various membrane-based technologies. The primary objective of this review is to take a broad look at the literature from the past few decades by analyzing how different types of industrial effluent have been handled and concentrating on the use of innovative materials and membrane processes to treat water and reuse it in various industries. Finally, this review will discuss the principal difficulties in membrane processes such as membrane fouling and its prevention in different industries and lastly, offer suggestions and outlooks for the future.

II. DRIVING FACTORS FOR WATER REUSE

Due to a number of issues, including groundwater depletion and expensive water extraction costs, industrial reuse of wastewater has become more popular. Focus has shifted to the reuse of treated wastewater in water-intensive industries in many nations [25]. Common industrial uses include using treated water as boiler feed water, as process water for washing purposes, and cooling towers, based on the industry. For instance, the reuse of industrially treated water is quite common in Japan. In Singapore, reclaimed water is cleaned up and used again as process and cooling water [26].

Due to industries' high-water consumption, industrial applications for treated waste water is one of the solutions with the highest sustainability, which are strengthened by stringent water quality standards. Table 1 compiles the specific details about the use of freshwater and treated wastewater [27]. The 2006 World Health Organization (WHO) recommendations put forth a versatile method of risk management and risk assessment with targets based on health that can be established at a reasonable level given the circumstances in the area. Strict monitoring procedures must be used to support the strategy [28].

Table 1: Fresh Water and Treated Wastewater Utilization Status in different Countries

Country	Water Utilizing Sectors	Status of Water Reuse	Reference
Europe	Agriculture: 44% Industry, energy: 40% Public water supply: 16%	Landscape irrigation: 20% Groundwater Recharge: 2.2% Recreation: 6.8% Non-potable urban uses: 8.3% Indirect potable uses: 2.3% Agriculture: 32% Industrial: 19.3% Environmental: 8% Other: 1.5%	EEA CSI, 2018 [29]; GWIPUB Water Reuse Inventory, 2009[30]
South Africa	Agriculture : 60% Domestic: 27% Industrial: 3% Power: 4% Mining: 3% Other: 3%	Landscape and sports field: 9% Industry: 48% Agriculture: 43%	Adewumia et al., 2010[31]; CoCT, 2007[32]
USA	Thermal power: 41% Agriculture: 37% Industries: 6% Domestic: 14% Livestock: 3%	Agriculture: 37% Geothermal energy: 2% Golf course irrigation: 7% Landscape irrigation: 17% Groundwater recharge: 12% Seawater intrusion barrier: 7% Recreational impoundment: 4% Wetlands, wildlife habitat: 4% Industrial and commercial: 8%	Kenny et al., 2009[33] ; SWRCB, 2011[34]

		Other: 2%	
India	Agriculture: 87% Industrial: 7% Domestic: 4% Energy: 2%	Agricultural irrigation: 78% Industrial use: 12% Thermal power plant: 4% Groundwater recharge: 6%	Jindal &Kamat, 2011[35]
Greece	Irrigation: 83% Animal husbandry: 1.3% Industry: 2.2% Public use: 13% Other: 1.2%	Agricultural irrigation: 58.4% Irrigation of forested land and Firefighting: 17.7% Landscape irrigation: 23.9%	Frontistis et al., 2011[36]; Tsagarakis et al., 2001[37].

Even though India's high wastewater discharge rates present opportunities for water reuse, it is frequently wasted because of insufficient study and direction, and unstable institutional structure. The development of an integrated strategy taking into account all the aspects of technical viability, financial viability, and social acceptance along with a directing management structure that may supplement the current water supplies is suggested as being necessary for the reuse of wastewater [25].

III.MEMBRANE TECHNOLOGIES

In order to meet the ever-increasing demands of mankind, the levels of activity in the areas of industry, agriculture, and domestic life all rise proportionately as populations expand. These operations result in the production of vast volumes of wastewater, the water from which can be reused for a variety of applications. Conventional wastewater treatment procedures have, to a certain extent and over the course of many years, been successful in treating effluents for the purposes of release. However, it will be important to make advances in wastewater treatment techniques in order to render treated wastewater applicable for use in industries such as agriculture as well as in domestic purposes. Membrane technologies have the potential to successfully treat the vast majority of wastewater from industrial processes [38–42], The production of waste water is unavoidable given that it is an intrinsic component of the value chain in every sphere of human activity. For instance, in the oil refining business, the processing of one barrel of crude oil results in the generation of around ten barrels of wastewater [43].

Because of the many benefits that it offers in the treatment of water and wastewater, membrane technology has experienced substantial growth over the past few of decades. Membrane technology offers several opportunities within the realm of the treatment of wastewater, due to its significantly reduced footprint in terms of both equipment and energy consumption as well as its low initial investment price [44]. Nghiem and Fujioka, [45]claims that the technology of membranes has the potential to close the gap, both economically and in terms of sustainability. With the possibility of using few or no chemicals, being kind to the environment, and being easily accessible to a large number of people, now a days membrane technology has shown itself to be a more successful choice in the treatment of wastewater than other available options. Despite the fact that membrane technology is not a very recent development, because of the various characteristics and complexity of wastewater, there is opportunity for even greater advancements in terms of efficiency, energy needs, the quality of permeate requirements, area requirements, and technical skill requirements are all included.

