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Nanomaterial Membrane Bioreactors in Current Scenario

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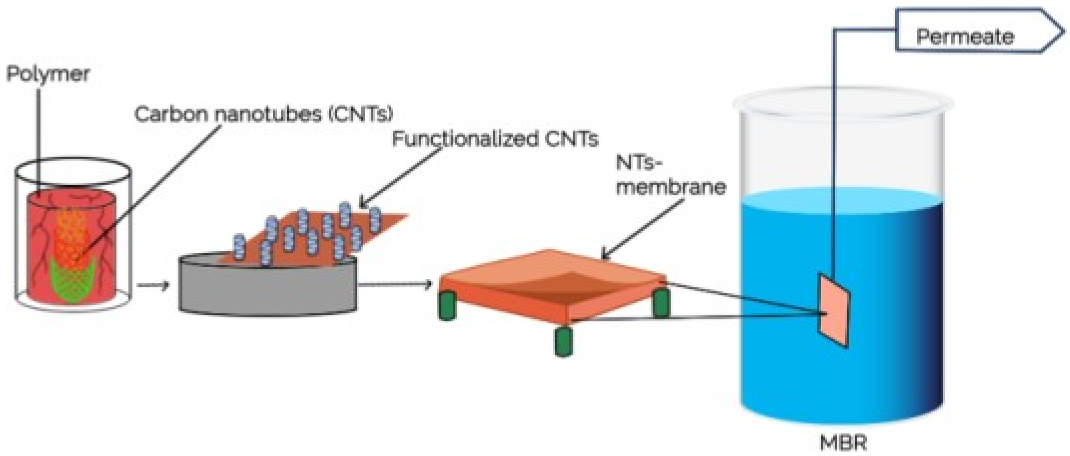
Abstract: The concept of nanomaterial membranes (NMs) promises to be a sustainable route to improve the membrane characteristics and enhance the performance of membrane bioreactors (MBRs) treating wastewater. This review provides a the utilization of membranes adjusting nanomaterial in membrane bioreactor (NMs-MBR) for wastewater treatment. Novel types of nanomaterial membranes were seen and described based on their structures. For each type, their design and fabrication, modern and power have been presented. The performance of NMs-MBR system in terms of efficient treatment of common pollutants and membrane fouling. The review also shows the sustainability and cost viability aspects of NMs-MBR technology that can increase their widespread use in wastewater treatment applications in the current scenario.

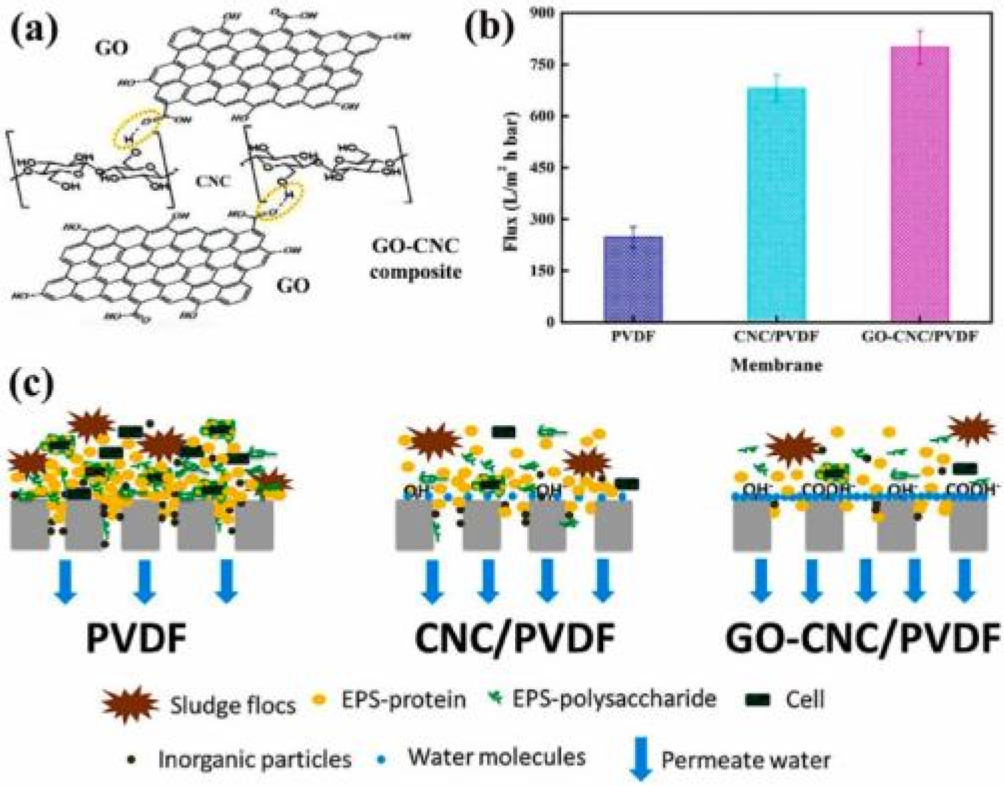
Keywords: Nanomaterial, bioreactors, wastewater, efficient, current, sustainability, treatment, scenario, structures

