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REVIEW

Biological treatment solutions using bioreactors for environmental contaminants from industrial waste water

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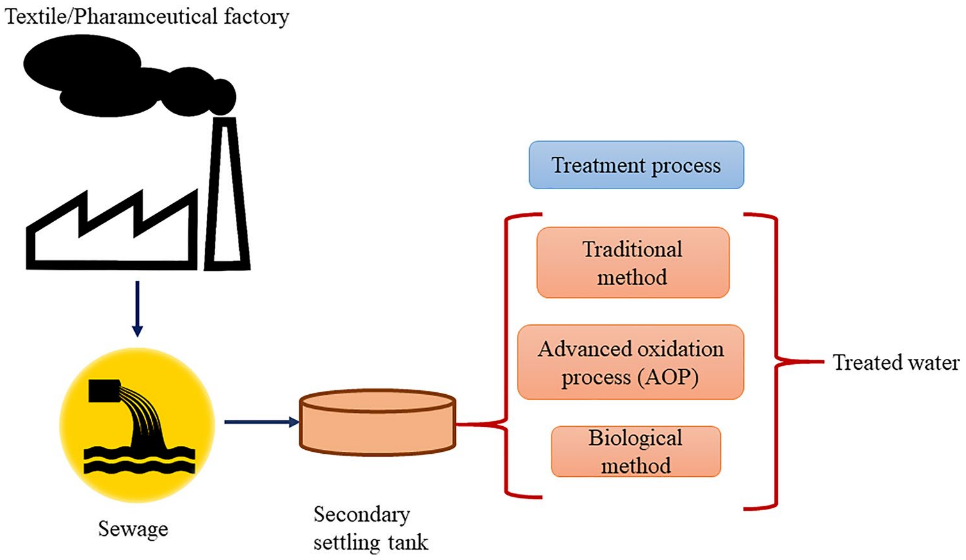
Abstract

Human needs have led to the development of various products which are produced in the industries. These industries in turn have become a source of various environmental concerns. As industries release regulated and unregulated contaminants into the water bodies, it has become a serious concern for all living organisms. Various emerging contaminates from industries like pesticides, pharmaceuticals drugs like hormones, antibiotics, dyes, etc., along with byproducts and new complexes contaminate the water bodies. Numerous traditional approaches have been utilized for the treatment of these pollutants; however, these technologies are not efficient in most cases as the contaminants are mixed with complex structures or as new substances. Advanced technologies such as bioreactor techniques, advanced oxidation processes, and so on have been used for the treatment of industrial wastewater and have served as an alternative way for wastewater treatment. Overall, biological treatment techniques based on bioreactors provide a long-term and ecologically useful solution to industrial wastewater contamination. They play an important role in saving water resources and encouraging a greener sustainable future for mankind. The current review outlines the industrial effluents that are released into water bodies, contaminating them, as well as the numerous traditional and novel treatment procedures used for industrial wastewater treatment.

Graphical abstract



Keywords Advanced treatment · Bioreactor · Oxidation process · Pollutants · Wastewater

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1 Introduction

Emerging contaminants are substances that are infrequently found in the environment but have the capability to affect both ecological and human health. These substances can be chemicals, bacteria, or other man-made or natural components [1]. These modern-day products were not previously considered to be “contaminants”. These include a wide range of medicinal substances such as anti-inflammatory, anti-diabetic, and antiepileptic pharmaceuticals, prescription medications, industrial chemicals, pesticides, personal care items, surfactants, hormones, and endocrine disruptors [2].

One of the most significant EC categories is the category of pharmaceutical and personal care products (PPCP). These are new global contaminants that have lately caught experts’ attention. These substances have been labelled as emerging pollutants due to our poor understanding of the environmental incidence, disposition, or fate of PPCP compounds and how they affect aquatic and terrestrial ecosystems. New contaminants are entering the environment more quickly due to anthropogenic activity and industrial outputs [3]. Public health is concerned about emerging poisons, yet despite substantial research being done on the issue globally, no workable solutions have been proposed. Environmental pollution, particularly in the aquatic environment, is alarming, according to recent scientific studies [4]. Pesticides, cosmetics, synthetic colours, and pharmaceuticals are some of the rising contaminants that are causing the most worry worldwide (hormones, antibiotics, and other forms of medications). Agricultural food is protected from pests by using pesticides, but their residues usually spread well beyond the areas they are intended to treat (including antibiotics and other drugs).

Heavy metals are naturally present in the planet’s layers. On a daily basis, urbanisation and industry are increasing the amount of heavy metal contamination in the environment. Heavy metals come from both natural and man-made sources that leak into the environment. Industrial effluents from a variety of industries, such as electroplating, electrolysis, electro osmosis, mining, waste disposal, water pipe corrosion, energy and fuel production, pesticide, iron and steel, leather, metal surface treating, metal surface finishing, aerospace and atomic energy installations, etc., are primarily to blame for higher metal concentrations in the environment [5]. However, these cannot be completely stopped as they as daily needs for better life styles and these industries need significant new methods for treatment before they can discharge the waste water. Many low-cost sorbents have been processed and investigated for their capacity to bind heavy metals, including bacteria, fungi, algae, and lignocellulosic agricultural wastes [6]. However, these methods have limitations based on the complexity of the contaminants and new improved methods have to be developed for better treatment process.

Biological treatment alternatives for environmental toxins in industrial wastewater utilizing bioreactors are extremely important for the environment. These revolutionary technologies use live microbes to breakdown or eliminate toxins in wastewater, providing a long-term solution to the negative environmental consequences of industrial activity [7]. Bioreactors offer a regulated environment in which microorganisms may grow and efficiently degrade or change pollutants into less dangerous compounds. These methods reduce the discharge of harmful chemicals, heavy metals, and organic materials that may contaminate water bodies and destroy ecosystems by exploiting the force of nature [8].

Using bioreactors in water treatment minimizes the need for chemical-based treatments, hence reducing the development of toxic byproducts. This strategy encourages environmentally beneficial practices and aids in the preservation of water quality, aquatic life protection, and biodiversity conservation. In addition, bioreactors assist the sustainable economy by allowing precious resources to be retrieved from effluent [9]. Anaerobic digestion is a sustainable replacement for conventional fertilizers and fossil fuels that may convert nutrients and organic materials into biofertilizers or biogas [10].

2 Environmental pollutants in industrial wastewater

Industrial effluents are a significant problem because they are not treated or because there is no treatment method. One of the main contributors to the pollution of surface and groundwater is these effluents.

2.1 Pesticides

Pesticides are lethal to non-target receptors all around the planet, including humans, and they reach them through the food chain. Because of their solid internal connections and molecular structure, the majority of pesticides are not biodegradable [11]. The problem of pesticide poisoning of natural streams has spread widely. The diversity of the physical structures of the pesticides, the composition of the influent, and the pH of water tainted with pesticides, which ranges from extremely alkaline to highly acidic (0.5), are only a few of the difficulties that must be overcome when treating water polluted with pesticides. Furthermore, according to the literature, between 0.1 and 107 mg/L of pesticides are found in diverse sources of water [12].

Human health issues brought on by pesticides include immune system suppression, hormone disruption, decreased IQ, aberrant reproductive processes, and cancer [13]. The most frequent pesticide entry points into surface and groundwater are associated with intensive agriculture and include runoff and erosion, leaching, drainage, and discharges from pesticide producers [14]. The quality of surface and groundwater is at risk due to the hazardous organics and insecticide residues that can be found in wastewater from the synthesis processes in the pesticide-producing sectors [15]. Because of their high concentrations and recalcitrance in wastewater, pesticide treatment from water sources is a critical research subject.

Coagulation/flocculation [16], activated carbon adsorption [17], and chemical oxidation [18] are a few physical and chemical procedures for pesticide removal. However, the use of those technologies generally entails a significant cost, necessitating the consideration of alternate possibilities.

2.2 Synthetic dyes

Synthetic dyes are widely employed in many modern technological domains, such as the manufacturing of paper, numerous branches of the textile and leather tanning industries, food technology, agricultural research [19]. There is a varied range of structural variety among synthetic dyes. The azo, anthraquinone, sulphur, indigo, triphenylmethyl (trityl), and phthalocyanine derivatives are the chemical classes of dyes that are used most commonly on an industrial basis. It must be underlined, nonetheless, that azo derivatives make up the vast majority of synthetic dyes utilized today in the sector [20].