Again, Continuous modifications are made to membrane elements and membrane modules in order to improve the decrease in membrane fouling, which is a significant barrier for membrane processes [46,47].

In accordance with the kind of materials that compose them, membranes can be categorized as either organic or inorganic. Synthetic organic polymers are used in the production of organic membranes. Mostly, membranes for pressure-driven separation processes (micro-filtration, ultra-filtration, nano-filtration, and reverse osmosis) consist of organic synthetic polymers in their construction. Polyethylene (PE), Polytetrafluoroethylene (PTFE), Polypropylene, and Cellulose Acetate are just few of the materials that fall into this category [48]. Inorganic membranes are created from such materials as ceramics, metals, zeolots, or silica. They do not change in either chemical or thermal properties, and their uses in industry, such as ultra filtration and microfiltration, are widespread [49,50]. Several different driving factors are responsible for the flow of the medium across the membranes. There are equilibrium-based, non-equilibrium based membrane processes, pressure driven and non-pressure driven processes[51]. Some of these methods and the causes behind them are summarized in the Figure 1.

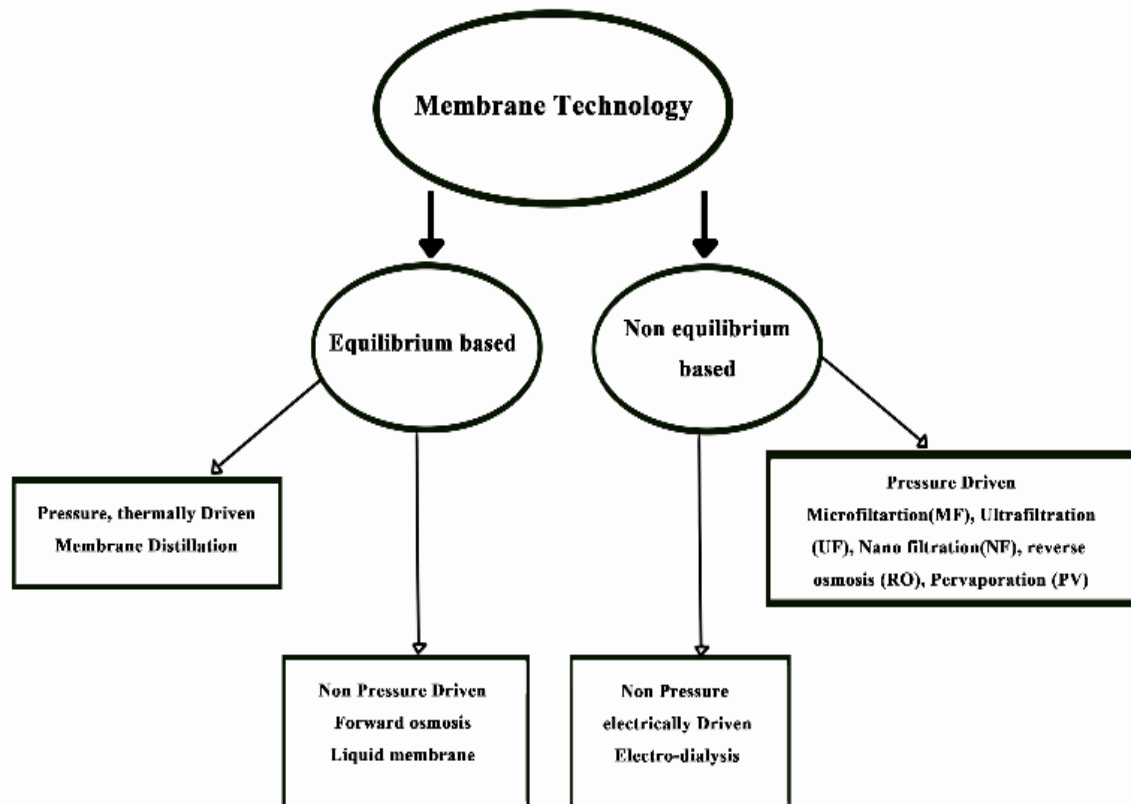


Figure 1: Schematic Representation of Some Membrane Processes. Modified from [52].

There are four different types of membranes: MF, UF, NF, and RO (Figure 2). In pressure - driven membrane process, after loading the stream of feed into the filtration unit that is outfitted with required pressure and a membrane panel to be applied immediately

during the operation in order to separate the solution into the permeate and the retentate phases [53]. Due to the fact that it is responsible for the removal of significant quantities of organic matter, membrane rejection behavior is of utmost significance in this kind of operation. Raw effluents that contain micro-pollutants and dyestuff, which yields superior quality permeate water that can be used for a variety of purposes including flushing toilets, washing clothes and dishes, watering gardens, and growing soil and fertilizer [54].

