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Review Article

Progress on the Development of Techniques to Remove Contaminants from Wastewater: A Review

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Abstract

The continuous depletion of fresh drinking water resources throughout the world has increased the necessity for the development of new techniques for wastewater treatment and recycling process. Domestic, industrial and agricultural wastes are major sources of aquatic contamination all over the world. Before discharging wastewater into natural water bodies, it must be treated. Apart from primary, secondary and tertiary treatment, membrane separation techniques and electrochemical membrane bioreactors for wastewater treatment have all been studied in this review paper. The electrochemical membrane bioreactor (EMBR) system has a lot of potential for treatment of wastewater and energy recovery. These novel EMBR techniques give feasible solutions for renewable treatment of wastewater and resource resumption.

Keywords: Bioreactor, Electrochemical membrane technology, Membrane separation processes, Wastewater treatment

1 Introduction

Water is necessary for survival of humans and preservation of natural balance for the future of our planet. It is critical for human survival as well as the survival of almost all other living things on earth. According to the National Water Policy [1], every human being has the right to consume pure, clean water. Potable water is required for the survival of living creatures as well as the proper operation of all systems, the economy, and the institution. Water-based ecosystems provide a wide range of important services for the advancement of human civilization, including freshwater delivery. Due to the rising imbalance between freshwater supply and use, water resources are becoming increasingly scarce across the world, making access to clean and safe water one of our contemporary key issues in society. Two main categories of wastewater, which are recognized are domestic and industrial [2]. The major factors that are causing an increase in water demand are population growth and migration to drought-prone areas, rapid industrialization and rising water use per capita and climate change is causing weather patterns to shift in inhabited regions. On the contrary, presence of high number of biological pollutants which infiltrate urban and rural water bodies endangers water quality. Before wastewater can be discharged into natural water bodies it usually undergoes treatment as shown in Figure 1. Water treatment is becoming increasingly difficult due to the complexity of water contamination concerns. To tackle the present water treatment difficulties, new ideas and technologies are necessary. Electrochemical treatment of wastewater has gained popularity recently. Electrochemical treatment technology has received a lot of attention and has risen to the top of the priority list. By electrochemical reactions heavy metal, colloidal particles, and bacteria may be removed. This paper focuses on basics of waste water treatment like sampling of wastewater, impurities and their impact, necessity of treatment, characteristics of wastewater and then the traditional and advance wastewater treatment processes.

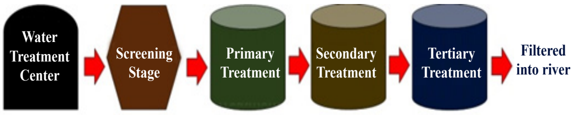


Figure 1: Schematic diagram of the wastewater treatment process.

2 Wastewater Sampling and Impurities Present

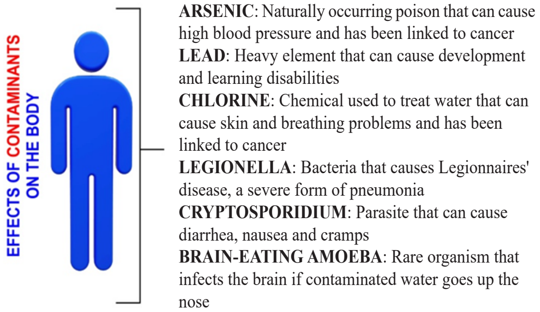
There are three types of sampling while collecting wastewater depending on the purposes or treatment method [3], such as a) grab sampling, b) composite sampling, and c) integrated sampling. Grab samples may also be referred to as spot samples or capture samples. A single attempt is made to sample at a predetermined time and place. Only when the source's composition is known to stay stable over an extended period of time, these samples should be taken. Groundwater samples, well-mixed surface waters, big lakes, rivers, estuaries, shorelines, and wastewater streams with a predictable composition over time like distillery used wash line. Grab samples can be obtained from appropriate sites when the source composition varies from location to location, such as upstream and downstream of a river. This helps in finding out the extent of variation and period of variation.