In the twenty-first century, untreated dyeing effluents pose a severe hazard to the environment. Due to dyes' toxicity, carcinogenic, and/or mutagenic effects on living things, their release into the environment is hazardous [21]. The amounts of BOD (biochemical oxygen demand) and COD (chemical oxygen demand) might rise when synthetic colours are present in wastewater. Additionally, the chromophoric groups greatly absorb sunlight, which inhibits an organism's ability to photosynthesize [22]. Synthetic dyes have been shown to negatively affect the growth of the foetus as well as the oestrous cycle and reproductive system in rats as well as the biochemical indicators of important organs including the liver and kidney [23].

To reduce the environmental effect of synthetic dyes, a range of strategies for removing them from water and wastewater have been developed. The technologies include chemical precipitation, chemical oxidation, adsorption, decolorization by photocatalysis and/or oxidation processes [20, 21], microbiological or enzymatic degradation, and so on [24, 25].

2.3 Heavy metals

Transition metals, metalloids, lanthanides, and actinides with large atomic weights and densities greater than 5 g/ cm^3 are classified as heavy metals since they cannot be broken down. The earth's crust contains heavy metals, and both anthropogenic and natural sources contribute to their release into the environment [26]. As very stable pollutants that are partially non-degradable, heavy metals penetrate the ecosystem. They are deadly even at low concentrations and can enter the human body by processes like ingestion, absorption, and inhalation [27]. They are also present in soil, water, and the air. Copper (Cu), Chromium (Cr), Cobalt (Co), Manganese (Mn), Arsenic (As), Lead (Pb), Mercury (Hg), Zinc (Zn), Nickel (Ni), Molybdenum (Mo), Tin (Sn), Cadmium (Cd), Antimony (Sb), and Iron (Fe) are the principal elements that are classified as heavy metals [28].

Heavy metal pollution in the environment has developed into a significant hazard as a result of the increase in heavy metal input to the environment. Heavy metals cannot be removed like organic contaminants and persist in the ecosystem after accumulating at various points along the food chain [29]. Effluent samples were taken in 2010 by Oguzie and Okhagbuzo from a variety of sources that were discharged into the Ikpoba River in Benin City. The effluents and receiving water were examined using an atomic absorption spectrophotometric method. It was discovered that Cd, Cr, Cu, Ni, Pb, and Zn were present in the effluent. Findings demonstrated that higher metal concentrations in effluents surpassed the Nigerian Federal Ministry of Environment's recommended limits for release into surface waters. To find heavy metals, Ramola and Singh (2013) examined the pharmaceutical effluents of an industrial region in Dehradun (Uttarakhand), India. The atomic absorption spectrophotometer was used to analyze the metals in the study, which included Cd (0.16–0.56 mg/L), Cr (0.12–0.31 mg/L), Pb (0.158–0.26 mg/L), Ni (0.05–0.12 mg/L), Zn (1–1.3 mg/L), and Cu (0.08–0.38 mg/L). The World Health Organization's permitted limit for Cr, Pb, Cd, and Ni was found to be exceeded. Using an atomic absorption spectrophotometer, El-Sayed MH and Helal (2016) examined the industrial wastewater from a plastic factory in the Saudi Arabian province of Hafer Al Baten. The examined effluent showed greater levels of all metals measured, with Pb, Cd, As, and Cr identified at 12.56 mg/L, 23.90 mg/L, 24.12 mg/L, and 28.23 mg/L, each. Thus, from the above results it's evident that heavy metal contamination is reported worldwide. Heavy metals and trace elements are used as terminal electron acceptors by microbes to obtain the energy needed to detoxify metals via enzymatic and non-enzymatic processes [30].

2.4 Pharmaceutical drugs

Prescription drugs are compounds that, even in very small amounts, have a healing impact on the body [31]. The years 1945 to 1960 are recognized as the "golden era" of antibiotic discovery. Prior to focusing on natural compounds, early research was centered on the manufacture of small pharmaceuticals. With the discovery of generally safe medications made from environmental bacteria and fungi, the golden age of antibiotics officially began. These discoveries ushered in the "golden age" of antibiotic study (1945–1960). Antibiotics were widely used in medicine from 1970 to 1980, a period regarded as the "golden age of antibacterial medicinal chemistry" [32].

Antibiotics have been designated as emerging pollutants due to their extensive use, continued ingestion, and persistence in numerous environmental domains even at low levels. In India, fluoroquinolones, broad-spectrum penicillin, and cephalosporins are the top three treatment classes. Cephalosporins' bactericidal properties and wide anti-bacterial spectrum resulted in increased clinical use and economic production [33]. The original parent forms of antibiotic residues do not exist in the environment. They can be transformed into different metabolites by the action of bacteria as well as by physical or chemical mechanisms. Many drugs are utilized for both human and veterinary purposes, hence they will be found in the environment as multicomponent chemical mixtures [34]. There are no regulations governing antibiotic tolerance or environmental concentration limitations. Municipal wastewater often has lower concentrations than hospital effluents, which typically have higher amounts. Variable concentration ranges exist in various surface waters, groundwaters, and oceans. Many nations have varying laws. Concentration limits have not been established for any of the antibiotics that are found in every food item and every species that generate food. So, from an environmental standpoint, controlling veterinary drug residues is essential [34]. Each year, China adds approximately 8000 tons of antibiotics to water and feed to aid in the development of animals, yet there are currently no official regulations in place [35]. Antibiotics are not restricted by the current environmental water quality standards in Europe since they demand evidence of their widespread environmental degradation and risk [36].

2.5 Organic and inorganic chemicals

Pesticides poison non-target receptors throughout, including people, and they reach them through the food chain. Most pesticides are not biodegradable due to their strong molecular linkages and internal connections [19]. The problem of pesticide poisoning of natural streams has spread widely. Human health issues brought on by pesticides include immune system suppression, hormone disruption, decreased IQ, aberrant reproductive processes, and cancer [37]. Pesticides enter surface and groundwater via the most prevalent entry points, which are associated with intensive agriculture and include erosion, runoff discharge, and drainage from pesticide manufacturing plants [32]. The diversity of the physical structures of the pesticides, the composition of the influent, and the pH of water tainted with pesticides, which ranges from extremely alkaline to highly acidic (0.5), are only a few of the difficulties that must be overcome when treating water polluted with pesticides [38].

2.6 Petrochemical wastes

Petrochemical waste is a byproduct of the oil industry. Before being released into water bodies, wastewater must be properly treated because it contains a variety of organic and inorganic components. Oilfield production, crude oil refineries, olefins plants, energy facilities, refrigeration, and other sporadic effluent sources are just a few of the sources of petrochemical wastewater [39, 40]. During the extraction of crude oil from oil wells containing substantial volumes of synthetic surfactants and crude oil that have been emulsified but have a low COD and biodegradability, wastewater from the oil field is released [41]. It is produced during oil extraction and comprises complex, robust organic contaminants such as humus, polymer, phenols, radioactive compounds, benzenes, and various types of heavy mineral oil [38, 39].

Petrochemical effluents having harmful contaminants is stabilized and organics are removed with the use of various bacteria. Owing to their affordability and efficiency in removing pollutants, biological treatments are now receiving more attention as a result of strict environmental regulations and water recycling for reuse [42]. Biological treatment to remove pollutants still faces difficulties due to the complexity of petrochemical effluent, despite its enormous potential [43]. It is well known that the complex structures of polycyclic, aromatic, along with heterocyclic ringed compounds inhibit biological decomposition [44]. Recent research initiatives have, however, led to considerable reductions in the contaminants present in petrochemical effluent [45]. Since this wastewater from petrochemical companies includes a broad range of chemicals, the methodologies often used to treat it depend on and are customized according to the source of the wastewater, the specifications for discharge, and the potency of the treatment. Due to being directed to a biological function for organic treatment, pretreatment methods are normally used in the treatment of effluent in petroleum refineries. Primary treatments include enhancing wastewater biodegradability, removing free oil and gross solids, and removing dispersed oil and solids using flocculation, flotation, sedimentation, filtering, micro electrolysis, and other methods [19].

3 Hazardous effects of environmental pollutants

Industrial wastes seriously harm the ecosystem by contaminating the air, water, and soil. Depending on the enterprise, the quantity and quality of wastewater produced can range from biodegradable materials like paper, leather, and wool to non-biodegradable trash like heavy metals, pesticides, and plastic. Industrial effluent may be poisonous, flammable, reactive, or cancer-causing. Consequently, waste discharge into bodies of water can have disastrous consequences for the ecosystem and human health if not treated and managed properly. Numerous waterborne pathogens grow in wastewater and release toxins that impact human health and the planet's environment [46] (Table 1).