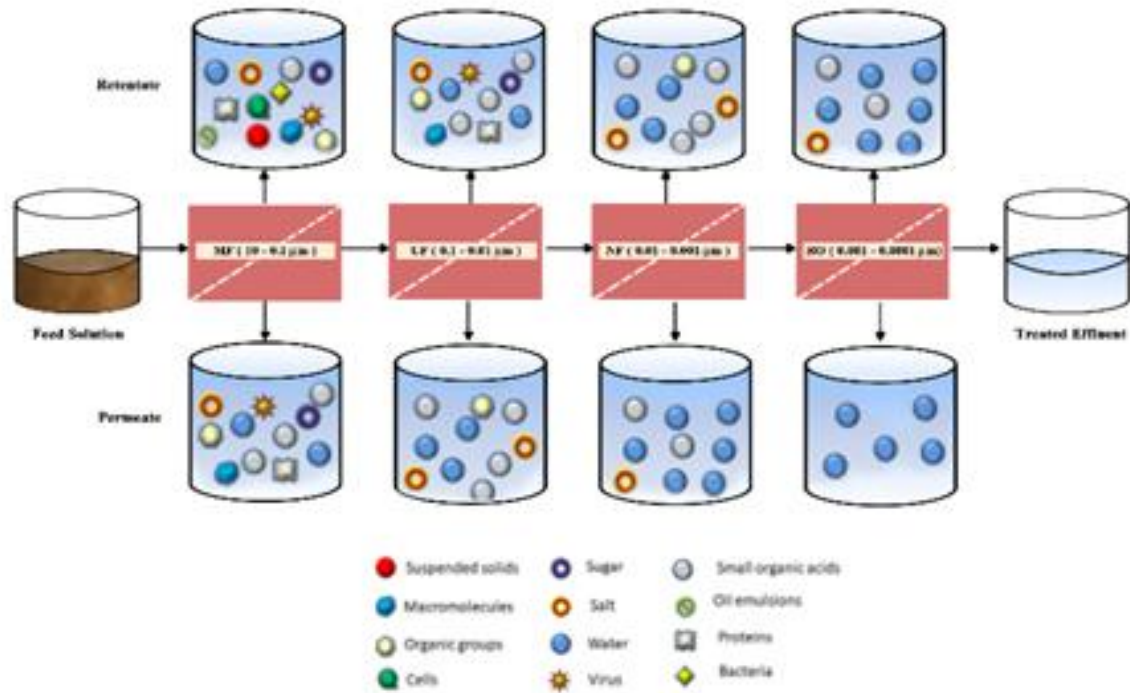


Figure 2: Typical Representation of Pressure-Driven Membrane Process.

Table 2: Applications of Pressure-driven Membrane Processes in Wastewater Treatment

Pressure Driven Membrane Process	Wastewater Treated	Results	Reference
UF	Vegetable oil factory	COD (91%), TSS (100%), TOC (87%), PO43 (85%), Cl(40%)	[55]
MF-RO	Urban wastewater	Pesticides and pharmaceuticals removed to discharge limit	[56]
MF	Municipal wastewater	Contaminants eliminated to below detection limit	[57]
MF	Emulsified oily wastewater	95% removal of organic contaminants	[58]
NF-RO	Dumpsite leachate	95% water recovery	[59]

UF	Poultry slaughterhouse wastewater	COD and BOD ^c removal >94%, fats (99%), suspended substances (98%)	[60][61]
NF	Textile	COD (57%), color (100%), salinity (30%)	[62]
UF-RO	Metal finishing industry	90–99% removal of different contaminants	[63]
UF-RO	Oily wastewater	Oil and grease (100%), TOC (98%), COD (98%), TDS ^e (95%), Turbidity (100%)	[64]
UF-NF/RO	Phenolic wastewater from paper mill	COD (95.5%), phenol (94.9%)	[64]

Table 2: Displays a number of other contexts in which similar pressure-driven membrane processes have been used.

* Note: ^a—chemical oxygen demand, ^b—total suspended solids, ^c—biochemical oxygen demand, ^d—total organic carbon, ^e—total dissolved solids.

In majority of these uses, MF, UF, and NF are precursors of RO. This will help keep the RO membrane cleaner and allow for more steady flux. Furthermore, this method acts as a multi-stage treatment for purging wastewater of harmful substances[65,66]. Water reuse from sewage is feasible now because to pressure-driven membrane technologies. However, the issue that still has to be addressed is the pressure's demand for a certain amount of energy. However, non-equilibrium pressure-driven processes still face challenges, such as fouling and high energy demand. In order to find a long-term answer to them, ongoing research is required, or by instituting stringent, low-cost pre-treatment procedures or through creating membranes that can withstand fouling[66].

