

Antibiotic Separation from Effluent: State of-the-art of Practicable Treatment Techniques

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ABSTRACT

Pharmaceutical pollutants are seen in effluents due to their abuse and discharge from many sources, including as agriculture, industry, and human activities. This presents a danger to the environment by negatively affecting the health of local organisms. Contemporary medical practice depends on the use of antibiotics to combat microbial diseases. However, excessive or inappropriate usage of these drugs leads to unintended consequences and necessitates significant adjustments in approach to mitigate the issue. Un-metabolized antibiotics that contaminate or pollute wastewater may be damaging to both human health and the ecology. This is because they can contribute to the development of antibiotic-resistant bacteria, as well as the introduction of changed genes and pathogens into aquatic systems. Therefore, it is crucial to implement appropriate treatments in order to prevent harmful consequences on both health and the environment before antibiotics are released into water. The presence of antibiotic pollution is anticipated to have a particularly disruptive impact on aquatic habitats, since it hinders ecological processes and affects species that come into contact with it during their natural life cycle. In nature, bio-organisms digest pollutants and convert them into less hazardous or non-toxic substances using mechanisms such as bio-degradation, stimulation, and augmentation. Aerobic and anaerobic microorganisms function as energy converters and play a crucial role in removing contaminants from wastewaters via bioremediation processes. This review discusses innovative treatment methods that are complex but effective in removing antibiotics. These methods use biotechnological techniques and artificial adsorbents. Additionally, the review outlines the microbiological effectiveness and important processes of a mix of microalgae and bacteria in the separation process.

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Introduction

In 1929, Sir Alexander Fleming made a chance discovery of Penicillin, which led to the development of approximately 2000 antibiotics. In 1942, Sir Selman Abraham Waksman identified the ability of some antibiotics to kill or suppress microorganisms, which has been essential in fighting infections [1]. Antibiotics may function in two ways: as bactericidal agents, such as penicillin, which eliminate bacteria by inhibiting the components of their cell walls, or as bacteriostatic agents, such as chloramphenicol, which halt bacterial reproduction. The worldwide usage of antibiotics is increasing every year. For example, China consumes 162,000 tons, the USA consumes 13,000 tons, and Europe consumes 10,000 tons [2]. Antibiotics are now used for several purposes, including the treatment of infectious diseases caused by harmful microorganisms, prevention of illnesses, promotion of aquatic life production, and enhancement of animal husbandry. Additionally, they are employed in the spreading of manure and as fertilizers in sewage, which may result in an excessive amount of effluents [3,4]. Pharmaceutical contaminations in rivers and related areas worldwide are poorly regulated due to the inability of wastewater treatment systems to completely eliminate persistent pollution, resulting in the emergence of highly resistant antibiotic-resistant bacteria [5]. Several non-metabolized antibiotics become present in natural aquatic systems and have significant deleterious

effects on health, as shown in [6]. Approximately 30-90% of the antibiotic that is given is excreted in active forms or residues in the surface/ground water and soil in the vicinity. This occurs as a result of residential runoff, as well as the release of agricultural and industrial waste [4-6]. Some antibiotics can persist in the environment due to their long half-life, which can have adverse effects on aquatic organisms. These antibiotics can alter microbial communities and exert selective pressure on susceptible bacteria, leading to the emergence of antibiotic-resistant strains. This can contribute to the development of antimicrobial resistance, which is ineffective in treating newly emerging infectious diseases [7-9]. Furthermore, the presence of long-lasting antibiotics in aquatic environments might lead to the development of allergies and disrupt the natural microbial balance if they reach the human body via food chains or water bodies [10,11].

In 2021, the Veterinary Medicines Directorate agency in the UK estimated that around 387 tons of antibiotics were used as common food additives to treat infections in farmed fish, prevent microbiological illnesses in plants and animals, and support global livestock production [12]. Although antibiotics are metabolized in the body after performing their function, some parent/active metabolites are expelled via urine, feces, and manure. This leads to the contamination of many resources, including residential wastewater, sewage, agro-wastewater, and hospital/pharmaceutical effluents [13-15]. The uncontrolled release of pollutants into water bodies through partial or non-metabolic flux during effluent dispersal poses numerous risks, including damage to pathogens

and organisms, development of zoonotic resistance, and toxicity to aquatic species. Additionally, this pollution can contribute to the emergence of highly resistant superbugs. Therefore, it is necessary to implement effective treatment techniques to address polluted effluent before its discharge [16].

Various methods, such as coagulation, adsorption, ion-exchange, Fenton-reagent, ozonation, photo-catalysis, membrane separation (such as reverse osmosis, micro/nano/ultrafiltration), adsorption, and biochemical reactors, are used to purify antibiotic-contaminated effluents [17]. Various bio-wastes and materials may be used as adsorbents or membranes according to their intended functionality, allowing for a range of interactions such as dipole-dipole, electrostatic, hydrophobic, π - π bond, van der Waals, and hydrogen bonding. These interactions make them suitable for separating antibiotics from effluents [18-20].

Methods for Isolating Antibiotics from Effluents

Efforts to eliminate antibiotics from wastewater by common methods such as filtration, coagulation, flocculation, and sedimentation are ineffective owing to their limited ability to completely remove these substances [21]. Advanced oxidation mechanisms, such as UV photolysis, photo-catalysis (H_2O_2 - O_3), Fenton's reagent, and ionizing radiation, cause complete and non-selective degradation of antibiotics by the generation of $\bullet OH$ radicals at the same location. However, these oxidations have significant limitations, including high costs, challenges in managing catalysts, and the presence of hazardous by-products and effluents [22-24].

Recently developed innovative techniques are effective and capable of removing antibiotic contamination from wastewater using a newly developed adsorptive method. These techniques offer advantages over previous methods due to their inherent features such as low cost, easy design of reactors/adsorbents, simple operation, and customized selectivity [25-28]. Diverse adsorbents such as zeolites, ceramics, clay, metal organic/inorganic frameworks, multiwall carbon nanotubes, activated carbons, and organic polymers have been created to facilitate the removal of antibiotics from effluents [29-31]. Zeolite and activated carbon stood out prominently owing to their micro/meso-porosity range of less than 2 nm to 2-50 nm, making them suitable for adsorbing antibiotics from effluents [32]. The global research and development efforts are mostly focused on modifying adsorbents to produce organic-inorganic hybrids that resemble zeolite and activated carbon materials [22-32]. A very effective and misleading adsorbent is capable of working at many pH levels. It efficiently removes antibiotics from wastewater by quickly filling its pores by compatible sorption. This process is facilitated by electrostatic interactions between the charges of the adsorbent's functionality/substituents and hydrogen bonding. Currently, unique first-generation polymers such as PTMSP (poly(1-trimethylsilyl-1-propyne)) and PMP (poly(4-methyl-2-pentyne)) are being prepared. These polymers possess distinctive characteristics such as enclosed rings, contort sites, high free-volume, lack of packing space, and ease of processing in various forms such as powder, membrane, and fiber. Additionally, they exhibit high sorptivity, solubility, and surface area, along with excellent thermal and chemical stability. These properties make them suitable for adsorbing antibiotics from wastewater [33].