Composite sampling is employed when it is anticipated that the liquid matrix may vary throughout multiple sample locations, from top to bottom, or over time. With this sampling technique, a representative sampling for this kind of matrix is created by combining portions of several grab samples collected at regular intervals. If the flow is anticipated to remain consistent, volume-based sampling may be used. A flow-based composite can be used for sampling if the flow varies, as it can in a sewage line, and it entails taking a sample proportionate to the discharge. This, only composite samples for matrix that will not change under sampling, preservation, or storage circumstances are used. It is suggested to avoid composite sampling and analyze individual samples as quickly as possible, preferably in the field, for parameters such as pH, temperature, residual chlorine, carbon dioxide, alkalinity, sulfide, dissolved oxygen, oil & grease, and so on. Grab samples are combined from various sites at once during integrated sampling. The points could vary either horizontally or vertically. Examples include a lake, river, stream, reservoir, or lake with a range in composition over its width and depth. In businesses with various streams, integrated sampling of several streams is likewise possible, and combined treatment is advised to comprehend the significant influence on treatment.

Natural water contains many organic and inorganic pollutants, particulate materials, mist, and vapors that originated from industrial and household usage. Since this generated wastewater contains high amount of total organic components, it can neither be directly discarded to natural water body nor can be used directly for agricultural, residential, or industrial applications. Therefore, wastewater must be treated before further use or discard. Given the scarcity of resources for home use and the rising need for water for domestic consumption, it is the time to act on water purification and adequate treatment. The impurities that are present in wastewater can be classified into the following categories, such as suspended solids, biodegradable solids, nutrients, pathogens, volatile organic compounds, colloidal and dissolved solids [4]. Due to the presence of suspended solids, untreated wastewater that is released into the aquatic environment may cause the creation of sludge deposits and anaerobic conditions. Biodegradable organics, which are mostly constituted of proteins, carbohydrates, and lipids, are typically evaluated in terms of COD and BOD. If it is released in the surroundings untreated, its biological stabilization may deplete natural oxygen supplies and contribute to the development of septic diseases. Both phosphorus and nitrogen, as well as carbon, are necessary for growth. These nutrients, when released into the aquatic environment, can promote the growth of unwanted aquatic species. When released in large quantities on land, they have the potential to pollute groundwater. Pathogenic organisms that may be found in wastewater can spread infectious illnesses among human and aquatic animals [5] as classified in Table 1.

3 Effects of Contaminants

Illness-causing microorganisms, often called pathogens, transmit disease directly to humans as shown in Figure 2. Floods caused by excessive rains also cause water pollution because all of the pollutants combine with the rushing water and end up in places where people live [6]. A large portion of the human



ARSENIC: Naturally occurring poison that can cause high blood pressure and has been linked to cancer
LEAD: Heavy element that can cause development and learning disabilities
CHLORINE: Chemical used to treat water that can cause skin and breathing problems and has been linked to cancer
LEGIONELLA: Bacteria that causes Legionnaires' disease, a severe form of pneumonia
CRYPTOSPORIDIUM: Parasite that can cause diarrhea, nausea and cramps
BRAIN-EATING AMOEBA: Rare organism that infects the brain if contaminated water goes up the nose

Figure 2: Effects of water contaminants on human body.

Table 1: Types of contaminants and their effects

Type of Impurities	Contaminants	Effects
Metals Alloys	Mercury, nickel, lead	High levels can damage the brain, kidney
Inorganic materials	Any acidic material	Weakens bone
Commercial organic materials	Soaps, Detergents, fats, solvents	Virulent and bioaccumulation
Supplements	Ammonium, nitrogen and phosphorus	Reduction in oxygen level and increase in toxic level
Microbes	Worms egg, virus and bacteria	Itching on body
Biodegradable organic materials	Reduction of oxygen level in water bodies	Unwanted smell and death of aquatic animals

population is reliant on vegetables and food cultivated with polluted water. Consumption of polluted water poses health concerns such as diarrhea, lung sickness, neurological problem, cardiovascular disease, and cancer. The mortality rate in rural regions is generally greater than in urban areas; people in villages drink or cook with untreated water, and there is usually no water treatment facility in villages. Health of poor people is at more danger stage due to a lack of safe drinking water, hygiene, and sanitation. Consumption of polluted water has negative consequences for pregnant women, resulting in low birth weight due to fetal health issues.

