Water Pollution and Treatment Technologies

Subjects: Environmental Sciences

Contributor: J. Maldonado-Jiménez , B. Gómez-Lázaro , G.G. Flores-Rojas , E. Mendizábal

Water pollution is a global problem that poses risks to both the environment and human health. Water pollutants can be diverse, including physical, chemical, and biological substances, both natural and synthetic. Water treatment and purification are two of the most researched environmental topics currently. The water treatment process involves a series of steps and approaches that can be physical and/or chemical, including filtration, centrifugation, sedimentation, precipitation, coagulation, gravitation, flocculation, microbial degradation, oxidation, electrolysis, crystallization, distillation, photocatalysis, chelation, and adsorption, among others. Membrane systems are one of the most reliable and widely used technologies for removing contaminants from water due to their high efficiency at low cost. Currently, a considerable amount of research has been conducted on the design of novel, cost-effective, and versatile antibacterial membranes with customized properties for water purification.

Membrane Pesticide Removal Water Treatment Treatment and Reuse

Oil-Water Separation Contaminant Removal Dye Removal

1. Development of Advanced Membranes

For example, Munnawar et al.[1] investigated a PES-chitosan-ZnO nanocomposite membrane for water disinfection. It was observed that increasing the chitosan-ZnO nanocomposite content in the membrane improved characteristics such as uniform pore size, suitable texture, and hydrophilic behavior. Biofouling tests showed a decrease in bacterial colony counts for each membrane, with membranes with a 15% wt. NP concentration significantly reducing fouling caused by bacteria and fungi. The maximum water flux reported was 4135.8 J for the membrane with 15% NP content, due to the improved hydrophilicity and porosity. Antibacterial activity was evaluated on the membrane with the highest NP content (15% wt.) by bacterial colony counting. The bacterial count on the control membrane was 3.17×10^9 CFU/mL for Bacillus cereus and 3.5×10^9 CFU/mL for S. aureus, while the modified membrane showed a decrease to 0.36×10^9 and 0.40×10^9 CFU/mL, respectively. Furthermore, a significant 85.6% decrease in colony count was observed for the modified membrane.

1.1. Incorporation of Silver Nanoparticles

In another study, Haider et al.[2] modified PES with an amine (APES) and silver nanoparticles (Ag NPs) to treat water through the regulated release of Ag^+ ions. The study revealed an improvement in antifouling properties due to the addition of Ag NPs to the membranes. Regarding the controlled release of Ag^+, the AgNPs-APES membrane (0.1 wt%) was observed to release silver ions at an approximate rate of 5.1 µg L^{-1} h^{-1}, while the AgNPs-APES membrane (0.2 wt%) had a release rate of approximately 7.5 µg L^{-1} h^{-1} over a period of 12 days. The nonaminated PES membrane with Ag NPs showed a leaching rate of 35 μg L^{-1} h^{-1} for 5 days. Overall, the evaluation indicated that the Ag^{+} release from the membranes was 70% for 12 days. Antibacterial evaluation of the pristine PES membrane showed no antibacterial properties against *E. coli*, as expected, while the AgNPs-PES membrane showed minimal inhibition zone. However, the aminated membranes (AgNPs-APES) exhibited the highest antibacterial activity, showing notable inhibition rings.

1.2. Photocatalysis with TiO_2

Furthermore, the photocatalytic disinfection activity induced by TiO_2 nanoparticles has been widely investigated for water treatment. In this regard, Song et al.[3] prepared flexible photocatalytic membranes with Ag, TiO_2, and ZnO nanoparticles for water filtration. The functionalized membrane showed high photocatalytic degradation potential for antibiotics and enhanced antibacterial activity compared to TiO_2 and ZnO-TiO_2-embedded membranes. Furthermore, the membranes were found to be photocatalytically stable and reusable. The functionalized membranes achieved 91.6% photodegradation of tetracycline hydrochloride after one hour of exposure and almost 100% inhibition of Escherichia coli.