Contemporary results of science and technology, such as bio-remediation, bio-stimulation, and bio-degradation, are achieved by using natural organisms that are suitable for effectively treating

antibiotic-contaminated waste water. Indeed, the process of bio-remediation may accelerate treatment methods in an advanced research and development (R&D) field. The following are some specific remedial talents and approaches that are used in the treatment of antibiotic-contaminated effluent:

Liquid-Phase Polymer-Based Retention (LPR)

Liquid-phase polymer-based retention is a method that separates pollutants with molecular weights lower than the adsorbent by using certain polymers, such as those containing sulfonic acid and/or quaternary ammonium functionalities. The ultra-filtration process involves attaching it to cellulose membranes with a mass cut off version of 5-10 kDa. This method is very effective in separating pharmaceuticals pollutants owing to its exceptional retention capacity, which ranges from 215 to 732 mg/g polymer. Alkylated chitosan has the ability to undergo electrostatic speciation via quaternary ammonium/hydrogen bridging. This allows for efficient absorption of 632 mg/g of tetracycline from wastewater, making it the most effective option owing to its inherent functionality and low energy consumption [34]. The Ultrafiltration cascaded Low Pressure Reverse Osmosis (LPR) system provides a robust membrane-based solution for effectively treating wastewater including large-sized contaminants with high molecular weight. The retention of water-soluble high molecular weight species on UF membranes is strengthened by ionic interaction retention via accretion, facilitated by size-exclusion. Additionally, selective separation is achieved by the presence of chelating polymeric chains [35]. LPR may be categorized into many groups, including liquid-phase polymer-based retention, polymer assisted ultra-filtration (PAUF), ultrafiltration-complexation, poly-electrolyte improve ultrafiltration (PE-UF), and enhance ultrafiltration [36]. The development of LPR, which involves the retention of various water-soluble polymers, began in 1968 for diafiltration purposes. This process includes continuous ultrafiltration and the subsequent modeling and development of novel applications [37].

Membrane Separations

In 1960, the use of membrane separation was introduced as a method for treating wastewater. This process involves the selective passage of one fraction through holes or gaps in a diffuser, while the other fraction is retained or blocked [27]. The permeation and separation processes in a membrane are controlled by the gradients of concentration, pressure, electric potential, and temperature at the porous borders between two phases or films [37]. This membrane effectively separates antibiotic molecules from water using various methods such as electrolysis, electro-dialysis, reverse osmosis, ion-exchange, gas-permeation, counter diffusion, osmotic distillation, and ultra/micro/nano-filtration per-vaporation [27-38,50]. Nanofibro-porous membranes are designed to prevent capillary forces from causing phase mixing on either side. These membranes also have a large surface area for active interaction and sustained permeability via phase extraction. The diverse hollow-fibrous membrane effectively balances the module between two phases, making it suitable for separating pharmaceutical effluents such as antibiotics and proteins from wastewater. Therefore, various organic polymers such as cellulose, chitin, chitosan, plastics, as well as inorganic materials including ceramic, silica, alumina, and zirconia, are included into membrane separation processes such as reverse osmosis (RO) and hollow-fiber ultra-/nano-filtration. In order to achieve effective separation of antibiotics, it is necessary for these membranes to have excellent film-forming properties, allowing for high permeation-flows and great selectivity. Additionally, they should possess resistance to chemicals, bacteria, detergents, and disinfectants.z

Table 1: Diverse Benefits & Limits of Diverse Membranes used in RO, NF & UF Techniques

SN	Membranes	Benefits	Limitations
1	Cellulose acetate bio-plastic	High permeate flux, good salt rejection, easy making, cheap, biodegradable	Only operates at NTP & 3-6 pH, chlorine prone
2	Porous carbon, Bio-plastic	Great permeability, good salt rejection, low cost, easy creation, ecofriendly	Limiting temperature & pH operations
3	Polyamide (PANI), Synthetic-plastic	Temperature, pH & chlorine resistant, easy production, reusable	more sensitive to chlorine
4	Poly-sulphones, Synthetic-plastic	Temperature, pH & chlorine resistant, easy production, reusable	No resistant to high pressure-restricted to UF,
5	Polyvinylchloride Synthetic-plastic	Temperature, pH & chlorine resistant, easy production, reusable	
6	Poly styrene, Synthetic-plastic	Temperature, pH & chlorine resistant, easy creation, reusable	
7	Polycarbonate, Synthetic-plastic	Ambient Temperature, pH & chlorine resistant, easy production, reusable	
8	Poly ethers Synthetic-plastic	Temperature, pH & chlorine resistant, easy fabrication, reusable	
9	Ceramic Composite	Inert, Broad operating temperature, pH, chlorine resistant, easy wash	Moderate-costly
10	Zirconium oxide Composite	Neutral, Wide temperature, pH range, resistant, easy clean, reusable	Expensive, fouling advert efficiency & time
11	Aluminum oxide Composite	Sturdy, Wide temperature, pH performance, tough, easy, reusable	Costly, less-separation & less-permeable, fouling.

Membrane's Module

Membrane technology is a field that integrates the principles of material science with media separation. It offers many advantages, including high efficiency, accurate separation, simple operating requirements, and low energy consumption. The removal of antibiotics from wastewater is now mostly accomplished via the use of membrane separation technology, which has replaced traditional separation and purification methods in the mitigation of environmental pollution. Membrane-based separation is mostly effective in the clarification of desalination and the removal of antibiotics from wastewater or effluent [34-38].

Typically, antibiotics have a molecular weight ranging from 200 to 1000. The non-metabolized portion of antibiotics also has a large particle size, which may be separated and eliminated using membrane separation methods. The membranes used in this separation method may be categorized into two categories: synthetic membranes and bio/natural membranes. Nano-filtration membranes, such as thin-film composite, are often used for this purpose. The commonly used types of membrane modules are tubular, hollow fiber, flat sheet, and spiral-wound. The flat plate membrane plate-frame is a kind of plate filter press that utilizes a series of stacked plates with a center spacer and collecting plate to separate and remove permeate species [27,38]. This flat plate membrane has a large surface area that may be attached in a compact space. However, individual plates can be easily replaced owing to the presence of either laminar or turbulent flow. When compared to traditional separation methods, membrane-

based separation is much simpler, requiring less maintenance and saving both human and material resources, as well as reducing overall costs. Membrane separation is an energy-efficient process that allows for effective separation without the need for phase modification or high concentration, therefore avoiding any inherent harm. Membrane separation is the most suitable method for treating antibiotic wastewater owing to its low operating costs and its ability to effectively reduce environmental contamination.