Introduction

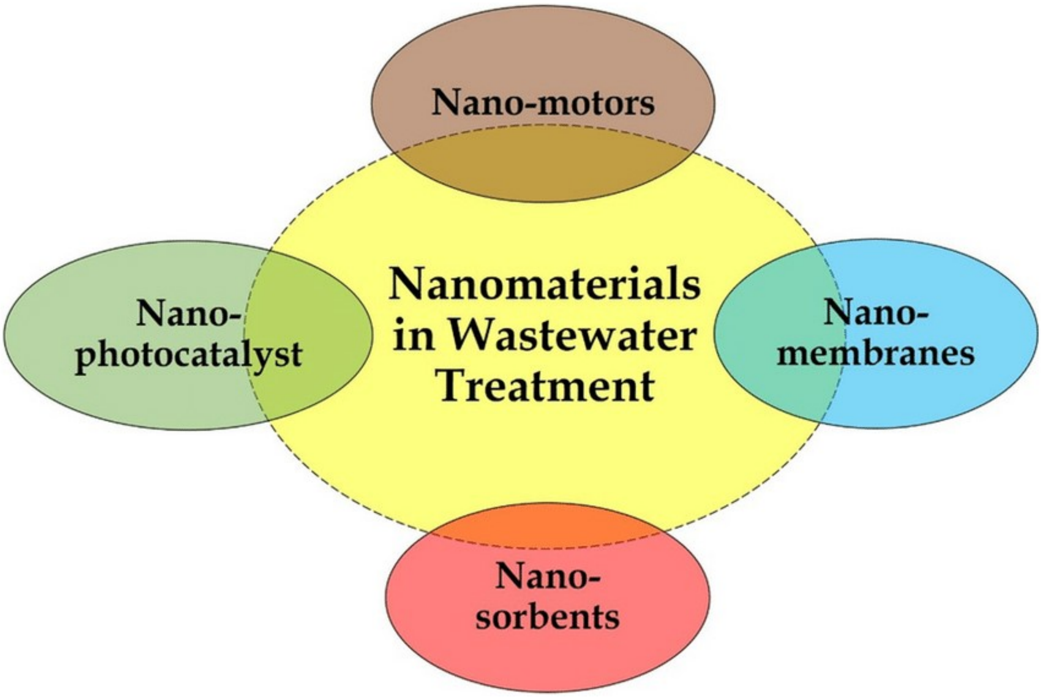
Both aerobic and anaerobic membrane bioreactors (MBRs) are able to remove contaminants of emerging concern from wastewater at increasing efficiencies. However, the main aspect of this technology is membrane biofouling.



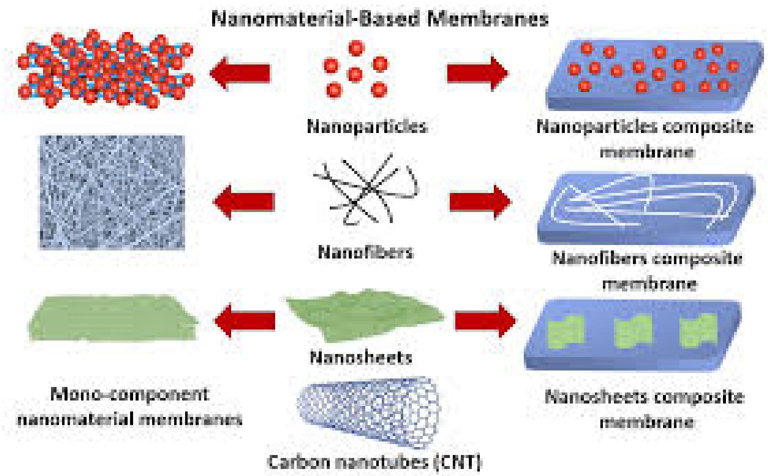
Coating heavy metal nanoparticles on the surface of bioreactor membrane has been proposed as an effective antifouling strategy. Nevertheless, metal nanoparticles can potentially result in high prospect on the overall functionality of the MBRs. This review aims to understand how nanoparticles impact MBRs. To achieve this aim, it starts off by illustrating the antibacterial mechanisms of nanoparticles. The detail then critically revises past studies that illustrate the antibacterial effect of nanoparticles against pure bacterial cultures and biofilm-associated colonies. Finally, it evaluates if the presence of nanoparticles would affect the overall performance of aerobic and anaerobic biological processes. Specifically, the impact of heavy metal nanoparticles on nitrogen and phosphorus removal process has been discussed. The effect on anaerobic fermentation, which is comprised of hydrolysis, acidogenesis, acetogenesis, and methanogenesis, has also been explained. [1,2]