More than 3000 molecules have already been certified by the Food and Drug Administration (FDA) as certain food additives to thicken, colour, or preserve food. Due to the discovery of unforeseen adverse effects, many of these additives are prohibited. Food and additive adulteration can occasionally lead to potential health hazards like hyperkinesis, tumors, renal damage, skin rashes, migraine, asthma, sleep disruption, and gastrointestinal distress [62]. Depolarization of the mitochondrial membrane was yet another early impact of food coloring action in the cell types studied. The colorants may increase the amount of ROS in the cell lines examined, causing mitochondrial damage. The effect of colorant concentration on ROS production in UV-exposed mouse fibroblast cells was examined. Following UV irradiation, ROS production was significantly increased in cases of higher concentrations of the tested colorants However, without irradiance treatment, only Unicert Red K 7008-J produced significantly more ROS [63]. Painters face a greater risk of adverse health effects due to their exposure to highly Volatile organic compound concentrations (ethylbenzene and 1,2-dichloropropane). However, the harmful components in the coating environment have not been thoroughly recognized, which results in Short-term exposure to high levels of volatile organic compounds that can induce eye, nose, throat, and lung irritation, as well as liver, kidney, and central nervous system damage. Long-term exposure to even low concentrations can cause asthma, decreased respiratory function, cardiovascular illness, and severe malignancies [64].

Heavy metal content in the environment has far-reaching consequences for animals, plants, and microbiological organisms. Human exposure to several metals, for example, produces problems and symptoms such as hypophosphatemia, heart disease, liver damage, cancer, and neurological issues. Most morphological and mutational alterations identified in plants are caused by metal exposure. These include root shortening, leaf scorch, chlorosis, nutritional insufficiency, and increased insect attack sensitivity [49]. Treated Tannery Wastewater severely harms fish and other aquatic creatures. The genotoxicity and mutagenicity of Tannery Wastewater contaminated water create significant harmful consequences for fish and other aquatic species.

Chromium toxicity is mainly determined by chemical speciation; hence, the related health consequences are regulated by the chemical forms of exposure [65]. Inorganic lead compounds and elemental lead can enter the body via the digestive and respiratory systems. The abundance of lead in the environment influences its toxicity. Organic lead compounds can reach the brain through the skin and cause a neurotoxin. Arsenic can harm the skin, liver, kidneys, and lungs. Arsenic has been linked to cancer, metabolic syndrome, and other metabolic illnesses. Cadmium can impair glycolysis in the liver and muscles by inhibiting fructose kinase phosphate activity. It also boosts the activity of numerous other enzymes involved in amino acid breakdown metabolism, including amino acid oxidase, glutamate dehydrogenase, and glutamate dehydrogenase. Nickel stimulates the creation of ROS and boosts the activity of antioxidant enzymes via the Fenton reaction. Excess nickel can also cause the generation of free radicals and ROS by direct transfer of electrons, which inhibits the activity of enzymes in antioxidant defense mechanisms. Mercury is a primary cause of autoimmune illnesses, and antinuclear antibodies created by those exposed to inorganic mercury also cause Alzheimer's and Parkinson's disease. As a result, all forms of mercury are highly hazardous to the central nervous and digestive systems [47].

Recent research has shown that pharmaceutical residues from a variety of therapeutic classes, including antibiotics, analgesics, anticancer drugs, contraceptives, and antidepressants, clearly harm the environment. Pharmaceuticals, in contrast to the majority of other chemicals that are released into the environment, are meant to affect physiological processes. Particularly, pharmaceuticals are designed to have an impact on people and have a high potential to become bioactive to wildlife [32]. A single medicine can be present in levels that have just marginally noticeable effects. Low amounts of medication exposure over a long period are unlikely to have an immediate negative impact, but they may have subtle effects on reproductive function, especially in aquatic species. Cell death or apoptosis, cancer-causing DNA mutations, and disruption of biochemical signaling pathways all contribute to cellular proliferation. All waterways are contaminated with oestrogens and oestrogen-like chemicals, which are harmful and to have endocrine-disrupting effects. These pollutants may also have an impact on the development, reproduction, and growth of marine life [66].

All rivers are contaminated by estrogens and oestrogen-like compounds because of their toxicity and endocrine

Table 1 Harmful effects of pollutants on human beings

Pollutant class	Groups included	Harmful effect	The specific site of action	References
Dyes	Sufur Drugs	Urinary tract disorders, hematopoietic disorders, porphyria, and hypersensitivity reactions	–	[13]
	Azo dyes	Reduction in human intestinal microflora, skin microflora	Human liver azoreductase	
	Azure-B	Inhibition in cellular redox homeostasis	Glutathione reductase	[22]
	Disperse Red 1	Inhibition of DNA damage repair	Formation of DNA adducts	
	Sudan I dye	Neoplastic liver nodules	–	
	Basic Red 9	Allergic dermatitis, skin irritation, mutations, and cancer	–	
	Crystal Violet	Chemical cystitis, irritation of the skin and digestive tract, respiratory and renal failure	–	
Heavy metals	Lead	Inhibit mitochondrial oxidative phosphorylation	δ-aminolevulinic	[47]
	Arsenic	Inhibition of DNA methylation	α-ketoglutarate dehydrogenase	
	Cadmium	Inhibition of DNA damage repair	Glutathione reductase and superoxide dismutase	
	Nickel	Inhibition of antioxidant defense systems	Glutathione reductase	
	Mercury	Glycolysis and hexose-phosphate lysis pathway	Hexokinase and pyruvate kinase	
	Flouride	Dental and skeletal fluorosis, gastrointestinal disorders, infertility, kidney impairment	–	[48]
	Nitrate	Methemoglobinemia in infants, oral and gastrointestinal cancers	–	
Broad-spectrum biocides	Chlorophenols	Multiple inhibiting actions	Phophosphorylation, protein synthesis, lipid biosynthesis	[2, 49]
	Tributyl tins, trialkyl tins	Respiratory system inhibition	Mitochondrial ATPase	
Organic and inorganic chemicals- Organophosphates	Carbamates	Nervous system inhibition	Acetylcholinesterase	
Organochlorines	Cyclodienes	Nervous system inhibition	GABA receptor	
Herbicides	Ureas, cyclic ureas, triazines, acylanilides, phenylcarbamates, triazinones	Photosynthesis inhibition	Hill reaction of electron transport	
	Bipyridiniums	Photosynthesis inhibition (light reaction)	Reducing the side of photosystem I	
	Pyridazinones	Biosynthesis inhibition	Carotene accumulation	
	Chloroacetamide	Biosynthesis inhibition	Fatty acid synthesis	
	Dinitroanilines, phosphoric amides, chlorthaldimethyl, propy-zamide, colchicine, terbutol	Biosynthesis inhibition	Microtubule formation	
Organophosphates	Piperonyl butoxide	Esterase inhibitor	–	[50]
	Diazinon	Genotoxicity	–	
	benomyl	Genotoxicity	–	
Pyrethroids	Cypermethrin	Skin rashes, respiratory problems	–	[51]
	Deltamethrin	Allergic reactions	–	[52]
Triazines	Atrazine	Hormone issues, reproductive complications, and developmental anomalies	–	[53]

Table 1 (continued)

Pollutant class	Groups included	Harmful effect	The specific site of action	References
Chloroacetanilides	Acetochlor	Liver and kidney damage	–	[54]
Organochlorine	Lindane	Reproductive complications weakens the immune systems	–	[55]
	Endosulfan		–	[56]
Glyphosate	Glyphosate	Cancer, endocrine disturbance	–	[57]
Imidazolinones	Imazapyr	Enter aquatic life due to improper disposal	–	[58]
	Imazethapyr		–	[59]
Phenoxy acid herbicides	2,4-d-MCPA	Hormone disturbance and adverse reproductive effects	–	[60]
	Mecoprop		–	[61]

disruptor effects. Superbugs, or germs that are resistant to several antibiotics, are currently one of the most difficult issues facing contemporary medicine. Pathogens and opportunistic pathogens are two different classifications that are involved in superbugs. The natural commensal flora of the same genus and species that live on humans makes up the first class of diseases. Over time, they developed virulent traits and genes for antibiotic resistance. Examples of this type of bacteria include drug-resistant *Escherichia coli*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant *enterococci* (VRE). The second category of opportunistic infections is so named because they commonly have environmental origins and typically only infect patients who are predisposed to infection. They naturally withstand a variety of antibiotics.