Tailored Membrane based Filtrations

While conventional approaches are used to treat antibiotic effluents, they have limitations such as adsorption difficulties in capacity-rate and the load of by-products during chemical oxidation. On the other hand, polymeric membrane filtration is chosen because to its inherent advantages such as simple competence, persistence, and setup [27]. So far, membrane filtration leads to fouling via the electrostatic interaction between the antibiotic molecules and the membrane surface. This ultimately decreases the permeability and stability of the solvent and also results in irregular pore structure. Additionally, it leads to a higher rejection rate of substances. Progressive bio-membranes are specifically engineered to have a continuous porosity that is similar to natural membranes, and they also possess good resistance to fouling [27,29,34]. These properties make them effective in overcoming obstacles in treatments that use antibiotics mixed with other substances. A diverse range of membranes, such as 2-D graphene laminar film, have been specifically developed to separate antibiotics from polluted wastewater [38]. These membranes possess excellent

atomic sieving capabilities. Graphene membranes exhibit high permeance and a satisfactory rejection ratio in nano-filtration and ion-sieving separation [30,34]. Advanced 2-D titanium carbide membranes provide organized nano-routes between neighboring sheets, allowing for efficient separation of antibiotics with improved permeability and selectivity. These membranes overcome the challenges associated with antibiotic separation. The use of granular activated carbon and anthracite bio-filters effectively adsorbs and degrades a range of antibiotics, including minocycline, chlortetracycline, doxycycline, oxytetracycline, meclocycline, demeclocycline, and tetracycline, from wastewater [30-38,50].

The Polydopamine-thin-film composite (PDA-TFC) membrane is designed to achieve impressive results, including decreased waste output and the recovery of purified water after antibiotic separation. Efficient and cost-effective treatment methods, such as the use of tailored membranes with adsorption, filtering, and photo-catalysis, are selected for the removal of antibiotics from contaminated wastewater [39,40]. Therefore, certain visitors such as activated-char, clays, and minerals like zirconia and titania have a proactive effect on the adsorption of tetracycline, sulphonamide, and quinolone-based antibiotics from natural effluents [27,30]. Antibiotics are trapped by many interactions at the interface, including covalent bonding, hydrogen bonding, ion-exchange chelation, surface complexation, and cation-bridging inside the matrix components of the membrane [18,27]. Specific bar-coated polydopamine (PDA) membranes, derived from bio-charcoal processed by ball milling, exhibit high penetration flux and rejection rate when removing tetracycline compounds from effluent [39]. Today, advanced technology has introduced a dynamic interlayer gapping/trade-off link in resulting thin-film composite (TFC) membranes. This innovation increases permeability and rejection ratio, making it suitable for separating pollutants. However, research and development are currently exploring the use of interlayering and reinforcing sorbents to design various thin-film composite (TFC) membranes. This is achieved through a combination of interfacial polymerization and bar coating techniques, such as using polydopamine (PDA-TFC). The goal is to create membranes with high permeability for separating chlortetracycline, tetracycline, ciprofloxacin, and oxytetracycline from effluents. This research is documented in reference [41]. Additionally, the PDA-TFC membrane is susceptible to fouling and requires regeneration by alkali washing. Extensive reconfiguration of high-flux separating membranes is carried out to reduce the presence of antibiotics and other contaminants such as dyes, phenols, and nutrients in effluents.

Nano-Filtration Membranes

Nano-filtration membranes regulate the diffusion process by means of mass transfer occurring inside the dynamic layer of these membranes. The process of separation or rejection is achieved using reverse osmosis, which involves the use of size selective steric interference caused by electrostatic and hydrophobic interactions between the permeate and membranes. Ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) filtration provide the necessary force to counteract the resistance caused by the diffusion of pollutant species from the separation medium in high concentration effluents [27,30]. Effluents containing antibiotics are seen to undergo degradation during photo-catalysis, hence reducing their toxicity. Nano-filtration efficiently removes contaminants from water using multi-functional membranes, such as gallic acid coated polyethyleneimine. This process achieves high rejections and maintains a steady solution flow for separating effluents at normal temperature and pressure (NTP) [30]. Polyamide coated

and/or silicon hybrid membranes provide exceptional percolation, permeability, and rejection properties because to their lack of phase change, little emission, low tenancy, permeation, automation, and high rejection of tiny and multivalent ions [27-41,50]. The multi-functional surface active nano-membrane, coated with dopamine, gallic acid, PAN, and PEI, exhibits high selectivity for permeability, stable solution flow, permeance consistency, and rejection in the separation of antibiotics from effluent [30]. The NiFe₂O₄/MWCNTs/BiOI system and tri-axial electrospun β -FeOOH/TiO₂ film have been designed to have two different semiconductor materials with adjusted energy band-gaps and electron-hole conductivity. This design makes them suitable for efficiently degrading doxycycline in wastewater [42]. Currently, synthetic membranes have been developed to provide a durable surface for effectively removing contaminants from effluent using microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). These technologies are superior to traditional approaches [27,30].

Carbonaceous Membranes

Chitosan cross-linked graphene oxide membranes have included interlayers to provide enhanced structural stability, resulting in improved resistance to fouling and increased effectiveness in separating antibiotics from water [27]. Chitosan facilitates several interactions, such as hydrogen bonding and electrostatic -OH/-CN binding, to enhance the penetration and separation of contaminants via well-designed nano-membranes. Polyamide nano-matrix membranes with improved interlayers are designed to functionally filter and separate antibiotics from effluents by nanofiltration. The use of organic inserted thin-film addresses the issue of non-selective defects caused by poor interfacial compatibility between inorganic additives and the polyamide matrix. This leads to a trade-off between permeability and selectivity, but also enhances the antifouling properties of the membrane. As a result, the membrane is able to effectively separate antibiotics from effluents. Electro-spun membranes formed from a solution containing poly-vinylpyrrolidone may enhance the filtering of antibiotic waste by using flexible interconnected nano-fibers. This is possible because these membranes include characteristics such as being water-attracting, strong, and having a small water contact angle.

Certain polymeric membranes include restricted porosity, uneven distribution of pore sizes, and unfavorable voids across their breadth, resulting in poor flux and fouling. However, these limitations may be solved by using non-woven electro-spun nano-membranes that are specifically tailored to have desired porosity, permeation flux, and surface-to-volume ratio. Various electro-spinning membranes are customized to exhibit specific properties such as Polyethersulfone, which enhances interfacial bonding to measure wettability/hydrophilicity, permeability, anti-fouling, durability, water flow stability, and efficiency in separating antibiotics from effluents [43]. Some fillers, such multi-walled carbon nanotubes in polybutylene terephthalate and titanium-oxide in polyamide, may be readily included using electro-spinning. This process modifies inherent qualities such as aggregation, conductivity, viscosity, and shape. Incorporating polyvinylpyrrolidone in electro-spinning enhances membrane properties such as hydrophilicity, anti-fouling, permeability, and pore diameter [44].