A novel membrane bioreactor system utilizes Multi-Walled Carbon Nanotubes (MWCNTs) coated polyurethane sponge (PUs), an electrical field, and a nanocomposite membrane designed to diminish membrane with fouling caused by activated sludge. The classical phase inversion was harnessed to prepare Zinc Oxide/Polyphenylsulfone (ZnO/PPSU) nanocomposite membranes using 1.5 g of ZnO nanoparticles (NPs). The prepared nanocomposite membrane surface was fully characterized by a series of experimental tools, e.g., Scanning electron microscope (SEM), Atomic force microscopy (AFM), contact angle (CA), pore size, and pore size distribution. The testing procedure was performed through an Activated Sludge-Membrane Bioreactor (ASMBR) as a reference and results were compared with those obtained with nanotubes coated sponge–MBR (NSMBR) and nanotubes coated sponge-MBR in the presence of an electrical field (ENSMBR) system. Observed fouling reduction of the membrane has improved significantly and, thus, the overall long-term was increased by 190% compared with the control ASMBR configuration. The experimental results showcased that sponge-carbon nanotubes (CNTs) were capable of adsorbing activated sludge and other contaminants to minimize the membrane fouling. At a dosage of 0.3 mg/mL CNT and 2 mg/mL of SDBS, the sponge-CNT was capable of eliminating nitrogen and phosphorus by 81% and >90%, respectively. [3,4]



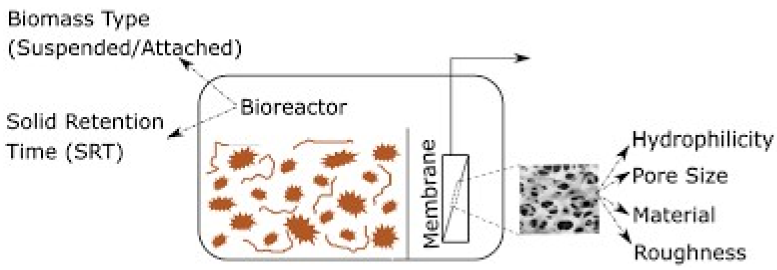
In another study, Ag nanoparticles (Ag NPs) as antibacterial substance and Fe_3O_4 nanoparticles (Fe_3O_4 NPs) as magnetic material were synthesized and then utilized in the MBR system (Ag NPs-MBR/Fe_3O_4 NPs-MBR), and for synthetic petrochemical wastewater treatment, their effect on biomass characteristics and consequently effect on membrane fouling were evaluated. Chemical oxygen demand (COD), extracellular polymeric substance (EPS), soluble microbial product (SMP), flux, membrane fouling resistance, as well as particle size distribution, Fourier transform infra-red (FTIR) spectroscopy, and scanning electron microscope (SEM) analysis were performed for performance evaluation. The average particle size of Fe_3O_4 NPs and Ag NPs was 2 and 10 nm, respectively. It was observed that overall, the application of nanoparticles results in better removal of organic matter in the system. Control-MBR, Ag NPs-MBR, and Fe_3O_4 NPs-MBR reduce COD by 80, 96.64, and 95.35%, respectively. Besides, improvement in flux rate by 41% and 32% for Ag NPs-MBR and Fe_3O_4 NPs-MBR was observed, respectively. EPS in Ag NPs-MBR and Fe_3O_4 NPs-MBR decreased by 49% and 38%, while SMP decreased by 66% and 54%, respectively. The FTIR analysis also confirmed the reduction in EPS and SMP. SEM images revealed that the cake layer on the membrane in the Ag NPs-MBR system has more porosity. Based on the results, the application of NPs in MBR systems lead to significantly improved performance and reduced membrane fouling.[5,6]