4 Challenges with wastewater treatment

The biological treatment process at a traditional wastewater treatment facility may produce a selective increase in the population of antibiotic-resistant bacteria as well as an increase in the prevalence of multidrug-resistant bacteria [67]. The "One Health" approach to understanding the sharing and management of etiological agents with their influence on the ecosystem has emerged in the current landscape of communicable illnesses. This situation raises serious concerns about the relevance of zoonotic illnesses [68]. In this setting, the gut serves as a bioreactor for the breeding of ARBs, which are then continuously discharged in various niches. These ARBs use quorum sensing, horizontal gene transfer, and vectors to spread resistance genes among the local flora. The well-known zoonotic diseases include hemorrhagic colitis caused by Escherichia coli, brucellosis caused by Brucella abortus, and anthrax caused by Bacillus anthracis. Similar to antibiotics, most antibiotics are not fully metabolized before being released into the environment. These unmetabolized forms penetrate the food chain and have an impact on different ecological niches through bioaccumulation. In the environment, antibiotics can remain active for 1 to 3466 days. The most prevalent zoonotic infections to be detected in the environment are ARBs. The host immune system, as well as antimicrobial medications, exert substantial selection pressure on the bacteria because of their shorter growth times [68]. Phenotypic antibiotic resistance (PAR) is the non-heritable and transitory capacity of bacteria to resist antibiotics. It is distinguished by drug indifference, persistence, biofilm formation, decreased antibiotic permeability, or increased efflux [69].

Numerous studies have demonstrated that some antimicrobial chemicals, particularly polar ones, are not eliminated by the techniques used to clean wastewater. It is crucial to ascertain how they break down and to assess how they will fare in the environment. The breakdown of antibiotics has received less attention in studies than the detection of parent chemicals (Table 2). One of the causes could be the absence of standards suitable for commercial use [70]. Ordinarily, environmental concentrations to which organisms are exposed are lower (for instance, 100 g kg1 in soil). This is the main obstacle to creating the recommendations for screening these pollutants [71]. These substances can have negative health effects at lower doses. A serious issue is the absence of legal framework for disposal and return to the agency in question. Unused and expired medications should be disposed of properly to reduce the risk of contamination in marine systems [72]. The removal of pesticides using traditional wastewater treatment methods is ineffective. Over the last few years, substantial advancements have been made in their application in wastewater treatment. The majority of treatment techniques are biologically based, followed by some physical or chemical methods (Table 2).

Even though biofilm bioreactors generate desirable products with high productivity, operating them has some constraints. Excessive sloughing of Extracellular polymeric substances (EPS) complicates downstream processing and product purification. Improper thick biofilm layer formation might hinder processes if mixing is not optimized, reducing reactor efficiency. The variability in physiological state and limitations inside the mature biofilm leads to a concentration

Table 2 Common pollutants degraded by using various wastewater treatment methods

Pollutants	Class	Method	References
Ampicillin	Antibiotics	Electroactive *Shewanella putrefaciens*	[76]
Cefotaxime		Electrocatalytic oxidation	[77]
Erythromycin		Radiation coupled with peroxymonosulfate oxidation	[78]
Ciprofloxacin		Ozonation with calcium peroxide	[79]
Disperse Red 1	Dyes	Flocculation-sludge based flocculants	[80]
Sudan I dye		Fenton oxidation	[81]
Basic Red 9		Biosorption	[82]
Crystal Violet		Thermally activated peroxide oxidation	[83]
Lead	Heavy metals	electrocoagulation	[84]
Arsenic		Adsorption- biochar-based sorbents	[85]
Cadmium		Iron–electrocoagulation	[86]
Nickel		Electrocoagulation with zinc electrodes	[87]
Copper		Membrane Bioreactor	[88]
Zinc		Biofilm-based bioreactor	[89]
Mercury		Ion-exchange membrane bioreactor	[90]
Chromium		Osmotic membrane bioreactor	[91]
Aluminium		Membrane bioreactor-Coagulation	[92]
Iron		Membrane Bioreactor	[88]
Chloroacetamide	Herbicide	Ozonation	[93]
Dinitroaniline		membrane-aerated biofilm reactor	[94]
Diazinon	Pesticide	Sequencing batch moving-bed biofilm reactor	[95]
Atrazine		Denitrifying bioreactor	[96]
Atrazine—Metolachlor		Multichannel biofilm reactor	[97]
Lindane		Slurry bioreactors	[98]
Endosulfan		Fermenter bioreactor system	[99]
Chlorpyrifos		Membrane bioreactor	[100]
Carbaryl		Horizontal tubular bioreactor	[101]
Phenols	Organic chemicals	Membrane bioreactor	[102]
Polycyclic aromatic hydrocarbons		Membrane bioreactor	[103]
Volatile organic compounds		Trickle-bed bioreactor	[104]
Polyaromantic compounds (e.g., bisphenol A, phthalates)		Activated sludge and membrane bioreactor system	[105]
Nonylphenol ethoxylates		Membrane bioreactor	[106]
Nitrate and nitrite	Inorganic chemicals	Single-Stage Bioreactor	[107]
Ammonia		Anaerobic membrane bioreactor	[108]
Phosphates		Oxidation ditch-membrane bioreactor	[109]
Fluoride		PVDF mixed matrix membranes	[110]
Cyanides		Bioreactors	[111]

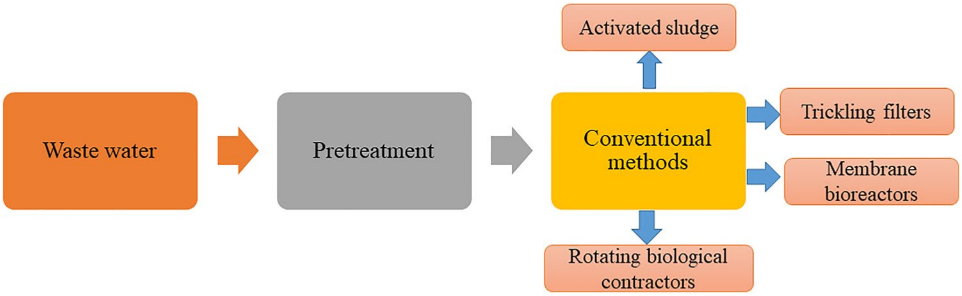


Fig. 1 Conventional methods of treatment of waste water

gradient of substrate take-up and waste compounds within the biofilm [73] (Fig. 1).

5 Conventional biological treatment technologies

Conventional treatment technologies are frequently nature-based, less mechanical, and suitable for any geographical environment. Several significant biological traditional treatment systems have emerged throughout time and are now widely employed for removing contaminants in wastewater from diverse sources [74].

5.1 Activated sludge

Conventional activated sludge treatments typically remove or reduce pathogen concentrations and bulk organic loads. However, they generally do not intend to eliminate trace organic substances. The ability to eradicate micropollutants in the treatment process is determined by several elements, including the physicochemical qualities of the specific component and the technology and process conditions [75].

Due to the harmful cation impact on biomass in wastewater with high metal concentrations, biological wastewater treatment is inefficient. Metal toxicity is negatively related to microbial biomass growth and treatment efficacy. Copper, zinc, and nickel were examined for their harmful effects in an activated sludge system, and it was observed that nitrifiers were more susceptible to these metals than heterotrophic bacteria. The metal accumulation potential of biomass was most significant in the copper scenario, and the presence of heavy metals was found to diminish microbial diversity richness in activated sludge systems. The impact of copper and zinc on biomass, both independently and together, revealed that copper was more harmful than zinc [112].

The most popular biological wastewater treatment technique for pollutants containing carbon and nitrogen is activated sludge. The eutrophication of aquatic organisms is facilitated by conventional sewage treatment, which results in considerable ammonia and nitrogen levels in landfill leachate. Despite applying biochemical treatments to lower ammoniacal nitrogen concentrations to acceptable levels, nitrite concentrations in leachate can remain high. Nitrogen removal is often accomplished by alternately switching between hypoxic and anaerobic environments or by establishing distinct zones with acceptable conditions for nitrification and denitrification, respectively. High rates of sequential denitrification and nitrification may also be obtained in activated sludge and biofilm systems under operational settings that include both hypoxic and anaerobic microenvironments [113]. Activated sludge technologies may eliminate it by converting biodegradable organic material into carbon dioxide and water. Sludge activated anaerobically or aerobically can be used in the process. The benefits of an anaerobic process include minimal energy usage and the ability to generate energy [114]. Salt concentration significantly impacts the structure and microorganisms of activated sludge in the biological treatment of saline wastewater [115]. *Proteobacteria*, *Bacteroidetes*, *Acidobacteria*, *Firmicutes*, and *Nitrospirae* were the most prominent phyla in the samples, according to the community structure study. The dominating phylum was comparable in each sample, although the percentage varied by operational unit [116].