Imprinting Molecular Polymers

Several imprinted molecular polymers function as receptors for certain pollutants, similar to antibody-antigen systems [45]. Computational design and molecular imprinting are used to create

polymers such as 2-hydroxyethyl methacrylate, 2-acrylamide-2-methylpropane sulfonic acid, and methacrylic acid for the purpose of extracting antibiotics from wastewater. Various bi-functional monomers are infused to create molecular frameworks using solid phase micro-extraction, providing exceptional ionic affinity and strength for the targeted absorption of contaminants from effluent. Diverse imprinted polymeric reusable frameworks have been developed that provide specific functionality for the adsorption of antibiotics such as oxytetracycline and tetracycline from natural effluents. 2D MXene-based high-permeable membranes, such as Ti₃C₂Tx nano-sheets, were designed to retain hydrophilic surface anionic ends (-O/-OH/-F) that enable high flux via electrostatic interactions. These membranes are also capable of rejecting fouling and effectively removing antibiotics from effluents. The MXene-based membrane has exfoliated groups such as -NH₂, -OH, and

-CO, which enable selective etching by electrostatic exchange of the anionic portion of antibiotics at a certain pH. This results in improved separation compared to existing 2D membranes [27,30,45]. 2D Akin graphene generated membranes have a large aspect ratio and maintain a stable interlayer space suitable for efficient rejection and sustained permeability in the treatment of antibiotic effluents. The use of firm ultra-ordered transition metal carbides/nitrides-based membranes offers superior performance in terms of proficiency, antifouling properties, rejection-ratio, and stability compared to conventional polymeric membranes in effluent treatments. Table-2 below displays some synthetic organic polymers used as adsorbents for removing antibiotics from wastewater effluents.

Table 2: Artificial Organic Polymeric Adsorbents used for Antibiotic Removal from Effluents

S.N.	Antibiotic Types	Ion exchange Resins/Polymers	Remarks
1	Macrolides	HP21 SK104S	Fermented liquor filtration
2	Reveromycin B,C,D: polyketides	Diaion® HP20 Aromatic, 1.3ml/g pore volume, pore size 300-600.	Filtration of fermented liquor
3	Desalaninebenanomicin A	HP20	Antifungal agents
4	Cephems	HP20SS	Filtration of mother liquor
5	Mitomycin:	HP20	Filtration of fermented liquor
6	Cepacidine:	HP20	Precipitation/ Filtration
7	Tubelactomicin:	HP20	Fermented liquor filtration
8	Nothramicin:	HP20	Fermented liquor filtration
9	Lankacidins	HP20	Filtration of ferment liquor
10	Daunomycin: anthracycline	HP20	Filtration of ferment liquor
11	Antitumor compound,	HP20 SP20SS	Filtration of ferment liquor
12	Anthracyclines	HP20	Tune pH = 2 Sediment /decant
13	Caprazamycin	HP20	Ferment filter, microbe extract
14	Captomycin	HP20 HP20SS	Ferment liquor Supernatant UF, hydrophobic Purification
13	Caprazamycin	HP20	Ferment filter, microbe extract
14	Captomycin	HP20 HP20SS	Ferment liquor Supernatant UF, hydrophobic Purification

Imprinted molecular polymers maintain a consistent distance between layers and enhance the water-attracting properties of the surface by using a technique called Tx/anionic directive parting. This technique involves applying antibiotics to 2D membranes that have been modified to resist electrostatic forces. The process has been described in studies [21,25]. Imprinted M-Xene, 2D-graphene, and metal-carbide/nitride reinforced poly-acrylonitrile/poly-vinylidene fluoride membranes have the potential to effectively prevent fouling.

Comparative antibiotic removal from effluent onto aquaporin bio-membrane and other synthetic adsorbents are demonstrated in Figure 1 below:

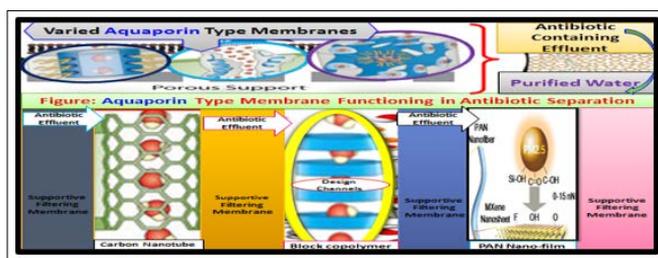


Figure 1: Comparative Antibiotic Removal from Effluent onto Aquaporin Bio-Membrane and other Synthetic Adsorbents

Effluent membrane promises to separate antibiotics from wastewater. A highly effective, hygienic, and secure elastic film that is suitable for certain applications requiring the capacity to cover and penetrate smooth surfaces with high sorption and permeability. Ceramic micro-filter membranes are the ideal choice for selectively separating and efficiently managing energy, cost, and material recovery, while

also being highly reusable. Some photo-reactor/photo-catalyst linked membranes may effectively separate substances owing to their inherent features, such as a simple separation barrier, high microfiltration rate, and the ability to reuse/recycle photocatalysts in continuous and pilot operations. Membrane-coupled photo-reactors offer several advantageous features, including practical controllability, stability, and the ability to reuse the photo-catalyst due to the constraints imposed by the membrane's environment. This results in efficient separation of organic pollutants from effluents, surpassing the capabilities of traditional photo-catalysis [27-30].

Ion-Exchange Resin

Various ion-exchange resins are used in the purification or treatment of pharmaceutical effluents [46,47]. The ion exchange resin consists of a cross-linked hydrophobic network of periodic ions along its native chain. These ions are replaced by counter ions from the solution. The majority of antibiotics are ionic, making treatments with ion-exchange resins an effective and efficient approach for separating them from the related effluent. For example, tetracycline, sulfonamide, and oxytetracycline may be removed by magnetic MIEX® resin via strong-base anion-exchange effects. If there is no dissolved antibiotic present, then agglomeration takes place instead of ion exchange, regardless of its original form. Certain antibiotics possess highly electronegative substituents that may be readily isolated by ion-exchange onto resins. Therefore, several organic resins/polymers with insoluble matrixes ranging from 25 to 50 microns are used to remove antibiotics from wastewater. The porous membranes reinforced with polystyrene-sulfonate, polyethylene amine, and poly-APTAC have a highly cross-linked ion-exchangeable framework. This framework allows for selective electro-dialysis due to the large surface area available for binding certain ions while allowing other ions to be discharged [27]. The ion-exchange phenomena occurring on porous membranes made from these polymers facilitates electrolysis and enhances the diffusion of salts, making it feasible to separate antibiotics from effluents. Tailored membranes are more effective than activated carbon for refining antibiotic separation methods. They also facilitate the development of new membranes, such as MN-150/200 and NDA-150, which are hydrophobic polystyrene amino-resins with high porosity.

These membranes efficiently adsorb tetracycline (443 ppm) from wastewater through hydrogen bonding and π - π interaction with the anionic sites on their surface [48].