Water of poor-quality leads to decreased agricultural productivity and contaminated food intake by people and marine life. Contaminants and heavy metals like chromium, zinc, iron, arsenic and others disrupt the food chain and can harm respiratory system of fish. Humans ingest fish; thus, fish has an indirect effect on the human body. The presence of heavy metals in polluted water causes nervous system disorders, liver cirrhosis, kidney disorders and loss of hairs.

Untreated drinking water is the leading cause of diarrhea. Diarrhea causes nausea, fever, headaches, and stomach pain. Antibiotics and proper cleanliness can help to avoid diarrhea. Cholera is a disease caused by contaminated water. This illness is caused by the bacteria Vibrio cholera. These bacteria generate toxins in the gastrointestinal system. The indication of this sickness includes renal failure, nausea, dysentery, vomiting, and dehydration caused by watery diarrhea. Antimicrobial therapy is required to eradicate this illness. Shigellosis is a disease caused by Shigella bacteria that damages the digestive tract of humans and intestinal linings. Salmonella bacteria can also be found in contaminated water, which causes salmonellosis, an infection of the intestines that causes swelling and can even result in death [7].

4 Necessity of Treating Wastewater

Contamination of water is a global issue apart from people, animals are suffering from the consequences of polluted water. Discharge by the human population, agricultural waste, and industrial waste are all major contributors to water contamination [8]. Polluted water, which contains germs that can cause sickness, has a negative impact on human health. As a result, it is advised that effective trash disposal management be implemented, with water being cleaned before being released into rivers [9]. To manage and monitor water contamination, a public awareness campaign should be established. Proteins, carbohydrates, lipids, oils, greases, and synthetic substances present in some detergents are all examples of organic stuff in wastewater. Organic matter enters lakes and rivers untreated, where it becomes a food source for the bacteria that live there. When these tiny creatures break down contaminants, they draw dissolved oxygen from the water. The greater the demand for oxygen in the water, the more contaminants are present. In lakes and rivers with high organic matter concentrations, this process spirals out of control. The oxygen levels in some watercourses are so low that fish, frogs, and turtles suffocate and die. Inorganic matters that include copper, lead, magnesium, nickel, potassium, sodium, or zinc are found in wastewater. These dangerous compounds are frequent results of commercial and industrial activities. Inorganic matters are difficult to decompose. They stay in lakes and rivers if they get into them through untreated wastewater. The water quality becomes a concern for humans and animals when their concentrations rise over time.

Nitrogen and phosphorus molecules are among the nutrients found in wastewater. Human feces and cleaning goods such as laundry detergent and dishwasher soap are common sources. Fertilizers commonly contain nitrogen and phosphorus, which is no surprise. They are quite effective when it comes to causing plants to grow and reproduce. However, allowing untreated, nutrient-rich wastewater to enter lakes and rivers poses a severe threat. Another issue that might arise from untreated wastewater is nitrogen. If our drinking water is contaminated with nitrate (a nitrogen component), it can impair ability of our blood to transport oxygen. This can cause what is known as "blue baby syndrome" in babies. The disorder can be lethal in extreme circumstances. If wastewater is not treated, the pathogens and chemical compounds it contains can harm birds, plants, and animals that live in or near water. It can harm people's health by contaminating crops and drinking water. The health of many ecosystems depends on the treatment of wastewater. Wastewater treatment that is efficient permits the maximum amount of water to be reused rather than wasted. Hence, treatment of wastewater for removal of organic, inorganic compounds and pathogens is necessary.