2. Antibiotic Separation and Fermentation Broth Concentration

Antibiotics are antimicrobial drugs that inhibit bacterial growth or kill bacteria. They are commonly organic compounds obtained industrially through natural fermentation or synthesis. The natural fermentation production process is preferred over synthetic and semi-synthetic processes due to the intricate composition of most antibiotics. Erythromycin (ERY) is an antibiotic metabolized by the actinomycete bacterium Saccharopolyspora erythraea. During fermentation, byproducts such as ERY B, C, D, E, and F are produced, as well as intermediates such as azithromycin and clarithromycin. Therefore, the purification and separation of ERY are complex and expensive processes[4]. In this context, the presence of antibiotics in water bodies represents an environmental and health threat[5]. For this reason, the EPA included ERY in the Candidate Contaminant List. Antibiotic removal can be efficiently achieved by finely tuned nanofiltration (NF) membranes. In this regard, Weng et al.[6] fabricated PSU-polyamide zwitterionic antibacterial NF membranes with N-aminoethylpiperazine propyl sulfonate to remove ERY as a model to further investigate antibiotic removal from industrial and environmental water. The zwitterionic membrane performance showed a water permeability of 8.4 L m^{-1} h^{-1} bar^{-1} and 96.5% ERY retention. The ERY concentration in the recirculation reached 350.7 mg L^{-1} after 7.25 h of uninterrupted filtration. Furthermore, the zwitterionic membranes performed stably for 168 h of filtration and showed good resistance to bacterial adhesion against *E. coli*. In a similar work, Qi et al.[7] modified a PES membrane by incorporating silver nanoparticles (Ag NPs) to concentrate a fermentation broth. The flux of the modified membrane was better than that of the unmodified membrane. A fouling assessment revealed that bacteria were effectively inactivated on the membrane surface and could be efficiently removed during the backwash cleaning process. Furthermore, the leaching of Ag NPs was low, thus having no effect on the fermentative bacteria.

3. Removal of Arsenite and Arsenate from Drinking Water

Arsenic is a metalloid found in various environments due to its high mobility. This mobility depends on its oxidation state, the mineral source, and transport pathways. Arsenic can exist in four oxidation states: -3, 0, +3 (arsenite, the most toxic and common form), and +5 (arsenate, more stable under aerobic conditions). Both forms, arsenite (As^{3+}) and arsenate (As^{5+}), predominate in water bodies and pose a serious health risk. The World Health Organization (WHO) classifies arsenic as a human carcinogen, highlighting its toxicity to all living organisms[8][9].

3.1. Membrane Technologies for Arsenic Removal

Arsenic contamination in drinking water is a global problem requiring efficient and sustainable solutions. In this context, membrane technology is emerging as a promising strategy. For example, Roy et al.[10] developed a printed membrane functionalized with a cysteine-TiO_2-ZnS nanomonomer to remove As^{3+} and As^{5+} from water. Key results include:

- High removal efficiency: 95% arsenic removal in waters of Jharkhand and West Bengal (India), critically affected regions.
- Improved water flux: The functionalized membrane showed superior hydraulic performance compared to conventional membranes.
- Antibacterial properties: 96% efficacy against Escherichia coli and 90% efficacy against Staphylococcus aureus, attributed to the electrostatic interaction of ZnS nanoparticles with the bacterial cell wall.
- Reusability: The membrane maintained its adsorption capacity after multiple regeneration cycles, demonstrating durability.

3.2. Environmental and Technological Implications

This approach not only addresses arsenic removal but also combats microbial contamination of water. The integration of nanomaterials such as TiO_2 and ZnS into membranes offers dual advantages: high selectivity for heavy metals and intrinsic antimicrobial activity. Furthermore, the scalability and stability of these membranes position them as a viable alternative for purification systems in communities with limited access to advanced technologies.

4. Biological Membrane Reactor Technology

Biological membrane reactors (MBRs) are a hybrid technology that combines an activated sludge process, characterized by suspended biomass growth, with microfiltration or ultrafiltration membrane technology[11]. This technology is effective for treating industrial and municipal wastewater. However, fouling is the main disadvantage of MBRs, as it reduces membrane performance and significantly increases maintenance and operating costs[12]. In this context, strategies to mitigate fouling are being investigated. For example, Ghalamchi et al.[13] prepared blended PES membranes modified with Ag_3PO_4-NH_2-g-C_3N_4 nanoparticles to address biofouling and improve flux in a biological membrane reactor. The hydrophilicity of the modified membrane increased due to the introduction of nanoparticles. Furthermore, water permeability, antifouling properties, and retention efficiency improved as the nanoparticle content increased from 0.1 to 0.5% by weight. However, concentrations as low as 1.0% by weight caused extreme membrane hydration, even leading to perforation. The antibacterial properties of the composite membranes prevented bacterial adhesion and increased their antifouling capacity.