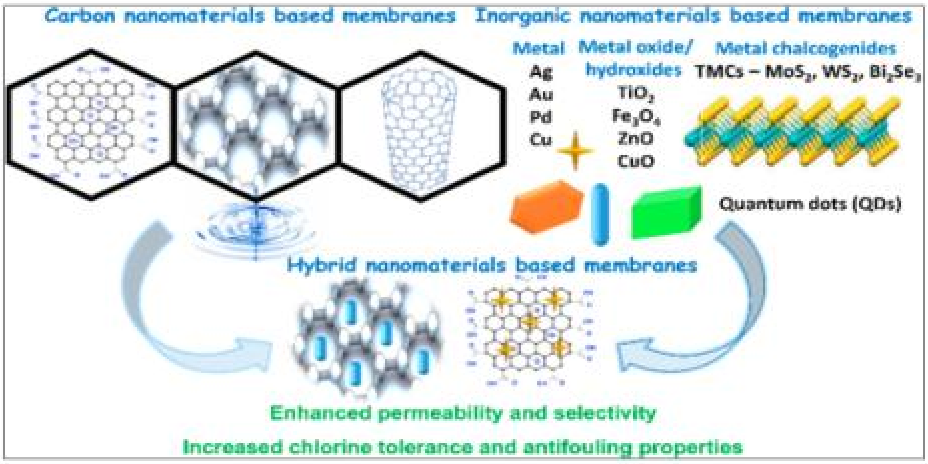
Membrane separation processes have been widely applied in the treatment of wastewater. Polysulphone (PSF) membranes are the most common membranes used in ultrafiltration of wastewater due to its mechanical robustness and structural and chemical stability. Unfortunately these membranes are mostly hydrophobic by nature and therefore highly susceptible to fouling. Many studies have been conducted to increase the hydrophilic properties of the polysulphone/ polyethersulfone membrane surface, more recently metal nanoparticles have been added to the polymer matrix in order to reduce fouling potential and increase membrane performance. TiO_2 nanoparticles have proven successful in mitigating fouling of organic matter onto PES. Embedded Ag nanoparticles have improved virus removal from wastewater due to the bactericidal properties of silver. Al_2O_3 and most recently ZrO_2 nanoparticles reduced the fouling rate of polyethersulfone membranes in wastewater, while the latter also showed lower flux decline of the composite membrane. These metal nanoparticles all impart specific properties onto the membrane surface. Scanning electron microscopy, steady state fouling rate and contact angle measurements are membrane characterisation techniques discussed in this review that reveal specific changes to membrane properties brought about by metal nanoparticles. This paper reviews the most recent developments and shortcomings of metal nanocomposite polysulfone and polyethersulfone (PES) membranes and strives to identify specific focus areas to consider in future research.

Discussion

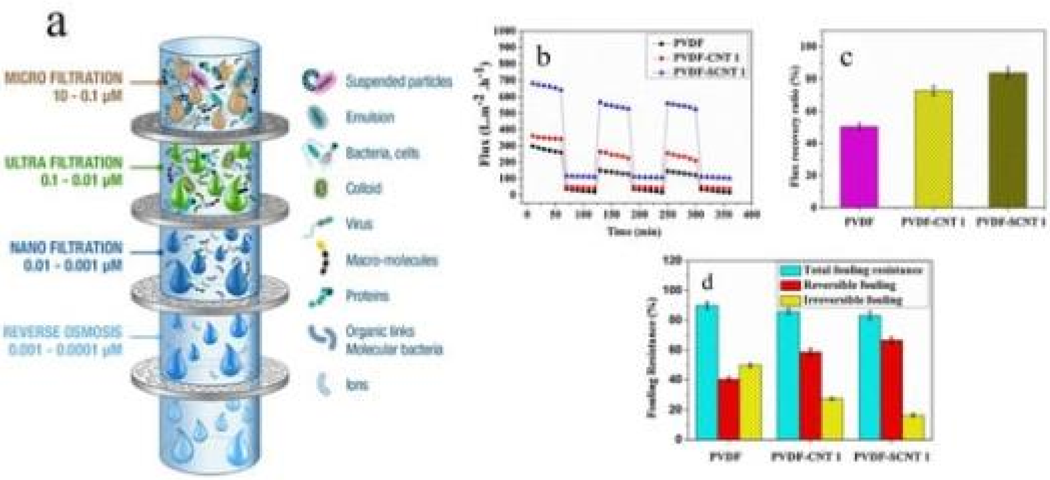
Polymeric ultrafiltration (UF) membranes often used in membrane bioreactor (MBR) prone to be fouled by fouling agents. Therefore, in this paper, the antifouling characteristics of polyvinylidene fluoride (PVDF) UF membranes for wastewater treatment are improved through modifying membranes by O-carboxymethyl chitosan (OCMCS)-functionalized Fe_3O_4 nanoparticles (OCMCSFe_3O_4). The modifier agent was manufactured by the adsorption of OCMCS on Fe_3O_4 nanoparticles, which were synthesized via co-precipitating method. Antifouling performance of membranes was assessed by permeation tests done using activated sludge suspension as a biological foulant, then the calculation of the pure water flux recovery ratio (FRR) and fouling resistance parameters. Also, to investigate the protein rejection of membranes, permeation tests were conducted by the bovine serum albumin (BSA) solution. According to the obtained results, surface hydrophilicity of the embedded membranes was improved in the low concentrations of the modified nanoparticles. However, the high quantity of the OCMCS-Fe_3O_4 nanoparticles (>0.1 wt. %) in the casting solution lessened membrane performance owing to the agglomeration of the nanoparticles in the polymer matrix. Although, the 1 wt. % OCMCS-Fe_3O_4 membrane revealed considerably higher PWF and permeation than that of the other membranes. It was because of defects and cracks in the membranes. The 0.05 wt. % OCMCS-Fe_3O_4/PVDF membrane exhibited the highest FRR (95.7%) and protein rejection value (48%) and the lowest irreversible fouling resistance (Rir) value (4.2%). It is concluded that the blended membranes with modified nanoparticles resulted in a high-flux ultrafiltration membrane comparable with microfiltration membrane, while its separation properties remained similar to UF membrane.[7,8]