1. Membrane Fouling: Fouling of membranes is a serious problem that affects every membrane-based activity. A higher water productivity, less cleaning, longer membrane life, and reduced capital and operational costs possible with a lower level of membrane fouling. Different types of foulants, such as inorganic (scaling), organic, and biofouling, cause different types of membrane fouling[67,68]. The conventional methods of dealing with membrane fouling are pretreatment technology, operation optimization, and routine membrane cleaning. Membrane alteration, on the other hand, is an approach that has the potential to be the most long-term in preventing fouling. Membrane features and qualities that influence fouling development include their chemical structure (functional groups, charge, and hydrophilicity) and morphology (pore size, surface roughness, or surface pattern). For reduced fouling propensity, it is preferable to have a surface that is highly hydrophilic, negatively charged, and has a smooth texture. Numerous membrane changes have been investigated to meet the aforementioned goals such as interfacial coating[69–71], surface grafting[72–76], addition of hydrophilic monomers or inorganic particles[77–80], and zwitterionic modification[81]. In many cases, flow is negatively impacted by membrane alterations intended to improve anti-fouling capabilities. Furthermore, many of them are either prohibitively expensive, overly complex, or limited to use in the lab. In

addition, most strategies can postpone the onset of fouling, but they cannot prevent it entirely. Thus, novel membrane materials that can balance anti-fouling capacity and permeability, as well as sophisticated yet straightforward approaches to membrane modification, are still needed.

- 2. Membrane Scaling:** New membrane materials with enhanced scaling resistance are being developed to avoid scaling. Although such membranes will not totally replace membrane-independent approaches are suitable for use with current desalination equipment, able to withstand greater amounts of scaling chemicals in the feed water and minimize brine volume without additional operational burden[82]. Mineral scaling comes in many forms and is influenced by the composition of the feed water, it relies on a variety of intricate chemical interactions and systems. Consequently, the development of scaling-resistant membranes is more difficult than that of membranes resistant to organic and biological fouling because of the intricacy involved. Recent research on fouling-resistant membranes has made extensive use of substances like alginate, humic acids, and bovine serum albumin (BSA). Excellent resistance to fouling by all these prototypical foulants has been demonstrated by membranes with a hydrophilic coating[83–85].

More investigations are necessary to link membrane surface properties with potentials under different scaling conditions and feed water saturation status. The reason for the design will come from the resulting chemistry-property scaling relationships as well as the production of innovative membrane materials that have an enhanced resistance to scaling. Extensive research have been undertaken to gain an understanding of the interactions that take place between organic and biological foulants and membrane surfaces[86–88], and the information gained has been important in the development of membranes that are resistant to fouling. Modern membranes have been fabricated from novel membrane materials such as covalent organic frameworks, metal-organic frameworks, 1D nanomaterials and 2D nano-sheets. This lightning-fast proliferation of novel materials and the procedures of fabricating membranes will result in the development of novel membrane products [89].

IV. NOVEL MATERIALS

Graphene oxide, carbon nanotubes, aquaporin proteins, and nanoporous graphene are just a few of the new materials that have shown promise in recent decades to be used in the synthesis of high-performance membranes for desalination. These materials have the possibility of achieving water fluxes of several orders of magnitude greater than those of cutting-edge polyamide reverse-osmosis membranes made from thin films[90,91]. However, there are drawbacks to membrane technology, including increased energy needs and fouling. Current methods for studying this topic involve the creation of novel membrane materials, calculating hydrodynamics, designing modules, and developing more efficient modes of operation, or the implementation of systems for water purification or wastewater more effectively. The recycling of industrial wastewater is a growing trend, recycling of useful substances, development of cutting-edge processes like forward osmosis and per vaporation, tracking fouling in real time, development of advanced methods for analyzing fouling, and fabrication of specialized novel membranes and membrane innovations also have use in extremely harsh environments[92].

Polymeric membranes continue to hold the majority of the market share in the membrane separation business because they are inexpensive and have a high degree of process ability, and a high level of separation efficiency with minimal effort required for operation. However, there is a Robeson bound where an intrinsic trade-off effect exists for the majority of polymeric membranes, i.e., low selectivity in highly permeable membranes and vice versa[93]. Polymeric membranes can be utilized in a variety of process applications; they can be utilized from the MF all the way to the RO. Both hydrophilic and hydrophobic polymers can be incorporated into commercial UF/MF membranes. Both polymers have some pros and cons because hydrophobic polymers are more durable than hydrophilic ones, yet hydrophilic membranes reduce bacterial attachment due to adsorption. The properties of some of the most frequently used polymeric materials are listed in **Table 3**[92].

Table 3: Properties of some of the most frequently used polymeric materials [94,95].

Polymer Material	Specifications
Cellulose acetate	In the production of MF and UF membranes, cellulose acetate and its mixes are quite commonly employed. Cellulose can be broken down by water and microbial attacks and has a consistent pH level between 4 and 6.5.
Polysulfone	Polysulfone is an amorphous polymer. It is chemically and thermally stable. Its primary applications are in UF and MF membranes as well as a backing for the NF and RO membranes. Different sized pores can be found in polysulfone membranes and modules can have capillary structures, flat sheet and hollow fiber.
Polyethersulfone	Extreme chemical and thermal stability. Their primary applications are UF and MF, flat sheet and hollow fiber module configuration exists.
Polyacrylonitrile	Polyacrylonitrile exhibits strong resistance to hydrolysis and oxidation. This product's primary function is in UF membrane preparation and porous supports of composite membranes.
Polyamide	Polyamide is a material that is both thermally and mechanically stable. It is not susceptible to attacks from organic solvents. On the other hand, it is vulnerable to chlorine contamination. It is applied as a very thin coating in the RO and NF processes.
Polycarbonate	Polycarbonate is a thermoplastic material that is clear and has high-performance characteristics. It possesses a good amount of mechanical strength and can be utilised in the phase inversion processes in order to create UF and MF membranes.
Polyvinylidene fluoride	Polyvinylidene fluoride is semicrystalline with a low glass transition temperature. It can withstand both chemical and thermal assaults without being damaged as well as to most inorganic and organic solvents. It is resistant to changes in pH over a broad range.