5.2 Oxidation ponds

Waste stabilization ponds are excellent for tropical wastewater treatment. Waste stabilization ponds are an option for wastewater treatment in regions where the climate is favorable, and land is accessible. Because of their unique features, such as ease of operation, low energy input, and low maintenance, wastewater stabilization ponds are cost-effective alternatives to traditional wastewater treatment methods. Due to their claimed high pathogen removal efficiency, wastewater stabilization ponds have become a popular wastewater treatment alternative, particularly in tertiary lagoons [21].

Using Maturation Oxidation Ponds as a post-treatment system should be a viable alternative for home sewage treatment. Fundamental sewage issues were already adequately addressed in most industrialized countries. Technology and laws were fine-tuned for managing and eliminating micropollutants and other diseases and evaluating the consequences of pollutants in sensitive regions. The Maturation Oxidation Pond is a primary scientifically built pond with a depth of 2–6 feet, where BOD reduction of wastewater occurs by encouraging algal–bacterial development. Maturation Oxidation Ponds are shallow manufactured basins that use natural processes under partly regulated conditions to reduce organic matter and destroy harmful organisms in wastewater. Domestic and industrial wastewater contains roughly 99% liquid waste and less than 1% solid waste. Cleansers, black water, grey water, toilet paper, and detergents make up most of these wastes. Showers, bathtubs, toilets, kitchens, and sinks drain into sewers are examples of liquid waste. Domestic wastewater in many locations also comprises liquid waste from business establishments [117].

Algal processes that have been essential in solar-powered agitation will still be required. The separation of suspended algae in WSPs remains a considerable problem, nonetheless, to prevent effluent degradation. In the case of high algal rate ponds, more research is required to increase algal growth yield, choose suitable strains, and enhance harvesting techniques in order to algal biomass production [118].

5.3 Trickling filters

A trickling filter is an intriguing biological wastewater treatment method. The microbial population in the trickling filters lives on the rock/plastic package in this biological mechanism of attachment growth. It comprises microorganisms that biodegrade the substrates to eliminate them from the wastewater. Aerobic and facultative bacteria, fungi, algae, and protozoans comprise the microbial community. The aerobic zone of the biofilm is influenced by an organic substrate, oxygen supply, temperature, ventilation, wastewater pH, and filter media specifications such as size, depth, weight, surface area, and relative density, among others. As a result, media selection is an important part of improving the performance efficiency of a trickling filter [119]. Bacteriophages are naturally occurring bacteria predators that are particular and exact in their predation activities and highly selective to fecal contamination. Because of their predatory strength and the fact that they are not pathogenic or dangerous to humans, phages play a significant role in wastewater treatment operations. Predation is the primary pathogen elimination strategy in artificial wetlands [120].

The ability of biological trickling filters to remove BOD and a more straightforward model to describe it. At two temperature ranges of 5–15 °C and 25–35 °C, a trickling filter with four different media—rubber, polystyrene, plastic, and stone—was assessed. At temperature ranges of 5–15 and 25–35 °C, the average clearance of chemical oxygen consumption and BOD was greater than 80 and 90%, respectively. At low temperatures ranging from 5 to 15 °C, the geometric mean of coliform bacteria in trickling filters using polystyrene, plastic, rubber, and stone as the filter medium decreased by 4.3, 4.0, 5.8, and 5.4 log10, respectively. At a better temperature range of 25–35 °C, the fecal coliform count was reduced by 3.97, 5.34, 5.36, and 4.37 log10, respectively, from polystyrene, plastic, rubber, and stone [121]. Many different species have been employed to remediate odour effluents biologically. For H2S removal, microorganisms such as *Acidithiobacillus thiooxidans, Thiobacillus thioparus*, and *Thiobacillus denitrificans* have been utilized. All of these microbes are bacterium species. Fungi were utilized in a bio-trickling filter for hydrophobic organic compounds. However, there have been few investigations on inoculating fungus into trickling filters to remove hydrophilic contaminants such as H_2S [122].

5.4 Biofilters

Biofilters are classified according to their architecture. Biofilters can be either open-bed or closed-bed. Open-bed biofilter medium is subjected to weather variables such as rainfall, snowfall, and temperature changes. Closed-bed biofilters are mostly sealed, with only a small exhaust aperture to vent the cleaned air. The most common biofilter used to treat air from livestock facilities is an open-bed biofilter. Most open-bed biofilters can be covered with roofs to provide weather protection. For reducing odors and gaseous emissions from mechanically ventilated livestock facilities and manure storage facilities, biofilters are a tried-and-true solution. In order for microorganisms to break down hazardous gases into carbon dioxide, water, and salts and use the energy and nutrients for growth and reproduction, they need to be absorbed into a biofilm, which is how biofilters work. The filters employed for ozonated wastewater post-treatment demonstrated unique removal tendencies for micropollutants. The different filtering systems lowered the concentrations of chemicals previously reduced by ozonation to values in the region of the limit of quantification. Sulfamethoxazole, erythromycin, caffeine, and 2-hydroxy ibuprofen are among the chemicals removed, and their elimination may be attributed to biodegradation [123].

The microalgal biomass was produced in sufficient quantities during the processing of municipal wastewater treatment plant effluent, with the added benefit of decreasing phosphate and nitrogen loading by 70–80% within 4 days. Dried biomass was very effective in batch testing at removing copper (80%) and cadmium (100%) ions from metal waste, with the maximum removal rate achieved within 5 min of contact time [124]. Microalgal biofiltration allows water recirculation, lowering pumping costs and increasing resilience to external forces. Furthermore, harvesting aids such as periphyton, microalgal-bacterial consortiums, and immobilized microalgae can minimize operational expenses [125].

6 Recent advancements in wastewater treatment

6.1 Bioreactors for water treatment

A biologically active environment is carried by bioreactors, which are employed in industry to treat effluents. To improve productivity, procedure consistency, and minimize manufacturing costs, enterprises use biofilm reactors [126]. The biofilm system uses microbial consortia of biofilms to remediate heavy metals while immobilizing microbes in a self-synthesized matrix. As a result, bacteria are protected against stress, toxins, and protozoan predators. Industries employ biofilm-based decontamination to clean up polluted groundwater and soil [127]. A bioreactor is classifiable as batch, continuous, semi-continuous, or fed-batch according to how culture and media are fed into it throughout the fermentation process. Slurry reactors are used to ex-situ treat contaminated soil or water [128]. Contaminated material is processed through a specially designed containment device. Both continuously stirred tank reactors (CSTRs) and conventional batch-stirred tank reactors (STRs) have been around for a while and continue to be used in the chemical and bioprocessing industries [53, 92] (Fig. 2).

6.1.1 Airlift reactors (ALRs)

ALRs have a wide range of applications in chemical processes such as desulfurization, hydrogenation, Fisher-Tropsch synthesis (FTS), coal liquefaction, cell culture, and biological fermentation. Simple fabrication, evident mixing, and loaded transport with low energy input are examples of these features. It also uses fluidized bed techniques to purify wastewater, reduce volatile organic compounds (VOCs), generate ozone, and apply Fenton catalytic oxidation [129]. The raised portion of the down comer, the bottom clearance, and the top of the gas separator are the three functional components of a typical ALR. ALR is divided into two types based on where the gas sparger is located: up-flow ALR and down-flow ALR. The most common design, up-flow ALR, draws gas from the reactor's base. Because gas sparging is configured at the reactor's higher half, a liquid flow inside this down-flow ALR permits the liquid state to inflow from the reactor's top. Fluid circulation was predominantly driven by the dynamics of the liquid stream, resulting in sufficiently high energy demand for the down-flow ALR. The kinetic energy of rising bubbles and the fluctuation of hydrostatic pressure in a steady phase are the primary sources of motor power for the classic airlift reactor. The unequal gas distribution on the riser and down comer causes hydrostatic pressure divergence. The gas concentration in the riser is frequently higher than in the down comer. The difference in fluid density between the raised zone and the down comer increases the flow of liquid significantly. However, it has been demonstrated that the kinetic energy of the ascending bubbles is insufficient to propel the reactor's flow [67].

6.1.2 Fluidized bed reactor (FBR)

As in a tubular reactor, fluid travels through the vessel of the bioreactor. Chemical and variable change are governed by positional functions rather than temporal ones. For any given cross-section of the tube, the reaction time for each segment of material flowing is constant, and fluids in a perfect tubular reactor flow as if they were pistons or solid plugs. The fluidized bed method, also known as the suspended carrier biofilm method, which uses solid particle fluidization technology, may keep the entire system fluidized to promote solid particle interaction with liquid and to achieve the cleaning principle. The number of living cells in the biofilms and the liquid phase surrounding the support medium was used to assess microorganism development in FBR [3]. The number of viable cells inside the reactor grows as more organic loads are eliminated. An increase in active biomass most likely contributed to a greater degree of breakdown of the high organic load in the wastewater. The treatment capacity is more than 1020 times that of the traditional activated sludge technique [72].