5. Defluoridation and Disinfection of Groundwater

Fluoride, the anionic form of fluoride, occurs naturally in groundwater due to geological processes such as the leaching of fluoride-containing minerals, such as fluorite and apatite[14]. Currently, more than 200 million people rely exclusively on groundwater for their drinking water, exposing themselves to toxic levels of fluoride that exceed the maximum permissible limit of 1.5 mg L^{-1} established by the World Health Organization (WHO)[15]. Chronic exposure to fluoride causes fluorosis, an irreversible condition that affects teeth and bones, causing deformities and motor disabilities[16].

5.1. Defluoridation Technologies: Advances and Limitations

Fluoride removal has been addressed through techniques such as nanofiltration (NF) and reverse osmosis (RO), but their high energy consumption and operating costs limit their applicability in resource-limited regions. To overcome these limitations, mixed-matrix membranes have emerged as a promising solution by combining high efficiency, low operating costs, and dual functionality (defluoridation and disinfection).

An innovative example is given by Chatterjee et al.[17]**,** who developed polysulfone (PSU) membranes impregnated with 15% by weight of carbonized bone meal to defluoridate and disinfect groundwater. Key results include:

- Enhanced Adsorption: Maximum fluoride adsorption capacity of 5 mg g^{-1}, attributed to improved hydrophilicity and surface texture.
- Reduced permeability: The addition of bone meal increased membrane density, reducing permeability from 5×10^{-10} m Pa^{-1} s^{-1} (pristine membrane) to 2.8×10^{-11} m Pa^{-1} s^{-1}, and lowering the molecular weight cutoff from 85 kDa to 23 kDa.
- Real-world efficacy: In tests with contaminated groundwater (18 hours of recirculation), the modified membrane completely eliminated bacteria, recording 0 CFU mL^{-1} in the permeate.

6. Desalination

More than 50% of the world's population faces freshwater shortages at least one month a year[18]. This shortage underscores the need to find sustainable solutions to meet the growing demand for water. Desalination methods remove salts and minerals from saltwater (brackish or seawater) to produce drinking water. Among the various desalination technologies, membrane systems are the most widely used[19][20]. Currently, reverse osmosis (RO) is the leading technology for brackish and seawater desalination. More than 50% of desalination plants worldwide use RO membranes due to their ability to remove monovalent and divalent ions[21].

6.1. Innovations in RO Membranes

Xu et al.[22] developed multifunctional organic covalent nanosheet (OCN) membranes for efficient RO desalination. The results highlighted that by increasing the OCN loading to 50 µg cm^{-2}, the water permeability improved up to 2.2 L m^{-2} h^{-1} bar^{-1}, and the NaCl retention reached 97.7%, compared to the pristine membrane, which had a permeability of 0.7 L m^{-2} h^{-1} bar^{-1} and a retention of 96.3%. Furthermore, the OCN-modified membranes showed remarkable resistance to chlorine of 18,000 ppm. The antimicrobial activity of the modified membranes was evaluated by a fluorescence microscopy and rolling technique using *E. coli* and *S. aureus.* The results showed that the incorporation of NOCs gave the membranes an antibacterial efficiency of 99.8%.

6.2. Advantages and Challenges of RO Membranes

RO membranes offer several advantages, such as high salt and mineral removal efficiency, but also present challenges such as fouling and energy costs. To overcome these challenges, research is focusing on developing more durable and efficient membranes, such as those modified with NOCs, which not only improve permeability and retention but also offer antimicrobial properties.

7. Dye Removal and Textile Wastewater Treatment

The textile industry is known to be one of the largest consumers of water and polluters of water bodies. In general, wastewater from this industry contains high levels of chemical and biochemical oxygen demand (COD), intense coloration, non-neutral pH, suspended solids, metallic components, high temperature, and salts. Textile dyes are the main component of this wastewater and pose a significant risk to the quality of water bodies, as they increase oxygen demand, inhibit the activity of organisms, disrupt the food chain, and are toxic, mutagenic, and carcinogenic[23][24].