5 Characteristics of Water

In the wastewater treatment process, analyzing the physical and chemical properties of wastewater is crucial. Water treatment procedures based on the biological, chemical and physical as shown in Figure 3 properties of the water are heavily emphasized before starting research work. The physical characteristics of water are color, odor, temperature and turbidity [10]. The chemical characteristics of water are chemical oxygen demand (COD), total organic carbon (TOC), amount of nitrogen, phosphorus, and other metal contents present in water. The biological characteristics of water are biological oxygen demand (BOD), nitrogen oxygen demand (NOD), etc.

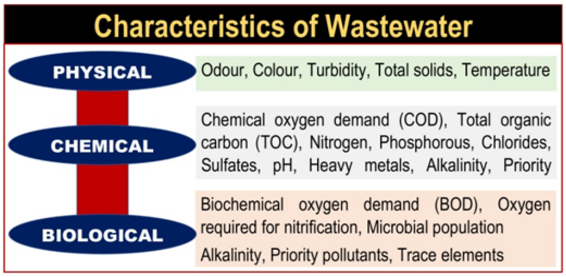


Figure 3: Major characteristics of wastewater in terms of physical, chemical and biological contents.

6 Reactors Used for Wastewater Treatment

There are several types of reactors used in treatment processes, such as batch reactor, complete mix reactor, plug flow reactor, complete mix reactor in series, packed bed reactor and fluidized bed reactor [11]. In batch reactor wastewater neither enters the reactor nor leaves reactor it is kept inside it and processes are carried out. In a complete mix reactor, the fluid particles enter the reactor and complete mixing happens instantly and uniformly across the reactor. In case of a plug flow reactor wastewater flows through the reactor with little or no longitudinal mixing, and it departs in the same order as it arrived. Complete mix reactors in series are those reactors in which the flow regime that lies between the ideal hydraulic flow patterns corresponding to complete mixing and plug flow reactors is modeled using a series of complete mix reactors. In packed bed reactors, the reactor is filled with packing materials like rock, slag, ceramic, and so on whereas a fluidized bed reactor is similar to a packed bed, except the packing material expands as it moves upward. After testing the wastewater parameters, selection of reactor is carried out based on the type of effluent that has to be treated, the treatment procedure is governed by the kind of reaction kinetics and environmental conditions.

7 Stages of Wastewater Treatment

Preliminary, primary, secondary and tertiary are four stages in which wastewater is treated as depicted in Figure 4. In preliminary treatment, large objects and non-degradable materials are removed, which helps in protection of pumps, mechanical equipment from damage, and prevents clogging of valves

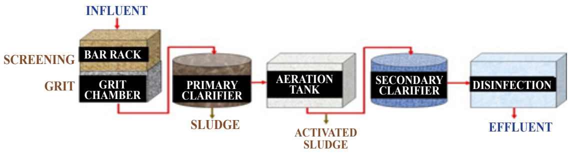


Figure 4: Various process stages for treatment of wastewater.

using screens and grit chamber [12]. Removal of suspended, easily settleable and floating material in the primary sedimentation tank is done in the primary stage. Secondary treatment stage involves removal suspended, colloidal and dissolved organic sand inorganics matter by biological treatment (rotating biological contactors, trickling filter, activated sludge process) and chemo-physical processes. Tertiary treatment involves polishing of treated effluent to meet the reuse/discharge requirements by absorption, advanced oxidation and disinfection.

8 Physical Unit Operations

Coagulation is a chemical technique in which a coagulant neutralizes the suspended particles' charge, resulting in the formation of a sticky material known as flocs. In this stage, coagulants such as iron or aluminium salts are employed. Flocs are formed when water reacts with any of the aforementioned coagulants [4]. One of the most significant aspects of the coagulation process is the production of flocs. Gradual blending increases the likelihood of encounter between the flocs generated throughout the operation. The smaller flocs cling together and create bigger flocs due to the sticky nature of flocs. The major goal of this procedure is to make flocs larger so that they may be readily removed in the next stage. Usually, the coagulants used are sodium aluminate, ferric sulfate, ferrous sulfate and ferric chloride. The movement of treated water from this stage is permitted slowly throughout the sedimentation phase. Detention at this step is long as compared to previous ones. Sludge is the flocs filtered at the sedimentation base foundation because of gravity. It is taken out of the sedimentation basin on a regular basis [2].