Ceramic UF membranes are superior than NF/DK membranes in separating pollutants because to their high porosity and permeability, as well as their low Donnan effect. However, the quantitative speciation differs depending on the zeta potentials. The polyphenylsulfone membrane is enhanced with a coating of polyaniline (PANI) to create a nano-porous structure that can be adjusted to different surface properties like as hydrophilicity, zeta-potential, and bacteria-stasis activity. This allows for effective high filtering while maintaining good permeability. A protected ultrafiltration membrane surface reduces electrostatic interactions within charge gradients and enables easy separation over a broad range of temperature, pressure, and pH levels. The use of bio-membranes for separating antibiotics from water has many inherent benefits, such as easy scalability, high penetration, and consistent separation. However, it is important to note that fouling might generate hydrophobicity, which may affect the efficiency of this treatment method. Hydrophilic membranes may be generated by many methods, including coating, grafting, strengthening with polymeric and nano-particles, or cross-linking. These methods result in surfaces that are proactive, cost-effective, easily adopted, and more stable. Membranes coated with plain/sulfonated polyaniline has unique characteristics such as contact angles of less than 90°, active charges, adjustable porosity, surface wetting ability, conductive hydrophilicity, and antibacterial properties, making them suitable for efficient separation. The initial polyphenyl-sulfone (PPSU) membranes are very hydrophobic, as shown by a contact angle of 65°. However, when PANI-coated PPSU membranes are used, the contact angle decreases to 55°, indicating an increase in hydrophilicity. The addition of cationic dopants to the PANI matrix increases its hydrophilicity by creating contact between counter-ions and protonated film surfaces. For example, the protonation of the -NH₂ surface results in a positive shift of -10.5 to -1.7 mV in zeta potential over a wide pH range of 2 to 7, and improves the membrane's rejection efficiency. Certain organic based bio-membranes involved in pharm derived pollutant mitigation from water characteristics are depicted in Table-3 below [27,28].

Table 3: Physico-Chemical Features of Organic based Bio-Membranes Involved in Pharm Derived Pollutant Mitigation from Water

Membranes	Isoelectric Point (pH _{iep})	Water Permeability L m ⁻² ·h ⁻¹ ·bar ⁻¹)	% Membrane Rejection
PPSU membrane	3.4	20.3 ± 3	3 ± 0.5
PANI-coated PPSU membrane	5.2	53.5 ± 5	96 ± 2

Biotechnological Approaches for Antibiotic Removal from Native Effluents

Various biotechnological methods, such as the use of micro-algae and microorganisms, may effectively absorb, accumulate, and break down antibiotics in water [27-32]. These methods are a suitable alternative for environmentally friendly treatment of antibiotic elimination.

Certain microalgae and microbes on adjoined with activated sludge, advanced oxidations, built wetlands; biofuel-cells and genetic engineering in order to attain hybrid approaches for antibiotic separation from effluent with high efficacy, microbial consortium, acclimation, and co-metabolism are mentioned in Figure 2 below:

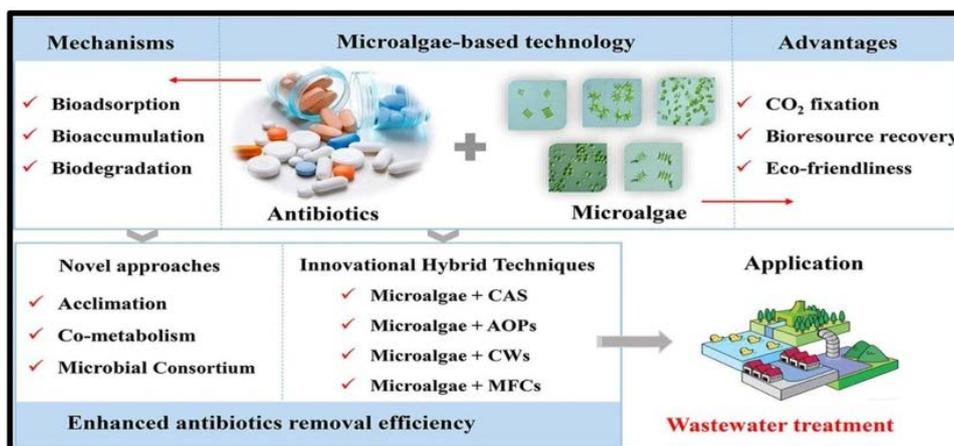


Figure 2: Efficient microbial consortium, acclimation, co-metabolism involved in antibiotic separation from effluent

Microalgae for Antibiotic Mitigation from Effluent

Several microalgae possess unique characteristics such as adaptable tolerance and the ability to reproduce under severe environments. These qualities make them suitable for removing antibiotics from wastewater via processes including bio-adsorption, bio-accumulation, and bio-degradation. Additionally, photo-degradation and volatilization methods may be used with microalgae/microbes to effectively break down antibiotics present in effluents [19].

Bio-Adsorption

Antibiotic components create non-metabolic electrostatic interactions with extracellular components, cell walls, and surface excretions of microbes. These interactions are due to the anionic charge of the antibiotics. The antibiotics also undergo bio-sorption through the carboxyl, amine, hydroxyl, phosphoryl, and hydrophobic properties of native polymer units such as proteins, sugars, nucleic acids, lipids, and humics. Microbial bio-adsorption is facilitated by many physico-chemical processes such as surface complexation, chelation, micro-precipitation, sorption, and ion exchange [20].

The efficacies and key mechanisms of antibiotics separation onto microbial bio-adsorption are shown in Table-4 below:

Table 4: Efficacies & mechanisms of antibiotic separation onto microbial sorption [48-49].

Antibiotics	Microbes	Microbe culture (operational states)	Separation paths
Cephalosporin C	<i>Chlorella sp/pyrenoidosa</i> , <i>Chlamydomonas sp.</i> <i>Mychonastes sp.</i>	BG-11, at NTP	Bioadsorption, hydro & photolysis
Amoxicillin Azithromycin	<i>Microcystis aeruginosa</i> , <i>Haematococcuspluvialis</i> , <i>Selenastrum capricornutum</i> , <i>Scenedesmus quadricauda</i> , <i>Chlorella vulgaris</i>	BG-11, at NTP, pre-sterilized synthetic sample,	Biodegradation
Cefalexin, Ceftazidime, Cefradine	nonliving <i>Chlorella sp.</i> & <i>Chlorella pyrenoidosa</i>	BG-11, at NTP	Bioadsorption & Biodegradation
Ciprofloxacin	<i>Chlamydomonas sp.</i> <i>Chlamydomonas mexicana</i>	pre-sterilization, BBM, NTP	Biodegradation
Clarithromycin	<i>Haematococcuspluvialis</i> , <i>Selenastrum capricornutum</i> , <i>Scenedesmus quadricauda</i> , <i>Chlorella vulgaris</i>	pre-sterilized sample, at NTP	Biodegradation
Enrofloxacin	<i>Chlorella vulgaris</i> , <i>Scenedesmus obliquus</i> , <i>Scenedesmusobliquus</i> , <i>Chlamydomonasmexicana</i> , <i>Ourococcusmultisporus</i> , <i>Micractinium resseri</i>	BG-11, at NTP	Biodegradation & photolysis
Florfenicol & Flumequine	<i>Haematococcus.pluvialis</i> , <i>Selenastrum capricornutum</i> , <i>Scenedesmus quadricauda</i> ,	BG-11, pre-sterilized sample, NTP	Biodegradation