Recently, a new family of promising materials known as two-dimensional (2D) materials has been discovered to produce high-performance 2D membranes for use in a variety of applications requiring separation. The performance of membrane separation can be increased by decreasing the thickness of the membrane, where two-dimensional (2D) materials will allow for the ultimate thickness refinement to be a single atom. Taking into account the possibilities offered by materials based on graphene and their unique physicochemical properties. These 2D nanomaterials are poised to become widely used in the quest to enhance polymer membranes' capacity for selective separations, together with improved physicochemical properties (including transport of molecules, hydrophilicity/hydrophobicity, mechanical and thermal features, and so on)[91].

Nano-channel regulation with pinpoint accuracy and sub-nano-channel found in the interlayer between nano-sheets or their pore size within 2D membranes allows for good molecular sieving performance to be attained. Numerous high-permeability 2D membranes have been developed to date and high selectivity have been reported, exhibiting high separation performance [93].

A fresh window of opportunity has opened up for membrane research and development with the emergence of novel 2D materials like graphene. Some more 2D membranes have been created up to this point, in addition to the earliest investigated graphene using building blocks of other materials such as graphene oxides (GOs), zeolites, covalent organic frameworks (COFs), layered double hydroxides (LDHs), metal-organic frameworks (MOFs), graphitic carbon nitrides ($g\text{-C}_3\text{N}_4$) transition metal dichalcogenides (TMDs), and MXenes. Because of the highly accurate control over the interlayer nano-channel and sub-nano-channel structures and decrease in mass transfer resistance, 2D nano-sheet-based ultra-thin membranes are a potential new option for separation as the newer generation membrane. They could overcome the limit set by conventional membranes in terms of permeability and selectivity because of their ability to do both[96–98]. In addition, RO and FO membranes with graphene materials (like GO) have been developed in order to achieve surfaces with reduced roughness. The use of membranes that incorporate Graphene quantum dots (GQDs) seems promising for dialysis and it has increased its ability to absorb water, exchange ions, and form compact structures, which slows down metal ion transport[91].

Graphene membranes made from polymer materials are a real thing and have been used in pressure-driven membrane processes (MF, UF, NF), reverse osmosis, forward osmosis, dialysis, membrane gas separation, membrane bioreactors, pervaporation, membrane distillation and electro-dialysis. The incorporation of graphene materials into membranes made of polymer not only brought about improvements in the physicochemical and other mechanical properties of the resulting composite membranes but also the separation effectiveness. By looking at recent publications, the following inferences are possible: In pressure-driven membrane processes, the majority of graphene and GO applications have been found within water desalination methods and water purification (achieving rejection rates of 100% for high levels of salt, heavy metal, and dye). For the most part, GO makes the membrane more hydrophilic, in which the antifouling qualities are enhanced[99,100]. This very hydrophilic substance also has a tendency to improve mechanical strength, water flux, and higher porosity[100].

More specifically, GO, which can be defined as sheets of graphene abundant in functional groups containing oxygen, may also be used to make nanocomposite membranes that have useful properties due to its strong hydrophilicity, excellent antifouling properties and high chemical stability. Polyethersulfone (PES) membranes with GO nano-sheets embedded in them were developed by Jin et al., in order to enhance the product's mechanical and thermal stability in addition to the original membrane's improved resistance to wetting [101,102].

Recently, Fryczkowska et al., recommended, the hydrophilicity of a polymer matrix and the pore formation process, e.g., poly vinylidene fluoride might change if GO nanomaterial were incorporated. In a nutshell, GO made the surface less hydrophobic and permissible to acquire a more refined finish with a larger surface area for filtering[103]. GO's high dispersibility in water is remarkable, together with its abundant oxygen-containing functional groups, contributed to antifouling characteristics, durability and heat resistance over time[104].

V. MEMBRANE TECHNOLOGIES FOR WATER TREATMENT AND REUSE IN INDUSTRIES

1. Water Treatment and Reuse in the Food Industry: Large quantities of water are needed for the food and drink processing industries; In fact, this industry consumes 33% more water than any other in the industrial sector [105]. In general, 75% of water used is considered beneficial as a result of its consumable nature in the food and drink manufacturing sector [106]. More than two-thirds of all freshwater that is extracted is used for agricultural purposes, and in some nations, this number can reach as high as 90 percent: It is predicted that throughout the world, freshwater supplies are dwindling by 2050 and 35 % of the global population will be residing in countries with severe water scarcity by 2025. As a result, the food industry has a responsibility to address the emerging trends associated with this resource, in common with other industries, and work toward increasing the efficiency with which water is used.