6.1.3 Packed bed reactor (PBR)

This is a simple-to-build and maintain tubular reactor supplied with biomass or microbial pellets. Another metabolic activity is going on the microbial biomass's surface. Close

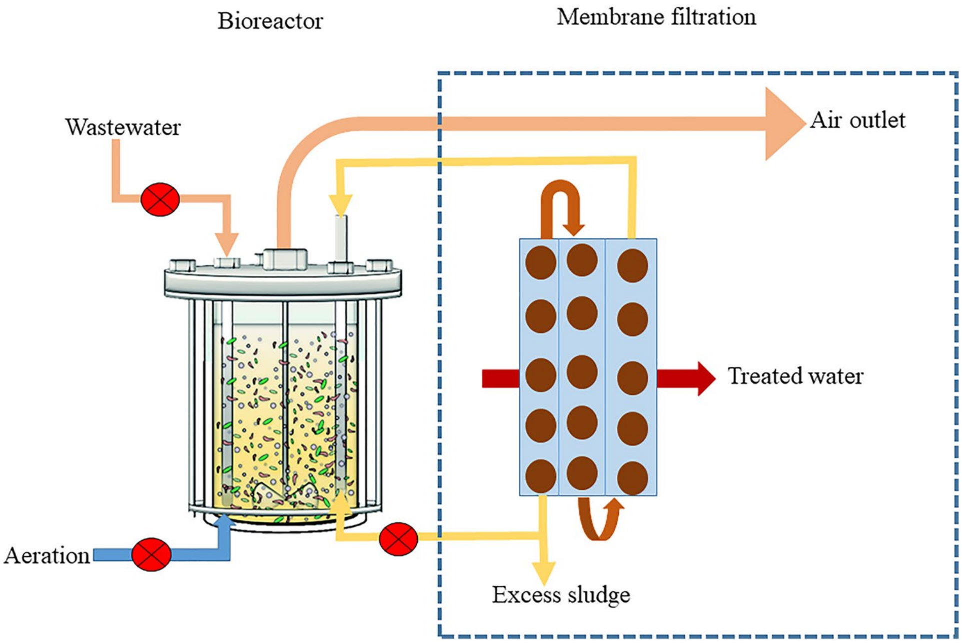


Fig. 2 General outline for the water treatment using bioreactor systems

to the bottom is a screen and a metal support grid to help support the microbial pellets [72].

6.1.4 Moving bed biofilm reactor (MBBR)

While loading, concentrations, and pH levels vary significantly, MBBRs are more capable and stable for harmful chemical and nutrient excretion [130]. This technique is effective at removing contaminants that are only marginally biodegradable as well as hazardous pollutants like phenolic volatile aromatic hydrocarbons, pesticides, and chlorinated solutions [131]. Its key advantage is its capacity to condense suspended and biofilm biomass into a single usable unit while allowing for a significantly higher biomass density in the system [78]. The MBBR presented an alternative to conventional activated sludge for the treatment of industrial wastewater because it exhibited all of the properties of a typical biofilm reactor and allowed for the integrated management of massive particle masses [132].

6.1.5 Membrane bioreactor

These semi-permeable membrane suspended growth bioreactors are employed in treatment processes along with membrane techniques like microfiltration and ultrafiltration [133]. A membrane can be used to concentrate or retain components depending on their relative size or electrical charge (permeate). There are numerous membrane configurations used, including pleated filter cartridges, hollow fiber, spiral wrapped, tubular, and frames [72].

6.1.6 Continuous stirred tank bioreactor (CSTR)

The CSTR operates in opposition to well-stirred batches and tubular plug flow reactors. A tank with a fixed volume and a stirring system are both present in CSTRs to mix the reactants. There are feed and exit pipelines for adding and removing reactant and product, respectively. Agitators are the stirring blades used in CSTRs to combine the reactants [134].

6.1.7 Sequencing batch reactors

The fill-and-draw concept of activated sludge technology is how sequencing biofilm batch reactors work. It operates primarily as a batch reactor and follows a set of procedures known as the sequencing batch reactors technique. In this system, the sequencing biofilm batch reactors are four equal column-type aerobic granular sludge reactors with a working volume of 6.16 l, an inner diameter of 0.14 m, a total height of 0.4 m, a water input, an outflow pipe, and a sludge discharge port. Air bubbles are released by a dispenser at the reactor's base. During the anaerobic or aerobic reaction phase, the mechanical stirrer generally stirs the liquids. Long-term operation reactors linked to mature anaerobic granular sludge have specialized capacity for COD, TP, and nitrogen removal [3].

6.1.8 Membrane distillation bioreactor

The first membrane distillation patent was acquired in 1963. Membrane distillation bioreactors use ultra- or micro-filtration membranes to remove suspended particles from the treated effluent. Unfortunately, the ultra-filtration or micro-filtration method falls short when it comes to organic solvents that have undergone biodegradation. Thus, the organic content of the permeate stream rises [135]. Membrane distillation bioreactors have a lower flow rate at atmospheric pressure in the range of 2–5 LMH but a higher permeate quality than traditional membrane bioreactors. Many investigations have combined membrane distillation with a photocatalysis approach for the breakdown of organic pollutants in aqueous solutions, with no obvious decline in the permeation flow of the membrane distillation [18].

6.1.9 Dynamic membrane bioreactor (DM)

The dynamic membrane outperforms the conventional membrane in terms of aerobic and anaerobic digestion, filtration capacities, simplicity of backwashing, in situ reformation, and financial feasibility. The importance of dynamic membranes in aerobic or anaerobic systems has grown as a result of the production of high-quality effluent with reduced absolute solids, improved operational stability, and treatment of industrial wastewater under difficult conditions [136]. The reactor operation was unstable and unsuccessful due to a variety of constraints, including a lengthy method that takes a lot of energy for pumping and membrane fouling from high-layer cake production. To overcome these challenges, the DM employs a cake layer membrane as its filtration mechanism. Pre-coated and self-forming membranes are split into two categories based on the substance that develops on the membrane in this reactor. The externally coated, porous material that makes up the pre-coated dynamic membrane is meant to resemble powdered activated carbon. On the other hand, self-forming dynamic membranes (SFDM) don't require a substance to function because they are constructed from substances found in the liquid that are comparable to the suspended particles that need to be filtered. The impregnated layer is crucial in minimizing the size of the filtration hole and reducing the fouling of the supporting and pre-coated membranes during the dynamic membrane growth process. The interaction between the impregnated layer and the supporting components influences the optimization of the dynamic membrane production process [137].

6.1.10 Aerated membrane bioreactor (AMBR)

These bioreactors are indeed a technique that combines an aerated bioreactor with a membrane. Because it contains microorganisms linked to nitrifying and denitrifying, a membrane bioreactor can achieve complete dissociation between solids and liquids and improve N removal. When it comes to the elimination of both organic compounds and contaminants, this is an advanced approach than membrane bioreactor and aerated bioreactor. Aerated membrane bioreactors have been shown to effectively achieve nitrification and denitrification without the need for an additional tank and to reduce the production of excess biological sludge as a result of having a shorter aeration period than membrane bioreactors [138].

6.1.11 Enhanced membrane bioreactor (EMBR)

An EMBR distinguishes itself from a classic membrane bioreactor in that it possesses an additional set of anode and cathode that can be employed to generate electricity for the system either internally or externally. Innumerable interactions are produced along by electricity provided into the EMBR, lowering membrane fouling and preserving the effectiveness of the treatment process [139]. The EMBR is made up of an oxygenated membrane bioreactor, an anaerobic tank, an oxygen-deficient tank, and a UV disinfection unit. MBR has already shown greater efficiency throughout a broad spectrum of industrial wastewater remediation incorporating micro-pollutants, in contrast with traditional treatment procedures [140]. The efficiency of an EMBR, which consists of two anoxic bioreactors, an aerobic membrane bioreactor, a UV disinfection unit, and an activated carbon column, is tested. The aerated membrane bioreactor was used to remove color, COD, total nitrogen, and total phosphorus over the course of 100 days [141]. The efficiency of the hollow fiber microfiltration membrane submerged in the bioreactor was investigated utilizing the rate of trans-membrane pressure escalation and the generation of treated water input [128].