Levofloxacin Lomefloxacin	Haematococcuspluvialis, Senastrum capricornutum, Scenedesmus quadricauda, Chlorella vulgaris	BBM, at NTP pre-sterilized sample, at NTP	Bio-accumulation & Biodegradation
Metronidazole	Chlorella vulgaris	BG-11, at NTP	Bioadsorption
Ofloxacin	Chlorellasorokiniana/ vulgaris, Scenedesmuobliquus, Desmodesmus sp.Coelastrella sp, Coelastrumastroideum,	BBM, at NTP	Biodegradation
Oxytetracycline	Phaeodactylum tricornutum,	Algal media, NTP	Bioadsorption
Roxithromycin & Sulfamethoxazole	Haematococcuspluvialis, Senastrum capricornutum, Scenedesmus quadricauda, Chlorella vulgaris/ pyrenoidosa,Nannochloris sp.Microcystis aeruginosa,	pre-sterilized sample, F/2 algal, Woods Hole Combo, NTP	Biodegradation Photolysis
Sulfamethazine	Chlorella vulgaris, Scenedesmus obliquus, Chlorella pyrenoidosa	BG-11, F/2 algal at NTP	Bio-decay, photolysis & bioaccumulation
Sulfamerazine &Sulfamonomethoxine	Haematococcuspluvialis, Senastrum capricornutum, Scenedesmus quadricauda, Chlorella vulgaris	pre-sterilize synthetic sample NTP	Biodegradation
Sulfadiazine	Chlamydomonas sp.	Sterilization, NTP	Photolysis
Tetracycline	Chlorella vulgaris Tetraselmis suecica,	pre-treats, sunray, BBM, NTP	Bio-adsorption & photolysis
Trimethoprim	Haematococcuspluvialis,Selenas trumcapricornutum/quadricauda, Chlorellavulgaris,Desmodesmus sp/sorokiniana	pre-sterilize sample, BBM, NTP	Biodegradation

Note: BG11=Blue-Green medium), BBM =Bold's Basal Medium

Bio-Accumulation

In the phenomena of bioaccumulation, microbial metabolic products have the ability to bind antibiotics and achieve the adsorption of intracellular proteins and other components [20]. Some microbes are capable of actively transporting antibiotics across a concentration gradient, from areas of high concentration to areas of low concentration, with the assistance of energetically facilitated diffusion. Several hydrophobic/non-polar antibiotics with low molecular weight, such as sulfamethoxazole, trimethoprim, levofloxacin, carbamazepine, and florfenicol, rapidly diffuse through bioaccumulation onto green microalgae of the Chlorellaceae family. This process is facilitated by high permeability and is influenced by various factors such as hyperpolarization, depolarization, pressure, and carrier proteins. Physicochemical factors like temperature, pH, time and concentrations also control rate of deposition/accumulation of antibiotic in microbial cells besides excite extreme signal transduces including O₂-, -OH, HO₂ and -OR, H₂O₂, and IO₂ which regulates progression, disparity, reproduction, cell-proliferation and metabolism. These signals trigger DNA, protein denaturation, and mutagenesis in bacteria, facilitating the removal of antibiotics from wastewater/effluents. For example, they enable the breakdown of sulfamethazine and levofloxacin by bio-accumulative degradation as mention in above Table 4.

Bio-Degradation

Antibiotics become more concentrated and are directly transmitted to microbial cells when they are absorbed [19,20]. For example, the drug florfenicol is known to be absorbed by Chlorella sp. L38, and the drug ciprofloxacin is absorbed by Chlamydomonas

sp. Haematococcus pluvialis, Senastrum capricornutum, Scenedesmus quadricauda, and Chlorella vulgaris. The carbon component of the antibiotic served as the foundation for metabolism controlled by electrons and ultimately decomposed into CO₂ and H₂O via biotransformation and biodegradation. The microbial extracellular polymeric compounds release various enzymes, such as sulfamethoxazole, which cause intracellular accumulation and disruption, as well as a decrease in extracellular metabolic activity. This process is seen in Chlorella pyrenoidosa. Advanced biochemical methods including as transcriptomics, proteomics, and metabolomics are being created to study the broad range of antibiotic degradation. However, these technologies are still in the early stages of development and need more research and development [19].

Novel Tactics for Enhanced Antibiotics Removal from Effluents Acclimation

Microbial physiology is influenced by the presence of harmful substances, which may lead to strain development. These strains are capable of acclimating to antibiotic-contaminated effluents and aiding in the removal of organic carbon. Wild microalgae, such as Chlorella pyrenoidosa and Chlorella vulgaris, have the ability to adapt and break down medicines like cefradine. This makes them very suitable for effectively removing antibiotics from liquid effluents and wastewater [5-12,25].

Co-Metabolism

The conversion of non-growth matter into living biodegradable organisms can generate biomass and serve as electron donors during co-metabolism. For example, microalgae such as Chlamydomonas

mexicana can be used for ciprofloxacin, while *Chlorella pyrenoidosa* can be used for sulfamethoxazole. This approach offers effective separation of antibiotics through catabolite repression, facilitated by the high production of extracellular polymeric substances (EPS) and enzymes. The assessment of the impact of microalgae is crucial for the effective removal of antibiotics from wastewater via bioremediation.

Microbial Consortium/Co-Cultivation

Several species that work together both inside and outside of organisms may promote the growth of microorganisms and provide significant advantages such as reduced complexity, effectiveness, accuracy, and efficient separation [1,31]. Various consortia, consisting of a combination of different types of algae and microorganisms, both eukaryotic and prokaryotic, have the potential to be very effective in using antibiotics for bioremediation. This is because they can coexist and work together in a mutually beneficial way, and they are able to withstand and adapt to changing environmental circumstances are compared in Table 5 below:

Table 5: Outline of Mix-Microalgae/Microalgae-Bacteria Consortium in Antibiotic Separation [5]

Entry	Microalgae-microalgae consortium	Microalgae-bacteria consortium
Relations	Cooperative, competitive amid varied microalgae.	Microalgae-bacteria consortia offer biodiversity through antagonistic interactions over microalgae-microalgae consortium in antibiotic separation.
Features Yet species choice plays key role in raising firm consortium for continuous separation treatments	Mixed-microalgae consortium offers enrich antibiotics removal; still ensue allele-chemicals badly co-cultivate microalgae growth.	Microalgae-bacteria consortia firm community for eco-function, more efficacy than mix-microalgae Yet species choice plays key role in raising firm consortium for continuous separation treatments
Budget	Microalgae degrade antibiotics to CO ₂ ; Aeration is must in mix-microalgae consortium for algae besides high efficiency is costly.	Microalgae endure bacteria growth by ingesting organic carbon, but bacteria eats electron/oxygen; Vit-B12 & auxin bacteria discharge aids microalgae Microalgae-bacteria consortium avoids external supplication of O ₂ , & cheaper
Efficacy	Mix-microalgae consortia apt bio-manufacturing over bioseparation	Microalgae-bacteria consortium apt for antibiotic separation due to bio-accumulative high separation

The combination of *Chlorella* sp. and *Scenedesmus* sp. microalgae consortia effectively breaks down ibuprofen with a shorter delay period. However, the consortium consisting of *Micractinium ressleri*, *Chlamydomonas Mexicana*, *Chlorella vulgaris*, *Scenedesmus obliquus*, and *Ourococcus multisporus* shows greater sensitivity to enrofloxacin, as indicated by a lower EC₅₀ value, compared to each individual microalgal species. Microalgae-bacteria consortia are the most suitable option for antibiotic separation due to their ability to do this with minimal energy requirements, cost-effectiveness, and the potential for recovering valuable resources. The antagonistic consortium of microalgae and bacteria consumes oxygen produced during photosynthesis and facilitates the conversion of organic carbon in effluents into CO₂ by bacterial mineralization, hence providing nourishment to the microalgae. In addition, bacteria play a role in providing nitrogen fixation, vitamin B12, and siderophores to support the development of microalgae. This leads to the transfer of organic carbon from bacteria to microalgae, resulting in a cooperative relationship between the two organisms. This collaboration, whether direct or indirect, enhances the overall effectiveness of the consortium in removing pollutants compared to a consortium consisting only of microalgae [19,20,49].