The recycling of water in the food business is an incredibly fascinating topic because of the continuously rising price of water and water discharge and its treatment. Given the detrimental consequences of wastewater from the food industry on societal and economic growth, public health system, and environment creating pollutant emissions in addition, effluent that is free of solid particles is an essential requirement before release. If the water quality meets precise guidelines set by authorities, wastewater that has been treated for reuse giving a different approach of ease the burden on scarce freshwater supplies [107]. The focus of this subsection is on the use of wide range of membrane-derived technologies that have experienced a significant expansion in the treatment of food wastewater.

Wastewater potential for re-use in different sectors depending on factors such as characteristics of the waste, concentration, volume, and raw water and effluent availability, treatment costs, operational and maintenance requirements, and the most effective treatment technologies available. The process of pressure-driven membrane filtration is currently being considered a viable option, the most versatile and efficient

wastewater reclamation technologies, offering a variety of advantages, including low-effort implementation and improved productivity [108,109].

- 2. Water Treatment and Reuse in the Pharmaceutical Industry:** The worldwide need for potable, sanitary, agricultural, and industrial water, has been on a continuous rise and in recent years, there has been an overwhelming amount of concern about water treatment and reuse requiring the highest possible level of compliance [110]. Surprisingly, the wastewater produced by pharmaceutical facilities possesses a wide range of substances and concentration and as a result, no attempt is made to use a novel approach since the volumes are low and the same collection of reactors and separators can be used to produce a wide variety of products. The reuse of water results in cost savings because it cuts down on the need for waste disposal and feed water requirements, compensating for the operational costs that are associated with the process of waste reuse. The waste streams produced by these enterprises can be extremely contaminated with potentially harmful substances, toxins, nutrients, and organics, presenting unique challenges in terms of how they are treated in light of the stringent regulations [111,112]. It is essential that, in order to facilitate reuse in both validated and non-validated systems high operating efficiency, water quality and product safety requires that the quality of the treated wastewater surpass that of the feed water. As a result, it's possible that production could be increased without going overboard on water discharge, drastically lessen the amount of raw water needed and expenses incurred in waste disposal in operation, and cut back on certain organics while maintaining the integrity of the other inorganic species. Therefore, it is imperative that methods of water reclamation and recycling be developed as soon as possible.

The typical molecular weight of pharmaceuticals is greater than 250 Da and can be reclaimed with the application of innovative membrane techniques assuming that the product is alone in the stream. Significant economic gains are possible by using ultra-filtration, nano-filtration and reverse osmosis, Nanofiltration is the most newly designed pressure driven separation process and in the recent decade, there has been a dramatic expansion in its use [113,114].

Nanofiltration can be beneficial in recovering more than 80% of the complex waste stream with a quality greater than feed water quality for product safety and high operational efficiency. This might be thought of as an intensification of the process which allows for an enhanced capacity for output, the limits of water outflow without compromising production capacity, significantly lowering raw water demands and the cost of waste disposal while reducing specific organics and leaving other remaining inorganic species [113,115].

Low-pressure membranes have the ability to remove microbial components without contributing to an increase in disinfection byproducts, and it serve a vital function as reverse osmosis (RO) pretreatment procedures, This is true regardless of whether the goal is to desalinate the water or to reuse it. In one of the tests, RO membranes were able to accomplish a rejection of diclofenac that was 95% effective. When there are constraints on available space and/or fluctuations in the quality of the feed water, microfiltration and ultrafiltration (MF/UF) systems come highly recommended [116]. The removal of natural organic matter (NOM) and micro-pollutants from drinking water and reclaimed

wastewater has been accomplished through the use of nanofiltration (NF) and ultrafiltration (UF) technologies respectively. Both RO and NF demonstrate superior removal of efficiency of particular organic medicines, despite the fact that the problem of retentate and concentrate disposal continues to be the same. As a consequence, additional processing of the concentrate that was produced is essential [117].

- 3. Water Treatment and reuse in the Steel Industry:** In both the present and the future, the steel industry will continue to be one of the most significant and vital industries. It is a nation's most valuable possession. Water is utilised extensively throughout the steel manufacturing process, including waste transfer, dust suppression and cooling. In order to remove pollutants from the final product and keep the finished stock at a cool temperature, all of these plants utilise a substantial amount of water. The production of steel results in the generation of a substantial amount of waste water. There are a great number of dissolved compounds and chemicals that are kept in the wastewater. Several of the manufacturing processes within the steel industry result in the production of wastewater and sludge. The creation of revolutionary new methods for the treatment of wastewaters produced by steel industry is a matter that gives us serious cause for concern [118].

The Membrane Bioreactor, or MBR for short, is the most recent advancement in technology for biologically degrading soluble organic contaminants. It is unavoidable that water reuse and recycling will emerge as the fundamental practises that are necessary for the preservation and conservation of water resources, they are becoming increasingly rare and polluted on a daily basis. The following three key uses are entailed in the reuse of water:

- Using water for purposes such as processing and cooling in industrial requirements.
- Irrigation for crops, golf courses, and the water demand that comes with the growing of plants and grass.
- Ground water recharge: The water that has been reused can either be pumped directly into aquifers or sprayed to soil so that it can percolate into the aquifer.