Nanotechnology offers novel nanomaterials having a good potential for the surface, ground and wastewater treatment contaminants using different technologies. Performance of membrane technology is based upon the type and size of material, and novel nano-structured materials range from 4 nm to 100 nm. Among the numerous 3D nanoparticles having high potential applications, nanostructured coated ceramic membranes, nanocomposite, TFC, carbon nano tubes (CNT), zeolite, silicate and mixed matrix membranes are considered as the most promising ones for water treatment technologies. This discussion provides the comparison among conventional methods and nanomaterials. Here, we discuss the basic principal, mechanism of membrane technology, characterization, advantages, limitation in comparison to other exciting membrane materials and the need for research and development for commercialization.[29,30]

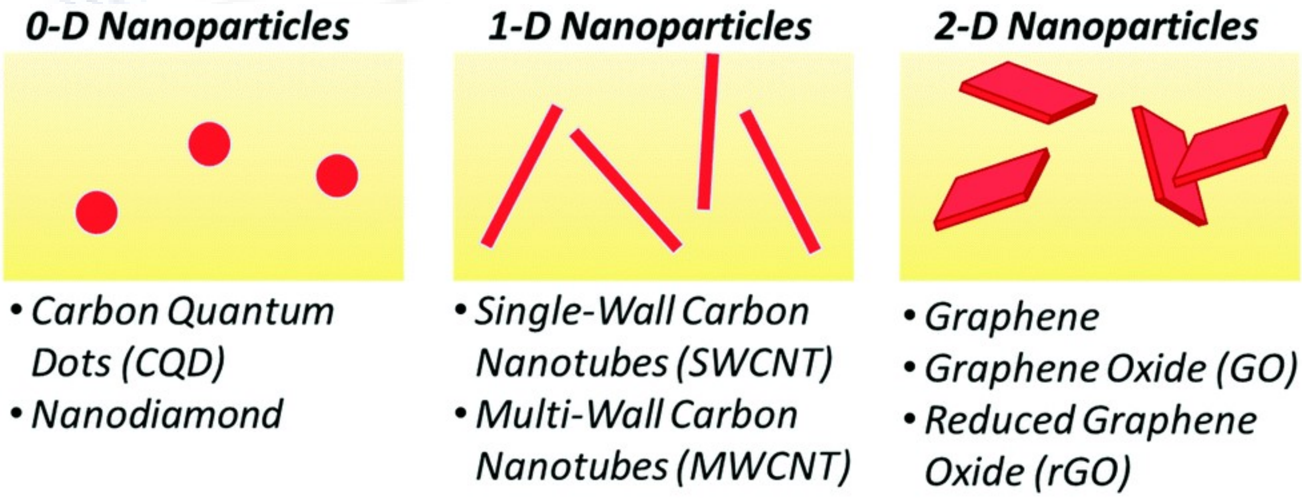


As the world focuses on reducing greenhouse gas emissions and recovering energy from sewage, technologies that can recover energy and reuse wastewater are becoming increasingly important. Anaerobic membrane bioreactor (AnMBR) technology has recently attracted attention, as it can achieve energy recovery and yields high-quality effluent. However, the large-scale commercial application of AnMBRs requires that certain barriers be overcome, including membrane pollution and dissolved methane recovery. In this review article, we summarize the basic principles of anaerobic wastewater digestion and discuss the excellent performance of AnMBRs for wastewater treatment. Various factors, membrane types, and pollution are discussed, and control strategies for dealing with membrane pollution are put forward. In addition, a variety of new AnMBRs are described that may better control membrane pollution.[9,10] Finally, future research directions for AnMBRs are presented to promote the large-scale integrated application of AnMBRs for industrial wastewater treatment.