State-of-the-Art

Several treatment methods that demonstrate effective removal of antibiotics include low-energy anaerobic-aerobic reactors, built wetlands, and disinfection using nano-adsorbents, among other selected procedures. Efficient removal may be achieved with the use of advanced solutions, subject to the proper management

procedures being abandoned. However, more investigation is required to address some gaps [50]. Therefore, it is important to address the following factors in order to effectively control the spread of antibiotic resistance:

- implementing cutting-edge methodologies on a large scale and in the distant future to achieve a tangible objective.
- Creating a risk assessment analysis to accurately identify the presence and abundance of antibiotic resistant bacteria and antibiotic resistant genes, in order to assess potential health risks.
- The removal efficiency of any treatment system is influenced by deliberating operation and eco-friendly aspects. Antibiotic-contaminated wastewater poses a threat to the local ecosystem, as it promotes the growth of harmful organisms. The use of additional preventative techniques such as adsorption, coagulation, sedimentation, membrane filtration, and bio-treatments exacerbates the situation. Various sophisticated materials, such as polymeric micro-porous and non-crystalline adsorbents, are being developed to efficiently adsorb antibiotics from wastewater. These materials are intended to have ideal conditions for adsorption and may be used in large-scale applications.

Conclusion

The ingestion of antibiotics from domestic agricultural and animal waste/effluents leads to the contamination of water bodies, resulting in harmful health effects due to the development of antibiotic resistance. In order to prevent aquatic contamination, many efforts are required since there are multiple possibilities

for the introduction of antibiotic residues from human or animal sources into the aquatic environment. Antibiotic use in medical and veterinary settings seems to be prevalent at high elevations worldwide. Antibiotics and naturally occurring remnants/metabolites seem to be enduring in the surrounding environment. Moreover, antibiotics accumulate in the food and aquatic systems due to their resistance to human beings. The unclear presence of leftover antibiotics in water poses a significant and escalating concern over time. As a result, the widespread use of antibiotics worldwide leads to significant releases into aquatic environments, which seem to be related to the current discussions. The presence of inactive antibiotics in wastewater is particularly problematic when they are only partially removed from water under optimal circumstances, which also limits their usefulness in large-scale operations. This bibliographic review aims to provide an overview of bio-based separation approaches used in the remediation of antibiotic-contaminated wastewater. It also includes several applicable purification systems that have been shown to be very successful in removing antibiotics with greater efficiency. Emerging bio- and/or solvent-based processes are intentionally prioritized owing to their practical advantages, such as being environmentally friendly, clean, and replacing traditional dangerous methods.

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References

1. Tan SY, Tatsumura Y (2015) Alexander Fleming (1881-1955): Discoverer of penicillin. Singapore Med J 56: 366-367.
2. Browne AJ, Chipeta MG, Haines-Woodhouse Hay SI, Dolecek C (2021) Global antibiotic consumption & usage in humans, 2000-18: a spatial modelling study. Lancet Planet Health 5: 893-904.
3. European Centre for Disease Prevention and Control. ECDC; Stockholm: 2018. Antimicrobial consumption: annual epidemiological report for 2017.
4. Ibrahim M, Ahmad F, Ahmad A, Ahmed S (2020) Current trends of antimicrobials used in food animals & aquaculture. Antibiotics and Antimicrobial Resistance Genes in the Environment 39-69.
5. Hocquet D, Muller A, Bertrand X (2016) What happens in hospitals does not stay in hospitals: Antibiotic-resistant bacteria in hospital wastewater systems. The Journal of hospital infection 93: 395-402.
6. Grenni P, Ancona V, Barra Caracciolo A (2018) Ecological effects of antibiotics on natural ecosystems: A review. Microchem J 136: 25-39.
7. Levy SB, Bergman MM (2003) The Antibiotic Paradox: How the Misuse of Antibiotics Destroys Their Curative Powers, Book 2nd ed. Clinical Infectious Diseases 36: 238.
8. Davies J (2006) Where have all the antibiotics gone?. Can J Infect Dis Med Microbiol 17: 287-290.
9. Abraham EP, Chain E (1940) An enzyme from bacteria able to destroy penicillin. Nature 146: 837.
10. Barber M, Rozwadowska-Dowzenko M (1948) Infection by penicillin-resistant staphylococci. Lancet 2: 641-642.
11. Bush K, Courvalin P, Dantas G, Davies J, Eisenstein B, et al. (2011) Tackling antibiotic resistance. Nat Rev Microbiol 9: 894-896.
12. UK Veterinary Antibiotic Resistance and Sales Surveillance UK- VARSS-2013 reports, Editor, S. Peter Borriello Veterinary Medicines Directorate Woodham Lane New Haw Addlestone Surrey KT15 3N, UK-2013.
13. Davies SC, Fowler T, Watson J, Livermore DM, Walker D (2013) Annual Report of the Chief Medical Officer: Infection & the Rise of Antimicrobial resistance. Lancet 381: 1606-1609.
14. Kümmerer K (2009) Antibiotics in the aquatic environment-A review-Part II. Chemosphere 75: 435-441.
15. Baquero F, Martínez JL, Cantón R (2008) Antibiotics and antibiotic resistance in water environments. Curr Opin Biotechnol 19: 260-265.
16. Rosi Marshall EJ, Snow D, Bartelt Hunt SL, Paspalof A, Tank JL (2015) A review of ecological effects and environmental fate of illicit drugs in aquatic ecosystems. J Hazard Mater 282: 18-25.
17. Cheng XQ, Wang ZX, Zhang Y, Zhang Y, Ma J, et al. (2018) Bio-inspired loose nanofiltration membranes with optimized separation performance for antibiotics removals. Journal of Membrane Science 554: 385-394.
18. Yin F, Lin S, Zhou X, Dong H, Zhan Y (2020) Fate of antibiotics during membrane separation followed by physical-chemical treatment processes. Science of The Total Environment 143520.
19. Reygaert WC (2018) An overview of the antimicrobial resistance mechanisms of bacteria. AIMS Microbiol 4: 482-501.
20. Johanna Zambrano, Pedro Antonio García Encina, Félix Hernández, Ana M Botero Coy, Juan J Jiménez, et al. (2021) Removal of a mixture of veterinary medicinal products by adsorption onto a Scenedesmus almeriensis microalgae-bacteria consortium. Journal of Water Process Engineering 43: 102226.
21. Baker RW (2000) Membrane Technology & Research Inc. (MTR), Menlo Park, CA, USA. Academic Press 189-210.
22. Na Zhang, Xiangju Song, Heqing Jiang, Chuyang Y Tang (2021) Advanced thin-film nanocomposite membranes embedded with organic-based nanomaterials for water & organic solvent purification: Review. Separation & Purification Technology 269: 118719.
23. Wang B, Liang W, Guo Z, Liu W (2015) Biomimetic superlyophobic and superlyophilic materials applied for oil/water separation: A new strategy beyond nature. Chem Soc Rev 44: 336-361.
24. Delcour AH (2009) Outer membrane permeability and antibiotic resistance. Biochim Biophys Acta 1794: 808-816.
25. Li ZK, Wei Y, Gao X, Ding L, Lu Z, et al. (2020) Antibiotics separation with MXene membranes based on regularly stacked high-aspect-ratio nanosheets. Angewandte Chemie International Edition 59: 9751-9756.
26. Ma X, Chen P, Zhou M, Zhong Z, Zhang F, et al. (2017) Tight Ultrafiltration Ceramic Membrane for Separation of Dyes and Mixed Salts (both NaCl/Na₂SO₄) in Textile Wastewater Treatment. Industrial & Engineering Chemistry Research 56: 7070-7079.
27. Pinnau I, Freeman BD (1999) Membrane Formation and Modification. 744. <https://pubs.acs.org/doi/10.1021/bk-2000-0744>.
28. Choi KJ, Son HJ, Kim SH (2007) Ionic Treatment for Removal of Sulfonamide and Tetracycline Classes of Antibiotic. Science of total environment 387: 247-256.
29. Dongre RS, Pathe PP (2004) Treatment of Colored Wastewater