Due to membrane filtration (micro/ultrafiltration), In the case of MBR systems, the treated effluent quality is significantly higher compared to that of typical activated sludge systems, so the the treated effluent can be immediately reused, for example as make-up for cooling towers or for gardening, etc[119].

- 4. Water Treatment and Reuse in the Pulp and Paper Industry:** The need for water is growing in every region of the world; therefore, It will become increasingly important to recycle process waters and effluents after they have been cleaned up. Electro-dialysis is a method that is currently being researched in the pulp and paper industry for the purpose of removing chloride ions and other non-process components prior to the reuse of purified fluids [120]. The removal of highly pigmented waste from bleached kraft pulp mills is one of the membranes' uses in the pulp and paper industry that has received the greatest attention from researchers. The production of paper and pulp results in effluents that have high concentrations of both COD and BOD. Fortunately, Because of the large sizes of the molecules and the high charge densities that result from the high pH, the effluents

from alkaline bleach plants are easier to filter using UF technology than the effluents from the step of chlorination that came before it, which contained substances with a lower molar mass. Therefore, a significant number of researchers have investigated membrane filtering with the purpose of cleaning the effluents from the alkaline extraction stage so that they can be reused [121].

The permeate produced by ultrafiltration has been shown to be appropriate for reuse in showers, as a component of sealing waters, and as a solvent for diluting wet-end chemicals. Due to the exceptionally high purity of NF permeate, it is possible to utilize it in place of warm freshwater in the paper machine. Wastewaters that have been coated produce a great deal of colour in the discharge water systems because they are not easily treatable using traditional methods despite the fact that the amounts of these effluents are typically insignificant in comparison to those of the mill as a whole (about 2-5 percent of total flow). If these wastewaters are discharged into sewers without first receiving the necessary pretreatment, they may pose operational problems in the treatment of effluent because they include a high concentration of particles and chemicals that are, by their very nature, sticky. On the other side, pigments are pricey, thus the (partial) recovery of coating colour for reuse is extremely beneficial, is cost-effective in most cases. Separate treatment of wastewater from coating operations is an appealing and environmentally safe solution to lowering the amount of colour in effluents; at the same time, reusing the coating material is beneficial to the mill in a number of ways. A stream of permeate that is free of solids is obtained primarily by the use of UF, which recovers diluted coating ingredients. and a stream of retentate that is comprised of the coating materials, ideally, at a concentration that makes it possible to recycle the material or dump it. In ultrafiltration (UF), the pore size of the membrane is made to be sufficiently tiny to prevent pore clogging while maintaining a high level of permeability. The stream of solids-free permeate can be simply discharged or recycled, depending on the situation. The permeate stream has several potential repurposing applications; for instance, it might be used for the manufacture of coatings, as washing water, or even as shower water for the paper machine. When more resistant polymeric membranes and more affordable ceramic membranes are developed, it will be possible to use membranes in environments that are either very alkaline or very acidic, even when the temperature is very high. Consequently, membrane processes are an appealing choice for use in applications related to pulp and paper mills [122].

- 5. Water Treatment and Reuse in the Power Industry:** It is common practice in the energy sector to use membrane process systems to purify a variety of water sources such as wastewater and to make water safe for consumption. In their natural function, membranes are filters. Particles are often separated using microfiltration or UF membranes, however, both NF and RO alter the water's chemical or ionic composition because they filter out the water's smallest molecules and ions. Normal operating conditions for membrane systems make them low-maintenance and chemical-efficient and constant water quality, which improves the system's dependability. The huge amount of energy required by membrane technology is its primary downside. This is particularly true in areas where, for example, the salt content of seawater is very high such as in the Middle East. There, RO systems are increasingly being used for desalination and for the generation of hydroelectric power. Polymers, often cellulose acetate or composite polyamide-type membranes, are used to create RO membranes [123].

According to Kabsh-Korbutowicz, membrane fouling is a common problem that prevents the efficient usage of filtering devices, this causes pressure drops, which in turn affects how much energy is used. There is thus a rise in the regularity of cleaning, which impacts membrane manufacturing speed. It is crucial, then, to keep the membranes from becoming fouled. This can be done by implementing the suitable pretreatment, utilising membrane materials that are less likely to become clogged with debris, and ensuring that the system is being operated and controlled effectively. The amount of energy that membrane systems use to operate has been steadily cut down over the years by the implementation of systems for the recovery of energy that bring the concentrate stream back up to its original pressure, using this energy to enhance the pressure of the feed flow [124].

Increasing the flow rate is another option for lowering the probability of fouling and cutting down on energy use. Hydrophilic membranes are frequently used to increase the flow rate. It is simple for water to move through these membranes; however, hydrophobic pollutants will be rejected, leading to less fouling. Hydrophilicity is greatest in cellulose acetate membranes but have a lower salt rejection compared with polyamide membranes. One more factor that contributes to the formation of fouling and the fluxes of the system is the surface charge of the membranes. The polyamide membranes have the ability to attract charged organic and colloidal particles from the feed water, in contrast to the cellulose acetate membranes, which have a neutral charge.