While water shortage across the world is threatening the well-being of the human community, emerging advanced technologies targeted to address this challenge are promising. In this regard, nanomaterials have played a crucial role. Nanomaterials, i.e., those materials which have at least one dimension in the 1–100 nm size range, have produced a new generation of technologies for water purification. This includes nanosized adsorbents, nanomembranes, photocatalysts, etc. Stemming from extraordinary structural characteristics and size scale of nanomaterials, the nanostructured membranes/adsorbents enable water purification with a high efficiency in terms of pollutants removal and water permeability, thereby reducing energy consumption and cost. [27,28]

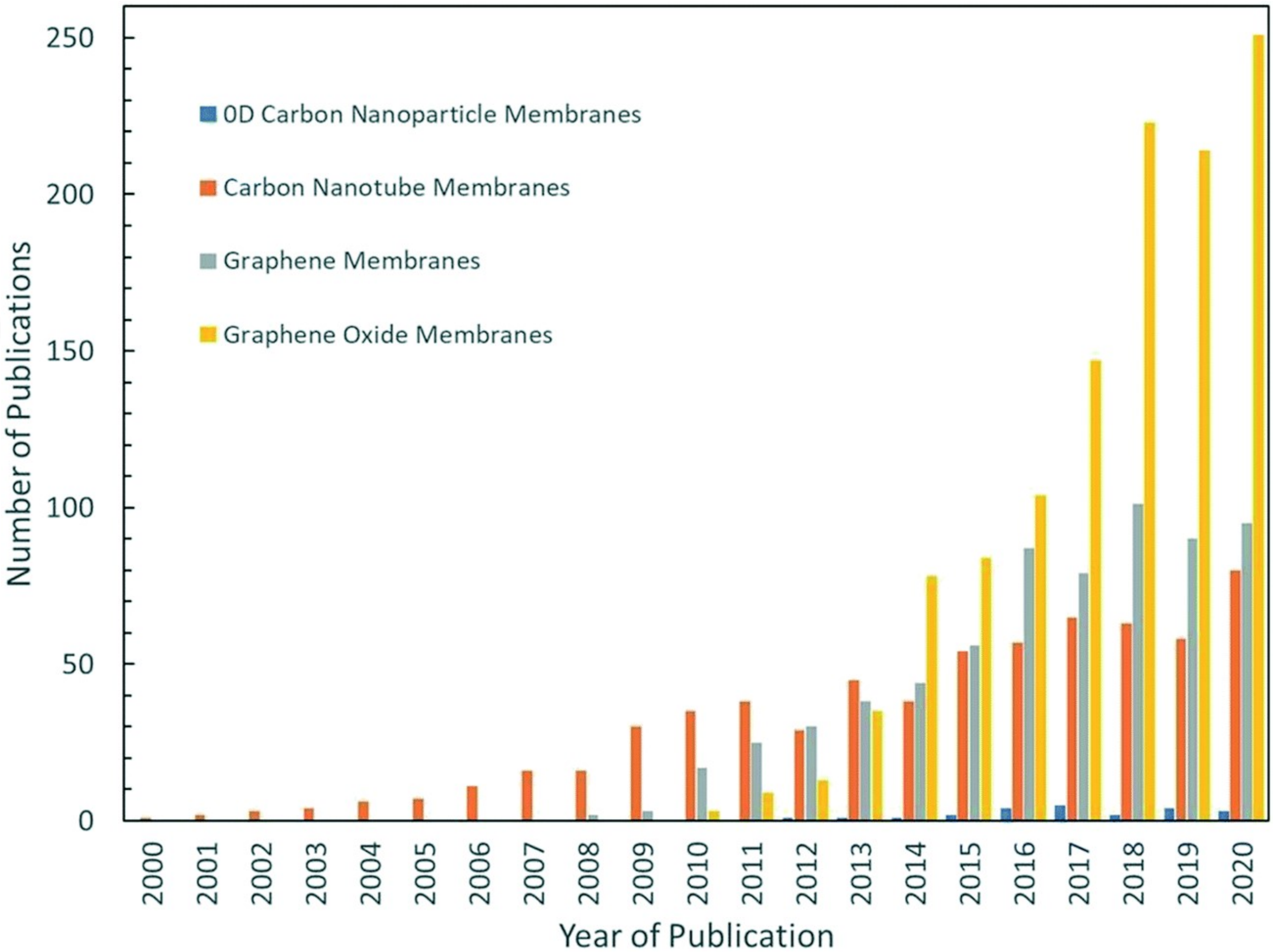
A membrane is a selective barrier located between two homogenous phases that splits a feed water stream into a retentate and a permeate fraction. The pressure difference between the feed and permeate sides acts as the driving force for the membrane's action and passes water through the membrane. Nanocomposite membranes comprising a thin polymeric film surface decorated or incorporated with nanofillers are a distinguished class of membranes able to dynamically purify water. Nanomaterials in different forms and dimensionalities can be used in construction of nanocomposite membranes. Nanoparticles, for instance, have been widely used as nanofillers for mechanical reinforcement or for hydrophilization of polymeric membranes. Clay nanoparticles have been into mixed matrix polysulfone ultrafiltration membranes to improve thermomechanical properties and water permeability of the membrane, while maintaining optimum rejection efficiency. Moreover, the membranes reinforced with clay nanoparticles showed a lower fouling tendency and higher flux recovery when tested with sodium alginate and natural water. One critical concern regarding ultrafiltration (UF) membranes is their biofouling and the presence of bacterial colonies on the surface and thereby clogging the pores and lowering the permeability of the membrane.[11,12] In this regard, extracellular polymeric substances (EPS) are released upon bacterial cell lysis and are adsorbed on the UF membrane and thus reduce the longevity and permeability of the membrane. Despite the significance of industrial production of such nanocomposite membranes for water treatment, their toxicity that could originate from the release of the incorporated nanomaterials during the high pressure difference-driven filtration process should be carefully evaluated to minimize their adverse effects on human health and the environment .[25,26]