7.1. Membrane Technologies for Dye Removal

Membrane technologies offer a distinctive separation process that involves electrostatic and intermolecular interactions. In this regard, nanofiltration (NF) membranes in the range of 200–1000 Da are very effective in removing dyes from water[25]. Gao et al.[26] prepared NF composite membranes with antibacterial activity by layer-by-layer electrostatic approach to recover dyes in industrial field. Three polyethyleneimine-metal ion NF membranes (Ag^{+}, Cu^{2+} and Fe^{3+}) showed permeabilities of 121 L m^{-2} h^{-1} MPa^{-1}, 71 L m^{-2} h^{-1} MPa^{-1} and 73 L m^{-2} h^{-1} MPa^{-1}, respectively. Fuchsine acid retention was 96.5%, 94.5%, and 91.6%, respectively, while $MgSO_4$ retention was 31.5%, 27.5%, and 23.7%, respectively. The membrane's antifouling capacity was determined by flux recovery ratios. The flux recovery ratios for the modified membranes were 76.4%, 83.2%, and 91.5%, respectively. Furthermore, the modified membranes displayed high hydrophilicity with contact angles of 59°, 39°, and 35°, respectively. Antibacterial activity results showed 99.61%, 97.63%, and 95.26% mortality against *E. coli*, respectively, and 99.95%, 92.01%, and 90.02% mortality against S. aureus, respectively.

7.2. Development of Antibacterial Membranes for the Removal of Dye and Coliforms

In another study, an antibacterial membrane was developed to remove dyes and coliforms from water. The membrane was prepared with polyurethane and oxidized graphite (GO) using the electrospinning method. The membranes were designed to remove the dyes rhodamine B and methylene blue. The study reported an adsorption capacity for the modified membrane of 109.88 mg g^{-1} of methylene blue and 77.15 mg g^{-1} of rhodamine B. Furthermore, the membrane with 10% GO exhibited a water flux of 17.706 L m^{-2} h^{-1}. The membrane also showed a separation efficiency of 99.99%, demonstrating good antifouling properties for oil-in-water emulsions. The antifouling property was determined by a Hermia model, which showed that the membrane modified with 10% GO effectively inhibited fouling formation.

8. Wastewater Treatment

Wastewater generated by industrial, commercial, domestic, and agricultural activities contains contaminants such as organic waste, heavy metals, and biological hazards. All of these contaminants endanger the environment and human health, making it crucial to tailor effective methods for their removal based on their intrinsic characteristics[27]. Although current membrane technologies can remove contaminants from wastewater, newer membranes seek to remove specific contaminants in water. In this context, Zhao et al.[28] fabricated PVDF membranes embedded with oxidized graphite (GO) and CuO nanoparticles to treat wastewater. The modified PVDF membrane exhibited high antifouling properties. It was observed that the nanoparticle dispersion influenced the final morphology, structure, and hydrophilic properties of the modified membrane, in addition to improving the flux recovery ratio compared to the pristine membrane. The modified membrane containing 5% CuO by weight achieved the best flux recovery ratio (92.09%). Fouling resistance improved with the addition of CuO and GO; the results were 87.04% (CuO/GO = 1), 86.38% (CuO/GO = 3), and 91.36% (CuO/GO = 5). The modified membranes exhibited antibacterial activity against E. coli, with higher CuO concentrations increasing the inhibition zone size from 1.7 mm (CuO/GO = 1) and 2.03 mm (CuO/GO = 3) to 2.53 mm (CuO/GO = 5), demonstrating that copper provided the antifouling activity.

8.1. Development of Electrospun Membranes for Contaminant Removal

In a similar study, electrospun polyacrylonitrile nanofiber membranes integrated with silver (Ag) and silver bromide (AgBr) nanoparticles were developed. Particulate contaminant removal was achieved by filtration of an aqueous dispersion of the red dye 1 (R1). The size distribution of the R1 suspension was measured in the range of 90–400 nm. The overall performance of the functionalized membrane was evaluated using an aqueous solution containing salicylic acid, E. coli, and R1, yielding a clear water permeate free of Ag^{+} or Ag nanoparticles. Antibacterial activity results showed 30%, 91%, and 100% bacterial kill after 1, 30, and 60 minutes of contact, respectively[29].

9. Oil-Water Separation

Oil-water wastewater represents a serious environmental problem due to frequent chemical and oil spills. Oil-water emulsions are extremely difficult to treat due to the small size of emulsified oil droplets and their complex composition, which can include other contaminants such as particles, surfactants, and organic matter[30][31]. Oil-based and organic contaminants can reduce the amount of dissolved oxygen, significantly affecting aquatic life forms and destroying water sources. In general, oily water can cause severe environmental damage. Some methods for oil-water separation include oil flotation, foam separation, oil coagulation, biological treatments, and membrane technology[30]. Membrane systems are low-cost and effective for separating oil-water effluents, including immiscible liquids and all types of emulsions. Permeable membranes with special wettability and specific surface roughness can effectively separate water-oil mixtures[32].