- 6. Water Treatment and Reuse in the Oil Industry:** As a result of rising water needs around the world, the oil industry has expanded to include drilling sites in every continent. The environmental risks of various oil extraction techniques include threats to ecological health, human, contamination of water, and soil [125,126]. Industrial effluent from oil drilling operations is the main source of pollution in the petroleum business and commonly known as produced water (PW). Typically, PW has high levels of petroleum compounds (such as volatile hydrocarbons, polycyclic aromatic hydrocarbons, and phenols,), production chemicals (such as corrosion inhibitors and biocides), dissolved gases (such as H₂S and CO₂), salts (such as sodium chloride and sodium bicarbonate), heavy metals and other minerals that have been dissolved (such as lead, barium, iron, zinc, etc.), and solids such as sand, carbonates, silt, and clays [127]. Due to oil spills and leaks, natural water supplies can be contaminated if PW is not properly managed and controlled [128]. More than 70 billion barrels of PW are produced each year, according to estimates, and the associated contaminants pose serious risks to marine life and human health [129].

PW has been known to contain high concentrations of both organic and inorganic substances; Shale gas wells are generally connected with the presence of these chemicals [129]. The concentration of these chemicals fluctuates according to a number of factors like the age of the reservoir, the local geology and the type of produced hydrocarbon. It has been reported that PW has dissolved organic carbon concentrations in excess of 5.5 g/L and include carboxylic acids, alkanes, aromatic compounds with potential carcinogenic, aliphatic, and severe health risks among others. According to rat studies, organic contaminants linked to PW can cause respiratory complications [129], mouse model of uterine infection, and adverse renal effects in animals and hemolytic anemia [130], and dysfunction of reproductive system in mice and respiratory complications.

Additionally, bacteria in PW create volatile fatty acids (53.7 mg/L), which contribute to foul odors and cause skin corrosion and may also irritate the eyes and nose[131]. There is also cause for concern regarding the inorganic components of PW [132] and the possible interactions between them. For example, if the combination of bromide in PW with disinfectant chlorine, it can produce brominated disinfection by-products that can cause liver damage, kidney and brain [133]. As another example, the mobilisation of radionuclides can be caused by the interaction of the salt in the shale water with the surrounding rocks[133]. This causes some PW to have an abnormally high level of radium-226[134].

Although methods of water treatment could cut radioactive contamination by 90%[133], Cancer, anemia, and tooth fractures are just some of the long-term health effects of drinking water contaminated with radium-226[134]. More research is needed to determine the most efficient means of eliminating radioactive contaminants in PW. Membrane treatment is effective in removing most pollutants from PW; for example, PW treatment has been shown to be effective at removing total suspended solids (TSS), oil and grease (O&G), and sulfate[135]. For instance, >99.9% removal of these three pollutants has been revealed for NF followed by RO using industrially obtained polyamide thin film composite (PA-TFC) NF and low-pressure RO membranes, including NF270 (an NF membrane for salt rejection application) or BW30 (an RO membrane for brackish water treatment application) [135]. The exceptional thermal stability, mechanical stability, and compatibility with severe cleaning procedures of ceramic membranes have piqued widespread interest in this class of materials (i.e., intensifying the cleaning regimes)[136].

PW that has been treated and reused could be a valuable source of water, particularly in water-required areas with enhancing oil production. Many other applications for processed PW have been proposed and include habitat watering, irrigation, dust control, livestock consumption, power generation, oil field operations, and as an extreme example, drinking water [137].Based on the intended use of treated water, different standards have been issued. The United States Department of Agriculture (USDA) has provided such guidelines for irrigation and livestock consumption. In the United States, the Environmental Protection Agency (EPA) typically provides guidelines for water reuse for human use (EPA)[135]. Reaching specified norms after the treatment, PW reuse for semi-arid areas and crop irrigation in arid has been recommended [138], particularly salt-resistant crop varieties[139].

VI. CONCLUSIONS

The study indicates that reusing water is preferable since it helps the planet and the economy while using fewer resources. More potential applications for membrane technology exist in the treatment of industrial effluents. The use of membranes in chemical processes could be made possible by developing membrane materials with high thermal and chemical stability. Novel materials with good resistance to harsh cleaning treatments (alkali treatments, acid and chlorine) would enhance the membrane life time and also in maintenance of wastewater treatment facilities, for which fouling is a severe issue. This would make the application of membranes easier for a separation task of expanding importance, the treatment of released water in industries.

Due to the intricate nature of mineral scaling, the development of membranes that are resistant to scaling is a difficult task. Various types of membrane scaling might require distinct membrane surface chemistry to convey best resistance to scaling. Furthermore, new evidence suggests that the co-existence of inorganic scalants and organic foulants modified membrane function compared to individual fouling and scaling. The 2D membrane family is the most promising class of membranes for separation have gained raising awareness in recent years. Most applications of graphene and GO have been in the field of water desalination and water purification (with high salt, heavy metal, and dye rejection rates 100%). Specifically, GO adjusts membrane characteristics into a more hydrophilic, which enhance the antifouling characteristics. Also, this highly hydrophilic material tends to increase water flux, higher porosity, and mechanical strength. Because of the development of superior materials in this area, Sustainable new technologies and separation procedures will be incorporated, a challenge for the material scientists of current and new generation.

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