6.1.12 Photobioreactor (PB)

In the 1950s, the initial version of the PB was put forward. At the Carnegie Institute in Washington, CO_2 sequestration was first used to utilize PBs in wastewater treatment in 1953. Under controlled and organized conditions, PBs provide the necessary conditions for the successful development of algae, including temperature, light, mixing, and nutrients [105, 142]. PBs that rely on microalgae are now available in a variety of shapes, sizes, and construction types. The tube, flat plate, and column formats are the three most widely used microalgae-based PB designs [106, 143]. Eventually, a newer PB prototype was produced, notably a soft-frame and hybrid PB, which increased its power and plasticity [108, 144]. To maximize the elimination of pollutants and boost biomass output, the conformations are continuously modified [145].

6.2 Bioreactors in metal removal

A bacterial consortium was formed from the surface water of Mexico's heavily copper-contaminated San Pedro River [146]. Ascending flow aerobic bioreactor packed with zeolite inoculated with bacterial consortium was used for continuous biosorption assay studies for 133 days. Continuous biosorption tests were performed with 50 mg Cu^{2+}/L without biomass recirculation, 20 mg Cu^{2+}/L without biomass recirculation, and 20 mg Cu^{2+}/L with biomass recirculation from pH 3 to 4. For the fourth and fifth experiments, the biomass was recirculated with pH between 4 and 5 and 20 mg Cu^{2+}/L. On the first day of the experiment, the biosorption capacity of the first and second assays was 96%. The third experiment achieved 97% biosorption for 6 days, and the operation was further improved by pH fluctuation. The biosorption capacity of aerobic biomass is 3.08 mmol/g.

A heavy-metal-resistant bacteria consortium was collected from a polluted river in Sao Paulo, Brazil, and used to construct a fixed-bed column for Cu removal [147]. A consortium biofilm was grown on granular activated carbon (GAC) and evaluated for the removal of copper in a fixed-bed bioreactor. The Biofilm-GAC column retained 45% of the copper mass contained in the influent, whereas the GAC-containing control column retained 17%. Native microbial populations can be immobilized in fixed-bed bioreactors to remediate heavy metal-contaminated water, according to the findings. Azizi et al. [148] reported that the modified packed bed biofilm reactor (PBBR) biological system was efficient to remove different loading concentrations of heavy metals. The removal efficiency occurs at an optimum hydraulic retention time (HRT) of two hours at the outlet. Selected heavy metals showed a removal trend in the series Cu > Zn > Ni > Cd. Composite heavy metals were recognized for the tolerable limit of 20 mg/L in PBBR treatment systems operating at optimum conditions over two hours and concentrations above this have a negative influence on treatment efficiency. Results revealed that high surface area media and huge microbial 32 (bacterial) communities of about 10000 mg/L are effective for removing industrial impurities from wastewater in PBBR biological systems.

Using Statistical Design of Experiment (DOE), Migahed et al. [149] created an immobilized microbial consortium using a combination of bacterial biomass and fungal spores in batch or continuous modes, Cr and Fe metal ions from industrial effluents were eliminated. Positive control was applied using baking yeast. To speed up a biosorbent separation from treated solutions in batch mode, the immobilized biomass was contained in a membrane made of cellulose that resembled a hanging tea bag. The continuous flow removal was carried out in a fixed-bed mini-bioreactor. Using the Response Surface Methodology, the procedure's pH (6.0) and flow rate (1 ml/min) were both tuned. Following optimization, it was discovered that standard solutions and industrial effluents were free of all Cr ions and more than half of Fe ions.

Pseudomonas aeruginosa was isolated from Mariout Lake in Alexandria, Egypt, and used to remove Cd^{2+}, Fe^{3+}, Cu^{2+}, Mn^{2+}, Co^{2+}, Zn^{2+}, Ni^{2+}, and Pb^{2+} [24]. They fabricated a fixed bed glass bioreactor packed with a solid support luffa bulb and observed the removal of metal ions in the wastewater samples. The bio removal in batch cultures was studied with the effect of various physicochemical parameters. The effectiveness of percentage metal removal raised on bacterial biomass 750 mg/L on pH 7.5. The fixed-bed column brought about an increased removal performance of 100% for Cu^{2+}, Zn^{2+}, and Cd^{2+} ions and decreased consuming time from 48 to 24 h controlled by optimum incubation conditions. Fe^{3+} and Pb^{2+} exhibited 62% and 47% removal each with a rise of 20% in contrast to the batch system.

6.3 Bioreactors in pesticide removal

An immobilized biomass reactor (IBR) colonized by activated sludge from a municipal wastewater treatment facility was utilized to clean phytopharmaceutical plastic containers [150]. Lin et al. [151] researched on the aerobic treatment of wastewater from organophosphate pesticide production facilities.

The aerobic biodegradability of pesticides has received a lot of research in recent years. Different bioreactors, including membrane (MBR) [152], fluidized bed (FBBR) [153], sequencing batch (SBR) [154], and sequencing batch membrane (SB-MBR) [155], have been used to treat phenoxyalkanoic acid herbicides such as mecoprop (MCPP), dichlorprop, 2,4-dichlorophenoxyacetic acid (2,4-D), and 2-methyl-4-chlorophenoxyacetic acid (MCPA). However, the anaerobic biodegradation of insecticides has received little research too far. Cyclodiene pesticides (aldrin, isodrin, dieldrin, and endrin) were dechlorinated by methanogenic granular sludge with removal efficiencies of more than 60% at starting concentrations in the range of 7–9 mg/L [156].

In 60 days, 66% of the chlorpyrifos (1 mg/L) was destroyed [157]. Picloram (82 mg/L) was found to have degraded by 85% in 30 days [158]. Atrazine removal of 50% was accomplished in up-flow anaerobic sludge blanket (UASB) reactors and wetland sediments at concentrations between 5 and 10 mg/L [124, 159]. In an extended granular sludge bed (EGSB) reactor operating at 16 mgPCP/L/d, pentachlorophenol (PCP)-containing low-strength wastewater has been treated anaerobically [160, 161].

6.4 Intimate coupling of photocatalysis and biodegradation

A unique treatment approach called intimate coupling of photocatalysis and biodegradation (ICPB), which combines the benefits of biological activity and photocatalytic processes, has shown a lot of promise as a low-cost, environmentally responsible, and long-lasting treatment technique. Biofilm, porous carriers, and photocatalytic materials make up the majority of the system. The fundamental idea behind ICPB is to use photocatalysis on the surface of porous carriers to convert bio-recalcitrant contaminants into biodegradable products. The biofilm inside the carriers mineralized the biodegradable materials at the same time. The microbe can continue to function even when exposed to UV light, the mechanical force of flowing water, or the attack of free radicals thanks to the protection provided by the carriers.

ICPB was demonstrated in a photocatalytic circulating-bed biofilm reactor by eliminating 2,4,5-trichlorophone (TCP) with a TiO2-coated cellulose carrier (PCBBR)[162]. TCP was destroyed and mineralized concurrently by photocatalysis into biodegradable compounds. In a continuous-flow PCBBR, Li et al. [3] employed ICPB to mineralize TCP, removing 96.2% of TCP and 90% of DOC [163].

Chlorophenol has been treated using a variety of techniques, such as physical absorption, biodegradation, and photocatalytic degradation [5]. Notably, it was recently demonstrated that ICPB systems had a good capability for degrading chlorophenol. Zhao et al. [43] created a new method for ICPB to break down 4-chlorophenol. In the ICPB system, the researchers employed polyurethane sponge carriers loaded with TiO_2/g-C_3N_4 and biofilms [67]. After 16 h of operation, the N_2 selectivity was 86.3% and the nitrate removal rate was 40.3%. They also suggested a potential mechanism for the ICPB's nitrate reduction.

6.5 Advanced oxidation process (AOPs)

It is a rapid technology to remove organic pollutants from wastewater. It reduces the toxicity, odor, colour and also improves the biodegradability of the pollutants by the microbes. The advanced oxidation process completely mineralizes pollutants to CO_2, water, and inorganic compounds. It was first proposed by Glaze and Kang in 1989 to treat potable water. During the oxidation process, hydroxyl radicals (OH) are generated to mineralize pollutants from the wastewater. Later, the Advanced Oxidation Process was expanded to include oxidative processes involving sulfate radicals [43]. AOPs primarily fall into two categories: homogeneous and heterogeneous [130]. Catalysts are frequently used in heterogeneous advanced oxidation processes to carry out compound degradation. When opposed to homogeneous processes, such heterogeneous catalysts have the advantage of easier product separation. Ozone-based [93, 127, 164] UV-based [80, 165] electrochemical (eAOP) [93, 128, 166] and catalytic (cAOP) [43, 129, 167, 168] are the different subcategories of AOPs (Fig. 3).