9.1. Development of Hydrophobic Membranes for Oil-Water Separation

Ma et al.[33] fabricated hydrophobic polyamide membranes by integrating a tannic acid-metal complex on the surface. The results showed that the modified membrane exhibited high hydrophobicity, with a water contact angle of 153.64° ± 1.6° and an oil contact angle close to 0°. Superhydrophobicity was demonstrated by low water adhesion and good oil-water separation. The membrane achieved a water flux of up to 6935 L m^{-2} h^{-1} and a separation efficiency of over 99%; the final oil content was less than 5 ppm at the end of 20 cycles. The membrane's self-cleaning ability was determined by coating the membrane surface with MnO_2 powder, and it was observed that water droplets easily moved from the surface, carrying the powder with them. Furthermore, the membrane displayed UV protection efficiency exceeding 90% at a radiation wavelength of 320 nm, attributed to the UV absorption capacity of tannic acid. The untreated polyamide membrane showed no antibacterial activity against *E. coli* and *Bacillus subtilis*, whereas the modified membranes effectively inhibited bacterial growth.

10. Produced Water Treatment

Produced water (PW) is generated during the extraction of petroleum-based fuels, petroleum-based energy production, and some industrial operations[34]. During oil and gas extraction procedures, large amounts of freshwater are pumped into the reservoir to maintain groundwater pressure, resulting in the re-emergence of water along with hydrocarbons[35]. Produced water may contain reservoir components and chemicals applied at various stages, such as drilling and extraction[34]. The chemical and mineral composition of produced water is unstable and depends on the site, geological factors, and operating conditions. The ionic content may include chlorides, sulfides, sulfates, carbonates, and predominantly alkali metals. In addition, produced water contains radioactive elements, usually in the form of Ra-226 and Ra-228. The total dissolved solids content of produced water ranges from 10,000 mg L^{-1} to 260,000 mg L^{-1}. The total organic carbon concentration in produced water is typically less than 1000 mg L^{-1}, but can occasionally reach up to 6000 mg L^{-1}. Produced water may also contain acid-producing, sulfate-producing, thiosulfate-producing, and sulfur-reducing bacteria[36].

10.1. Produced Water Treatment and Reuse

Treated produced water can be used for industrial and agricultural activities. The treatment of this water involves several removal stages, each targeting specific contaminants (pretreatment, primary treatment, and final polishing), as well as hybrid processes combining chemical, physical, and biological techniques[37]. However, the disadvantages of produced water treatment, such as expensive high-tech, the use of toxic substances, and secondary contamination, have driven the development of membrane systems for its treatment. However, the main current limitation of membrane technology for produced water treatment is fouling and scale formation[38].

10.2. Innovations in Membranes for Produced Water Treatment

In this context, zwitterionic forward osmosis membranes have been developed for produced water treatment by modifying PSU-polyamide membranes through interfacial polymerization integrating zwitterions. The hydrophilicity of the modified membrane was improved with the addition of zwitterions, reducing the contact angles from approximately 80° in the polyamide layer to approximately 15° in the functionalized membrane. The zwitterions endowed the modified membrane surface with antibacterial properties. The antibacterial properties were evaluated using confocal microscopy and *E. coli* on the membrane surface. The unmodified membrane showed bacterial adhesion of 4810 cells mm^{-2}, while the modified membrane had 352 cells mm^{-2} [39].

11. Pesticide Removal from Water

Pesticide use is intended to reduce crop losses and increase agricultural production. However, consumption and exposure to pesticide-contaminated water pose environmental and health risks. For example, organochlorine pesticides can hinder animal growth and disrupt their nervous systems. These compounds can progressively bioaccumulate in different species at different trophic levels through the food chain[40]. Currently, several methods exist to remove pesticides from water, such as the combination of photo-Fenton and biological oxidation, photocatalytic degradation, advanced oxidation processes, aerobic degradation, ozonation, nanofiltration (NF) membranes, coagulation, liquid-liquid extraction, solid-phase extraction, and adsorption[41].