The biological solids in unprocessed water are fully removed by sedimentation, coagulation, and flocculation processes. A filtering technique, however, may be used to remove very tiny particles. Sand, charcoal, and gravel are used to construct the filter [4]. The sediment-laden water passes through the filter, which filters out the smaller fragments. Smaller flocs, manganese precipitates, suspended particles, bacteria, silt and iron are all eliminated during the filtration process. The specified contaminants are removed from the water as it flows over the filter bed. Another crucial step in the water treatment process is disinfection. This method guarantees that bacteria and some hazardous scums are removed from water. Fluoride is commonly added to water to prevent tooth decay. Many public health organizations throughout the globe have advocated for fluoridation in some form. It is a cost-effective and efficient method. The disease-causing organisms are destroyed or rendered inactive during the disinfection procedure. Chlorine is another extensively used disinfectant as it kills disease-causing organisms efficiently. In water, chlorine evaporates soon. Usually, the disinfection process takes place in the distribution stage of water treatment plant. Chlorine kills pathogens after half an hour of contact and 0.2–0.5 milligram per liter of treated water is dissolved in the flowing water as a disinfectant [13]. The water should be drained and allowed to settle before being chlorinated if it is murky. Table 2 represents various treatment processes for removal of water contaminants.

Table 2: Few removal processes for different contaminants

No.	Contaminants	Removal Process
1	Suspended solids	Sedimentation, screening, filtration flotation, coagulation, sedimentation
2	Biodegradable organics	Biological treatment
3	Pathogens	Disinfection
4	Nutrients	Biological nutrient removal, physico-chemical treatment
5	Refractory organics	Adsorption, advanced oxidation processes
6	Heavy metals	Chemical treatment
7	Dissolved inorganic compounds	Ion exchange, reverse osmosis

9 Membrane Separation Processes

A membrane is a semi-permeable, delicate sheet of material, which separates things on application of driving force. Membrane separation processes are used to remove pathogens, bacteria and other organic

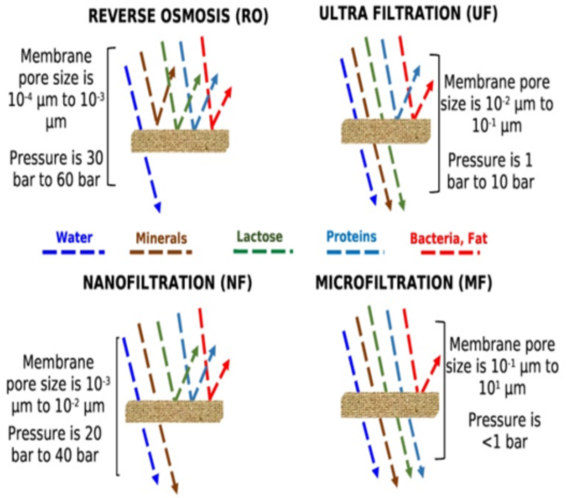


Figure 5: Schematic diagram of membrane separation processes.

materials that can provide color, flavor, and taste. As a result of recent developments in membrane manufacturing, operating and capital expenses have fallen. NF (nanofiltration), MF (microfiltration), RO (reverse osmosis) and UF (ultrafiltration) are all essential filtration techniques with unique characteristics [14] as shown in Figure 5.

Microfiltration is an estrangement method that employs membranes with pore sizes of 0.1 µm, a MWCO of more than 1,000,000 Daltons, and pressure as low as 1–4 bar. Sand, algae, clay and other bacterial species are among the objects that are removed, as is silt [4]. MF does not completely eliminate viruses. However, disinfectants can be added to eliminate germs. Chemical additives, like as chlorine, can be readily removed by MF once microorganisms have been physically removed. Fouling can be reduced to eliminate synthetic organic materials. Under normal working circumstances, MF eliminates just a small quantity of organic matter; however, when water is pre-treated, removal of organic matter increases. To minimize fouling, MF is generally utilized as a part of the pre-treatment procedure before RO and NF.