- from Textile Pulp & Paper and Chemical Industries by Chemical Coagulants. 2: 848.
30. Rajendra S Dongre (2018) Chitosan-Derived Synthetic Ion Exchangers: Characteristics & Applications. 1: 21-42.
 31. Rajendra S Dongre (2017) Marine Polysaccharides in Medicine. 181-206.
 32. Grella A, Kuc J, Bajda T (2021) A Review on the Application of Zeolites & Mesoporous Silica Materials in the Removal of Non-Steroidal Anti-Inflammatory Drugs and Antibiotics from Water. *Materials (Basel)* 14: 4994.
 33. Alnajrani MN, Alsager OA (2020) Removal of Antibiotics from Water by Polymer of Intrinsic Microporosity: Isotherms, Kinetics, Thermodynamics, and Adsorption Mechanism. *Scientific Reports* 10: 794.
 34. Palacio Daniel A, Leiton Lorena M, Urbano Bruno F, Rivas Bernabé L (2020) Tetracycline removal by polyelectrolyte copolymers in conjunction with ultrafiltration membranes through liquid-phase polymer-based retention. *Environmental Research* 182: 109014.
 35. Palacio Daniel A, Becerra Yerko, Urbano Bruno F, Bernabé L Rivas (2020) Antibiotics removal using a chitosan-based polyelectrolyte in conjunction with ultrafiltration membranes. *Chemosphere* 258: 127416.
 36. Cheryan M (1998) Ultrafiltration and Microfiltration Handbook. <https://search.worldcat.org/title/Ultrafiltration-and-microfiltration-handbook/oclc/833247780>.
 37. Geckeler KE, Bayer E, Spivakov BY, Shkinev VM, Vorob'eva GA (1986) Liquid-phase polymer-based retention, a new method for separation and preconcentration of elements. *Analytica Chimica Acta* 189: 285-292.
 38. De Souza, Dalva Inês (2018) Nanofiltration for the removal of norfloxacin from pharmaceutical effluent. *Journal of environmental chemical engineering* 6: 6147-6153.
 39. Cheng X, Liao J, Xue Y, Lin Q, Yang Z, et al. (2022) Ultrahigh-flux and self-cleaning composite membrane based on BiOCl-PPy modified MXene nanosheets for contaminants removal from wastewater. *Journal of Membrane Science* 644: 120188.
 40. Cheng Xi Quan, Cong Zhang, Zhen Xing Wang, Lu Shao (2016) Tailoring nanofiltration membrane performance for highly-efficient antibiotics removal by mussel-inspired modification. *Journal of Membrane Science* 499: 326-334.
 41. Zhang Dawei, Kejing Zhang, Xiaolan Hu, Yingwen Xue, Lu Zhang, et al. (2021) Ball-milled biochar incorporated polydopamine thin-film composite (PDA/TFC) membrane for high-flux separation of tetracyclic antibiotics from wastewater. *Separation and Purification Technology* 272: 118957.
 42. Xueqian Yan, Jin Qian, Xiangjun Pei, Lihong Zhou, Rui Ma, et al. (2021) Enhanced photodegradation of doxycycline (DOX) in the sustainable NiFe₂O₄/MWCNTs/BiOI system under UV light irradiation. *Environmental Research* 199: 111264.
 43. Li Ye, Qi Saren, Tian Miao, Widjajanti Wentalia, Wang Rong (2019) Fabrication of aquaporin-based biomimetic membrane for seawater desalination. *Desalination* 467: 103-112.
 44. Xue J, Wu T, Dai Y, Xia Y (2019) Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications. *Chem Rev* 119: 5298-5415.
 45. Ayankojo AG, Reut J, Nguyen VBC, Boroznjak R, Syritski V (2022) Advances in Detection of Antibiotic Pollutants in Aqueous Media Using Molecular Imprinting Technique-A Review. *Biosensors* 12: 441.
 46. Knappe D, Rossner A, Snyder S, Strickland C (2007) Alternative Adsorbents for the Removal of Polar Organic Contaminants. *Awwa Research Foundation*. https://www.researchgate.net/publication/299656916_Alternative_Adsorbents_for_the_Removal_of_Polar_Organic_Contaminants.
 47. Wang Tianyue, Pan Xun, Ben Weiwei, Wang Jianbing, Hou Pin, et al. (2016) Adsorptive removal of antibiotics from water using magnetic ion exchange resin. *Journal of Environmental Sciences* 25: 111-117.
 48. Chao Yanhong, Zhu Wenshuai, Ye Zhihong, Wu Peiwen, Wei Nannan, et al. (2015) Preparation of metal ions impregnated polystyrene resins for adsorption of antibiotics contaminants in aquatic environment. *Journal of Applied Polymer Science* 132.
 49. Alison M Franklina, Clinton Williams, Danielle M Andrews, John E Watson (2022) Sorption and desorption behavior of four antibiotics at concentrations simulating wastewater reuse in agricultural and forested soils. *Chemosphere* 289: 133038.
 50. Plevaya V, Geiger V, Bondarenko G, Shishatskiy S, Khotimskiy V (2019) Chemical Modification of Poly (1-Trimethylsilyl-1-Propyne) for the Creation of Highly Efficient CO₂-Selective Membrane Materials. *Materials (Basel)* 12: 2763.

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