11.1. Membrane Technologies for Pesticide Removal

NF and reverse osmosis (RO) technologies have been widely applied and accepted as means of remediating water contaminated with trace organic contaminants, including pesticides[42]. In this context, Mehta et al.[43] modified polysulfone (PSU) membranes by integrating an interfacial layer of poly(piperazine-amide) and Cu^{2+}. The unmodified membrane was labeled M1. The membranes were prepared using two different sequences. The first sequence, M2, consisted of immersing the PSU membrane in piperazine, then in a copper(II) acetate solution, and finally in a trimesoyl chloride solution. The other sequence, M3, involved immersing the PSU membrane in a copper(II) acetate solution, then in the piperazine solution, and finally in the trimesoyl chloride solution. Filtration tests indicated that the modified membranes exhibited different removal efficiencies for salts, disaccharides, and hexaconazole. The selective separation of SO_4^{2-} and Cl^- ions for M2 was 3.92, while that of M3 was 2.27. The modified membranes showed excellent separation performance for saccharide molecules in the molecular mass range of 180–520. M2 showed a low removal capacity and a higher flux compared to M3, which removed approximately 90%. Maximum hexaconazole removal was achieved with M3, followed by M1 and finally M2, which exhibited the highest flux. The antibacterial activity against E. coli and B. subtilis showed that the presence of Cu nanoparticles enhanced antibacterial properties. Since M2 contained more Cu than M3 and M1, it showed an adhesion rate of 30% for *E. coli* and 33.7% for *B. subtilis*, in contrast to M1.

12. Conclusion

Water pollution is a global problem that poses risks to both the environment and human health. Water pollutants can be diverse, including physical, chemical, and biological substances, both natural and synthetic. Water treatment and purification are two of the most researched environmental topics currently. The water treatment process involves a series of steps and approaches that can be physical and/or chemical, including filtration, centrifugation, sedimentation, precipitation, coagulation, gravitation, flocculation, microbial degradation, oxidation, electrolysis, crystallization, distillation, photocatalysis, chelation, and adsorption, among others.

Membrane technologies are emerging as one of the most reliable and widely used solutions for removing contaminants from water due to their high efficiency at low cost. Currently, a considerable amount of research has been conducted on the design of novel, cost-effective, and versatile antibacterial membranes with tailored properties for water purification. These membranes not only offer an effective solution for contaminant removal but also provide antimicrobial properties, which is crucial for protecting public health and the environment. In short, membrane technologies represent a significant advancement in water treatment, combining technical efficiency with economic sustainability and health benefits.

References

1. Munnawar I, Iqbal SS, Anwar MN, Batool M, Tariq S, Faitma N, Khan AL, Khan AU, Nazar U, Jamil T, Ahmad NM. Synergistic effect of chitosan-zinc oxide hybrid nanoparticles on antibiofouling and water disinfection of mixed matrix polyethersulfone nanocomposite membranes. . *Carbohydr Polym* . **2017**, *175*, 661–670.
2. Haider MS, Shao GN, Imran SM, Park SS, Abbas N, Tahir MS, Hussain M, Bae W, Kim HT. Aminated polyethersulfone-silver nanoparticles (AgNPs-APES) composite membranes with controlled silver ion release for antibacterial and water treatment applications. . *Mater Sci Eng C* . **2016**, *62*, 732–745.
3. Song Y, Fan JB, Wang S. Recent progress in interfacial polymerization. . *Mater Chem Front* . **2017**, *1(6)*, 1028–1040.
4. Shoushtari BA, Pazuki G, Shahrouzi JR, Shahriari S, Hadidi N. Separation of erythromycin using aqueous two-phase system based on acetonitrile and carbohydrates. . *Fluid Phase Equilib* . **2020**, *505*, 112360.