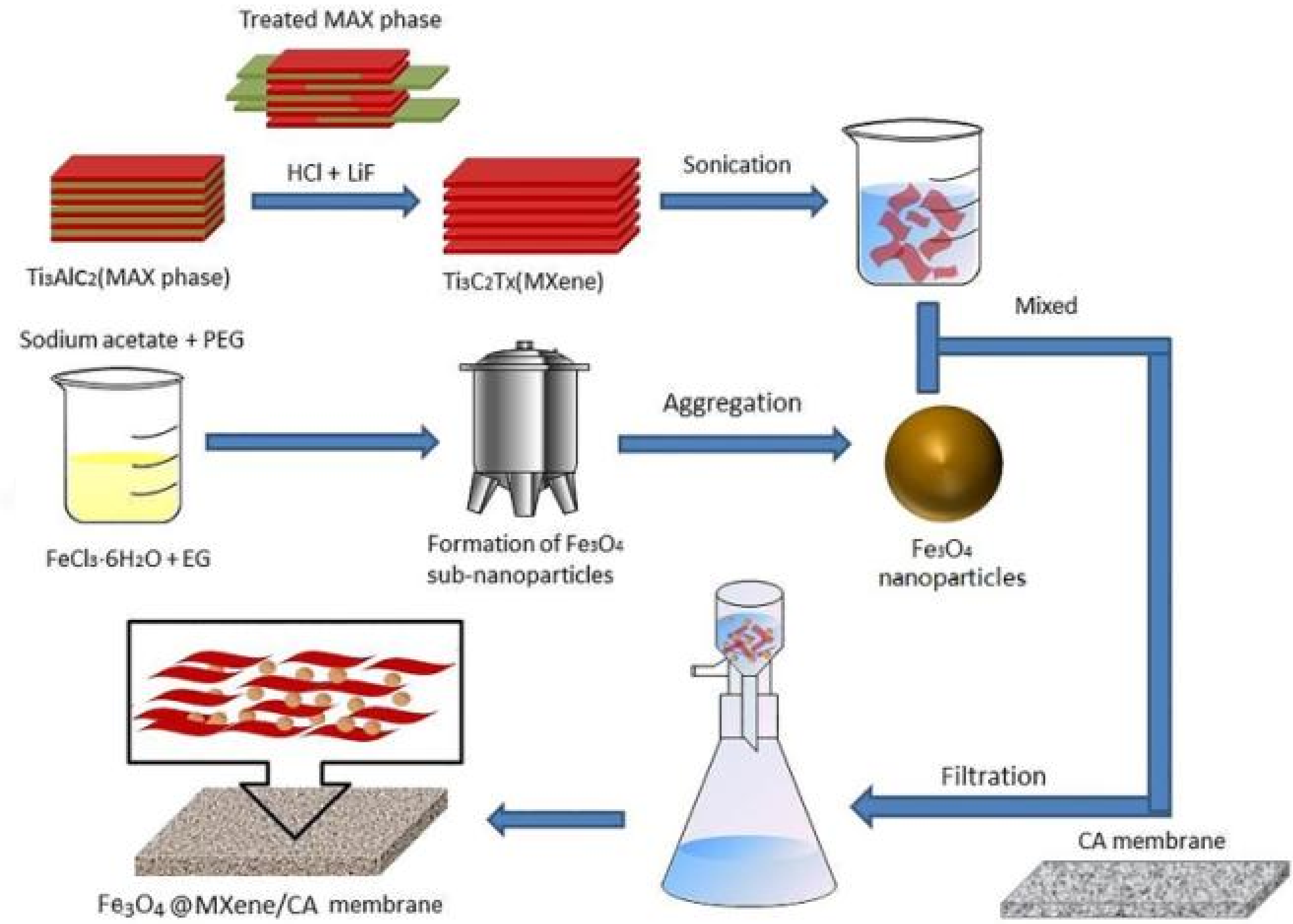
Results

The issue of drinking water is one of the most important nowadays for most countries, especially for densely populated and developing countries. The main reasons for such situation are population growth; drought; extraction of minerals, in particular oil; the widespread use of chemicals in the farm, etc.,[24] which are today that critical "pressure" on nature that prevents it from fully performing water purification from contamination. Therefore, minimizing the negative impact on nature and improving the technology of water purification are the main directions of solving such a global issue.Well-known physical, chemical and physicochemical methods do not always provide new levels of purification, which are required by norms, without the use of additional expensive chemicals for coagulation, deposition, etc.It increases operational costs and produces more volumes of hazardous waste.[13,14] In addition, international standards require more efficient separation systems than those that are used in full. Nanotechnologies can significantly affect the area of sewage treatment in the near future. Nanotechnologies are aimed at improving existing methods by increasing the efficiency of processes and increasing the reuse of nanomaterials.Nanomaterials are endowed with unique properties such as a large surface-to-volume ratio, high reactivity and sensitivity, self-sampling properties on film substrates, high adsorption, and others.Due to these properties, nanomaterials are effective against various organic and inorganic pollutants, heavy metals, as well as against various harmful microorganisms present in contaminated water.[15]

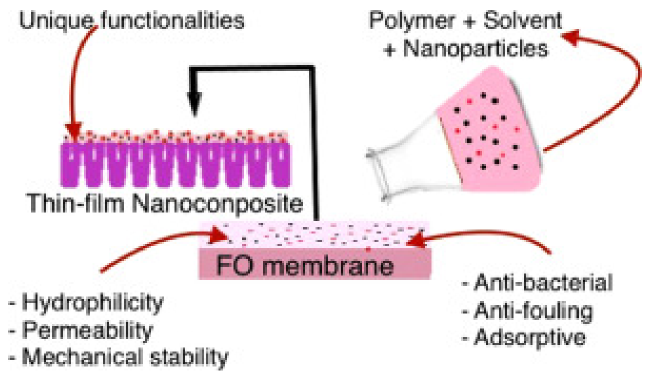
The application of membrane bioreactor (MBR) processes for conventional, municipal and industrial wastewater treatment [e.g., biological oxygen demand (BOD) reduction] is well established.



The research and development of MBR processes for nitrogen removal is more recent. To date, no thorough review of MBR technology for nitrogen removal from wastewater has been carried out. The review presented here provides an overview of MBR process configurations for the removal of nitrogen based on conventional nitrogen-removal pathways (i.e., nitrification/denitrification) as well as alternative nitrogen-removal pathways, such as anaerobic ammonium oxidation (ANAMMOX). A wide range of system configurations have been explored for the application of MBR for nitrogen removal, including immersed or side-stream membrane configurations, single or multichamber processes, and the application of fixed and moving bed biofilms.