Although multiple novel AOPs for water treatment, such as those based on plasma, electron beams [114] ultrasound [130, 131] or microwaves [115, 132] are always being studied, new reports of these studies are constantly being made by different researchers. The great variety of studies, as well as the expanding number of proposed technologies and process combinations, offer a significant obstacle to a critical evaluation of AOPs about their operational costs, sustainability, and overall viability [39, 133, 134].

6.6 Electrocoagulation

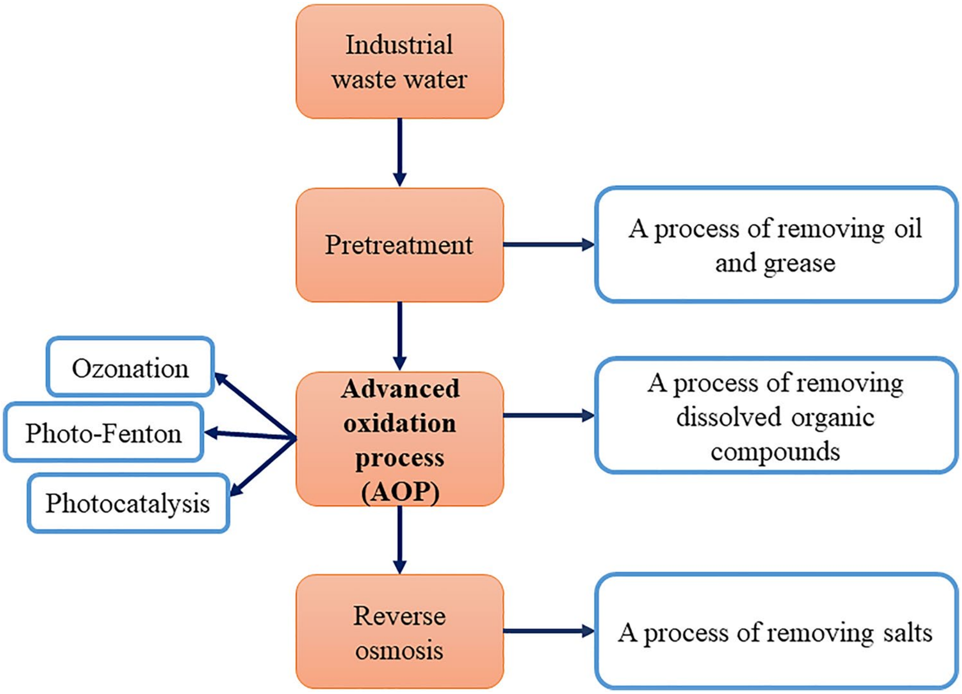
Electrocoagulation is an electrochemical technology for cleansing polluted water that involves corroding sacrificial anodes to release active coagulant precursors (often aluminum or iron cations into solution) [169, 170]. Electrolytic reactions at the cathode generate gas, often in the form of hydrogen bubbles [171]. Yet, electrocoagulation has never been considered a "mainstream" water treatment procedure. The lack of a systematic approach to electrocoagulation reactor design/operation, as well as the issue of electrode reliability, have impeded its adoption (especially the issue of electrode passivation over time). Until now, in light of recent technological improvements and increasing demand for small-scale, decentralized water treatment plants, electrocoagulation has been given a second look.

An appropriately sized and shaped container or reactor is used for electrocoagulation, inside of which two electrodes are positioned. The most basic configuration of an electrocoagulation reactor is an electrolytic cell with a single anode and a single cathode. When the cell is connected to an external power source, oxidation erodes the anode material electrochemically. The conducting metal plates are colloquially known as "sacrificial electrodes". Sacrificial anodes and cathodes can be made of the same material or a separate one, such as a Fe electrode (Fig. 4).

A stirrer is used to keep the liquid and slurries in the reactor consistent. Anodic reactions occur on the positive side of an electrolytic cell, while cathodic reactions occur on the negative side. Consumable metal plates, such as iron or aluminum, are generally used as sacrificial electrodes to continuously produce ions in the water. The charges of the particles are neutralized by the released ions, which initiates the coagulation process. Unwanted contaminants are removed by the released ions via chemical reaction, precipitation, or by causing colloidal components to coalesce, which can then be removed via flotation [172].

Water containing colloidal particles, oils, or other pollutants may undergo ionization, electrolysis, hydrolysis, and the generation of free radicals as it travels through the applied electric field, altering the physical and chemical properties of the water and contaminants. Pollutants are liberated from

Fig. 3 Water treatment using advanced oxidation process



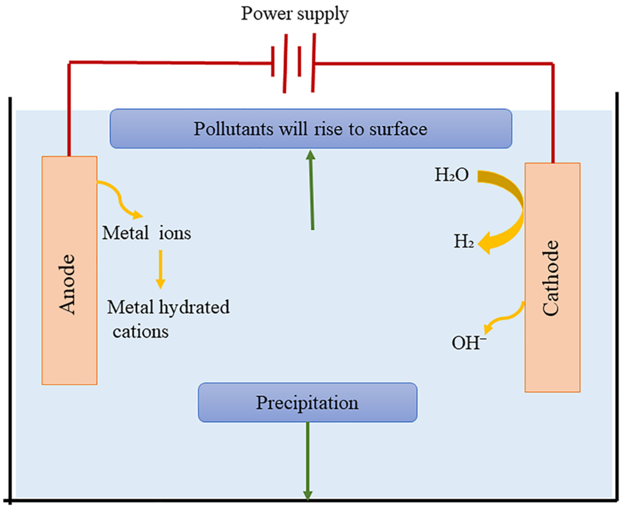


Fig. 4 Mechanism of wastewater treatment using electrocoagulation

the water and eliminated or made less soluble as a result of the reactive and excited condition [172].

7 Future aspects

Municipal sewage treatment plants (STPs) are one of the main possible entrance points for PPCPs into the environment [151]. In a given research area or between different geographic locations, significant variance in EC values was found in influent samples from several Waste Water Treatment Plants (WWTPs). This suggests that the environment's concentration of ECs is influenced by regional variations in usage patterns, climatic factors, population size and density, analytical techniques, and sampling techniques. The use of inappropriate sampling strategies could make it more difficult to detect ECs scientifically. Grab sampling was used as the basis for studies on the detection and fate of ECs in WWTPs. This method allows for the detection of EC concentration at a certain moment. The precise concentration and fate of ECs must be determined using composite sampling techniques [173].

The WWTP may facilitate the transmission of antibiotics, antibiotic resistance genes, and antibiotic-resistant bacteria by connecting several environmental compartments, such as city sewage and surface water [174]. To the best of our knowledge, no studies have looked at the antibiotic resistance pattern in both the WWTP and its receiving water at the same time. Researchers have looked at the impact of the wastewater treatment process on the prevalence of drug-resistant bacteria in WWTP or its receiving water body [139, 140, 175, 176]. The remediation of wastewater benefits greatly from the use of both natural and artificial microalgal consortia by microalgae or by microalgae plus bacteria [177]. Co-cultivated microbes can interact cooperatively, which improves the total uptake of nutrients and makes these systems more resilient to changes in environmental circumstances [178].

There is a dearth of comprehensive knowledge regarding the mechanisms of degradation involved and the impact of operational factors on pesticide removal. It is important to re-evaluate the removal performance of various procedures under varied operational circumstances using the appropriate sampling protocols.

8 Conclusion

Wastewaters from industries originating durine chemical synthesis may comprise lethal organic and inorganic residues which pose a threat to the quality of surface and groundwater. Therefore, pollutant treatment from water sources is a crucial research domain for the safety of aquatic systems. A sewage treatment plant is also the key point where surface water receives toxic residues. The removal of organic and inorganic residues using traditional wastewater treatment methods is ineffective. Substantial effective advancements have been implemented in wastewater treatment processes to eliminate toxic compounds. The majority of treatment techniques are biologically based, followed by some physical or chemical methods. For the emerging contaminants such as pharmaceutically active compounds existing technologies are to be analyzed for their effectiveness. Toxic organic and inorganic leftovers from chemical synthesis may be present in industrial wastewaters, endangering the quality of surface and groundwater. As a result, one of the most important study areas for the security of aquatic systems is the remediation of pollutants from water sources. The primary location where harmful substances are introduced into surface water is a sewage treatment plant. Using conventional wastewater treatment techniques to remove organic and inorganic contaminants is inefficient. Toxic substances have been removed from wastewater by the implementation of significant, successful breakthroughs. The bulk of therapy procedures are based on biological principles, then some use physical or chemical means. Existing technologies' efficacy about new pollutants such pharmaceutically active chemicals have to be evaluated.

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Declarations

Conflict of interest The authors hereby declare that they have no conflicts of interest and have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval Not applicable.

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