5. Danner MC, Robertson A, Behrends V, Reiss J. Antibiotic pollution in surface fresh waters: occurrence and effects. . *Sci Total Environ* . **2019**, *664*, 793–804.
6. Weng XD, Ji YL, Ma R, Zhao FY, An QF, Gao CJ. Superhydrophilic and antibacterial zwitterionic polyamide nanofiltration membranes for antibiotics separation. . *J Membr Sci* . **2016**, *510*, 122–130.
7. Qi L, Hu Y, Chai Q, Wang Q. Enhanced filtration performance and anti-biofouling properties of antibacterial polyethersulfone membrane for fermentation broth concentration. . *J Ind Eng Chem* . **2019**, *72*, 346–353.
8. Nicomel NR, Leus K, Folens K, Van Der Voort P, Du Laing G. Technologies for arsenic removal from water: current status and future perspectives. . *Int J Environ Res Public Health* . **2015**, *13(1)*, 1–24.
9. Bhakta JN, Ali M. Arsenic water resources contamination: challenges and solutions. . *Springer, New York*. **2020**, *1*, 207–230.
10. Roy E, Patra S, Madhuri R, Sharma PK. A single solution for arsenite and arsenate removal from drinking water using cysteine@ZnS:TiO2 nanoparticle modified molecularly imprinted biofouling-resistant filtration membrane.. *Chem Eng J* . **2016**, *304*, 259–270.
11. Deowan SA, Korejba W, Hoinkis J, Figoli A, Drioli E, Islam R, Jamal L. Design and testing of a pilot-scale submerged membrane bioreactor (MBR) for textile wastewater treatment. . *Appl Water Sci* . **2019**, *9(3)*, 1–7.
12. Iorhemen OT, Hamza RA, Tay JH. Membrane bioreactor (Mbr) technology for wastewater treatment and reclamation: membrane fouling. . *Membranes*. **2016**, *6(2)*, 13–16.
13. Ghalamchi L, Aber S, Vatanpour V, Kian M. A novel antibacterial mixed matrixed PES membrane fabricated from embedding aminated Ag3PO4/g-C3N4 nanocomposite for use in the membrane bioreactor. . *J Ind Eng Chem* . **2019**, *70*, 412–426.
14. Kumar Swarnakar A, Choubey D, Sar DK, Scholar ME. Defluoridation of water by various technique-a review development of phase-I campus including building for IIM Raipur at Naya Raipur carrying out of water test for construction & drinking purpose. View project analysis for total nitrogen and total phospho. . *Int J Innovat Res Sci Eng Technol* . **2007**, *3297*, 13174–13178.
15. Kimambo V, Bhattacharya P, Mtalo F, Mtamba J, Ahmad A. Fluoride occurrence in groundwater systems at global scale and status of defluoridation – state of the art. Groundwater for. . *Sustain Dev* . **2019**, *9*, 100223.
16. Vijayeeswarri J, Geethapriyai M, Ramamurthy V. Community level defluoridation of groundwater with limestone derived adsorbent. . *Process Saf Environ Prot* . **2019**, *127*, 9–15.

17. Chatterjee S, Mukherjee M, De S. Groundwater defluoridation and disinfection using carbonized bone meal impregnated polysulfone mixed matrix hollow-fiber membranes. . *J Water Process Eng* . **2020**, *33*, 101002.
18. Garrick D, Iseman T, Gilson G, Brozovic N, O'Donnell E, Matthews N, Miralles-Wilhelm F, Wight C, Young W. Scalable solutions to freshwater scarcity: Advancing theories of change to incentivise sustainable water use. . *Water Secur* . **2020**, *9*, 100055.
19. Rajakumar G, Thiruvengadam M, Mydhili G, Gomathi T, Chung I-M. Green approach for synthesis of zinc oxide nanoparticles from Andrographis paniculata leaf extract and evaluation of their antioxidant, anti-diabetic, and anti-inflammatory activities. . *Bioprocess Biosyst Eng* . **2018**, *41(1)*, 21–30.
20. Al-Najar B, Peters CD, Albuflasa H, Hankins NP. Pressure and osmotically driven membrane processes: a review of the benefits and production of nano-enhanced membranes for desalination. . *Desalination*. **2020**, *479*, 114323.
21. Lee XJ, Show PL, Katsuda T, Chen WH, Chang JS. Surface grafting techniques on the improvement of membrane bioreactor: state-of-the-art advances. . *Bioresour Technol* . **2018**, *269*, 489–502.
22. Xu L, Shan B, Gao C, Xu J. Multifunctional thin-film nanocomposite membranes comprising covalent organic nanosheets with high crystallinity for efficient reverse osmosis desalination. . *J Membr Sci* . **2020**, *593*, 117398.
23. Lellis B, Fávaro-Polonio CZ, Pamphile JA, Polonio JC. Effects of textile dyes on health and the environment and bioremediation potential of living organisms. . *Biotechnol Res Innovat* . **2019**, *3(2)*, 275–290.
24. Yaseen DA, Scholz M. Textile dye wastewater characteristics and constituents of synthetic effluents: a critical review. . *Int J Environ Sci Technol*. **2019**, *1*, 1.
25. Wang J, Qin L, Lin J, Zhu J, Zhang Y, Liu J, Van der Bruggen B. Enzymatic construction of antibacterial ultrathin membranes for dyes removal.. *Chem Eng J* . **2017**, *323*, 56–63.
26. Gao Z, Liu S, Wang Z, Yu S. Composite NF membranes with anti-bacterial activity prepared by electrostatic self-assembly for dye recycle. . *J Taiwan Inst Chem Eng* . **2020**, *106*, 34–50.
27. Herrera-Melian JA. Sustainable wastewater treatment systems. *Sustainability* . **2019**, *12*, 1–5.
28. Zhao C, Lv J, Xu X, Zhang G, Yang Y, Yang F. Highly antifouling and antibacterial performance of poly (vinylidene fluoride) ultrafiltration membranes blending with copper oxide and graphene oxide nanofillers for effective wastewater treatment. . *J Colloid Interface Sci* . **2017**, *505*, 341–351.
29. Qayum A, Wei J, Li Q, Chen D, Jiao X, Xia Y. Efficient decontamination of multicomponent wastewater by hydrophilic electrospun PAN/AgBr/Ag fibrous membrane. . *Chem Eng J* . **2019**,