[23] Operating variables play an important role in controlling nitrogen removal and fouling, especially feed composition (particularly the carbon:nitrogen ratio), membrane characteristics, solids retention time, and hydraulic retention time. Modeling approaches for predicting nitrogen removal using MBR are evolving and are better able to represent key process differences in MBRs compared to conventional activated sludge. Although several challenges remain (e.g., membrane fouling, cost, and energy consumption), a number of opportunities exist (such as new reactor configurations, new microbial pathways, and development of a better understanding of process function through metaomic approaches) that may lead to the broader application of MBR processes for nitrogen removal from municipal wastewater in the future [16,17]



Membrane-based technologies, such as micro (MF), ultra (UF) and nanofiltration (NF), have been widely applied for water treatment applications; however, the limitations of pure polymeric membranes have encouraged the incorporation of inorganic nanomaterials to enhance their performance. Today, nanocomposite membranes have greatly increased the attention of researchers for different water treatment applications, e.g., water purification, wastewater treatment, removal of microorganisms, chemical compounds and heavy metals. To date, different types of nanomaterials have been incorporated into polymeric membranes, such as carbon nanotubes (CNT), zinc oxide (ZnO), graphene oxide (GO), titanium dioxide (TiO_2), Ag and Cu-based nanoparticles, to mention just a few.[21,22]



Conclusions

To date, the incorporation of different classes of nanomaterials (e.g., ZnO, Ag or Cu-based materials, GO, TiO_2, Al_2O_3, Fe_3O_4, zeolite, clay, SiO_2, graphene oxide) into polymeric membranes tends to enhance the hydrophilicity depending on the type of polymer, contributing to suppress the fouling phenomenon in water treatment. Additionally, the filler materials can also provide the possibility to improve some other properties (e.g., mechanical, thermal, and chemical) as well.[18,19]

These current findings provide valid inputs concerning the potentialities of these smart membranes in water purification, according to the antibacterial properties of the fillers. Particularly, the exploitation of composite membranes can be synergistic towards efficient water treatment (e.g., wastewater processing), if there is a coupling to other technologies, e.g., photocatalytic process , electrocoagulation, electrofiltration, or membrane bioreactor. Finally, it is important to take into account that the compatibility between the nanomaterial and polymer is crucial in order to synthetize highly efficient nanocomposite membranes.[20,30]

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