361, 1255–1263.

30. Kang H, Zhang X, Li L, Zhao B, Ma F, Zhang J. Polydopamine and poly(dimethylsiloxane) modified superhydrophobic fiberglass membranes for efficient water-in-oil emulsions separation. . *J Colloid Interface Sci* . **2020**, *559*, 178–185.
31. Shao S, Liu Y, Shi D, Qing W, Fu W, Li J, Fang Z, Chen Y. Control of organic and surfactant fouling using dynamic membranes in the separation of oil-in-water emulsions. . *J Colloid Interface Sci* . **2020**, *560*, 787–794.
32. Lin X, Hong J. Recent advances in robust superwettable membranes for oil–water separation. . *Adv Mater Interfaces* . **2019**, *6(12)*, 1–23.
33. Ma W, Ding Y, Zhang M, Gao S, Li Y, Huang C, Fu G. Nature-inspired chemistry toward hierarchical superhydrophobic, antibacterial and biocompatible nanofibrous membranes for effective UV-shielding, self-cleaning and oil-water separation. . *J Hazard Mater* . **2020**, *384*, 121476.
34. Nasiri M, Jafari I, Parniankhoy B. Oil and gas produced water management: a review of treatment technologies, challenges, and opportunities. . *Chem Eng Commun* . **2017**, *204(8)*, 990–1005.
35. Ricceri F, Giagnorio M, Farinelli G, Blandini G, Minella M, Vione D, Tiraferri A. Desalination of produced water by membrane distillation: effect of the feed components and of a pre-treatment by fenton oxidation. . *Sci Rep* . **2019**, *9(1)*, 1–12.
36. Coonrod CL, Ben Yin Y, Hanna T, Atkinson AJ, Alvarez PJJ, Tekavec TN, Reynolds MA, Wong MS. Fit-for-purpose treatment goals for produced waters in shale oil and gas fields. . *Water Res* . **2020**, *173*, 115467.
37. Al-Ghouti MA, Al-Kaabi MA, Ashfaq MY, Da’na DA. Produced water characteristics, treatment and reuse: a review.. *J Water Process Eng* . **2019**, *28*, 222–239.
38. Nasiri M, Jafari I, Parniankhoy B. Oil and gas produced water management: a review of treatment technologies, challenges, and opportunities. . *Chem Eng Commun* . **2017**, *204(8)*, 990–1005.
39. Chiao YH, Chen ST, Patra T, Hsu CH, Sengupta A, Hung WS, Huang SH, Qian X, Wickramasinghe R, Chang Y, Lee KR, Lai JY. Zwitterionic forward osmosis membrane modified by fast second interfacial polymerization with enhanced antifouling and antimicrobial properties for produced water pretreatment. . *Desalination* . **2019**, *469*, 114090.
40. Nie J, Sun Y, Zhou Y, Kumar M, Usman M, Li J, Shao J, Wang L, Tsang DCW. Bioremediation of water containing pesticides by microalgae: mechanisms, methods, and prospects for future research. . *Sci Total Environ* . **2020**, *707*, 136080.
41. Tarannum N, Khan R. Cost-effective green materials for the removal of pesticides from aqueous medium. In: Green materials for wastewater treatment. . *Springer, Cham*. **2020**, *1*, 1.

42. Nikbakht Fini M, Madsen HT, Sørensen JL, Muff J. Moving from lab to pilot scale in forward osmosis for pesticides rejection using aquaporin membranes. . *Sep Purif Technol* . **2020**, *240*, 116616.

43. Mehta R, Brahmbhatt H, Bhojani G, Mukherjee M, Bhattacharya A. Poly(piperizinamide) with copper ion composite membranes: application for mitigation of Hexaconazole from water and combat microbial contamination. . *J Hazard Mater* . **2019**, *376*, 102–111.