Ultrafiltration is a segregation method that employs membranes with pore sizes of 0.01 microns, MWCOs of 10,000–100,000 daltons, and operating pressures of 2–7 bar. Microbial species along with pathogens and humic materials are eliminated by UF; disinfectants are usually added for successful use [4]. There are no flocculants, pH adjustments, coagulants, or disinfectants required in the case of UF. It is a one-of-a-kind membrane method since it is easy and automated, as well as consistent in quality output.

Membrane separation process with a pore size between 1 to 10 nanometer and a MWCO between 150–200 daltons is classified as NF [4]. When contrasted to MF and UF, it is generally done at greater working pressures, ranging from 6 to 10 bar. Humic debris, bacteria, cysts, and viruses are all easily removed with NF. If unused disinfectant is applied after the membrane filtration process, the use of NF prevents the production of disinfected by-products. Softening membranes and reducing alkalinity are two terms for NF; nonetheless, NF requires more energy to run.

Inorganic pollutants, viruses, radium, bacteria, pesticides, and certain natural organic compounds and cysts are all removed with RO [4]. When using RO and numerous filtering units, disinfection is advised. A RO membrane has several benefits because it not only removes the materials stated above but also keeps running without break; yet, this process has significant capital and operational costs but fouling is common.

10 Biological Processes for Wastewater Treatment

Bacteria and other microbes use organic substances as food in the biological process to clean wastewater. Almost every organic material can be consumed by one or more species of bacteria, fungi, ciliates, rotifers, or other microorganisms. Microorganisms use organic materials in wastewater as food and convert them to stable compounds as well as new cells. New cells, known as biomass, sank to the bottom of the system as sludge, including two separate metabolic phases: catabolism and anabolism [15]. The biological processes such as aerobic and anaerobic for wastewater treatment are presented in Table 3.

Table 3: Aerobic and anaerobic process for wastewater treatment

Type	Suspended Growth	Attached Growth
Aerobic Process	a) Activated Sludge Process b) Aerated lagoons c) SBR (Sequencing batch reactor)	Rotating biological contactors and trickling filters
Anaerobic Process	a) Anaerobic digesters b) Upflow anaerobic sludge blanket (UASB)	Anaerobic filters

10.1 *Aerobic wastewater treatment*

Aerobic wastewater treatment is a biological process that breaks down organic contaminants as well as other pollutants like nitrogen and phosphorus with the aid of oxygen. A mechanical aeration device, such as compressor or blower, continuously supplies oxygen to wastewater or sewage. Aerobic bacteria consume organic matter in wastewater and convert it to carbon dioxide and biomass, which may subsequently be recovered [15].

10.2 *Anaerobic wastewater treatment*

The biological method for treatment of wastewater without the use of air or oxygen is known as anaerobic wastewater treatment. Organic contamination in wastewater, slurries, and sludge is removed with this method [16]. Types of growth for biological treatment of wastewater are divided into two categories. Firstly, suspended growth in which microorganisms and bacteria that treat wastes are suspended in the wastewater being treated in wastewater treatment systems. Wastes flow around and through the growths hanging in mid-air. Suspended growth reactors are used in several phases of the activated sludge process. BOD removal, nitrification, and denitrification are all possible with these reactors. Secondly, attached growth in which wastewater treatment techniques in which the waste-treating microorganisms and bacteria are connected to the reactor medium come under this category. The wastes that are being treated pass through the media. Attached to growth reactors are trickling filters and spinning biological contactors.

10.3 *Biosorption*

It is difficult to describe exactly what biosorption entails. In the case of living animals, the entire method is determined by the biosorbent, the material to be sorbed, environmental variables, and the involvement of metabolism processes [17]. Absorption is the process of absorbing one material over another, while adsorption is the process of a solid surface holding molecules of fluid. Physisorption, which is also known as Vander Waals adsorption, is caused by the presence of intermolecular interactions between adsorbates and adsorbents, while chemisorption is any chemical reaction that occurs between an adsorbate and the surface. Biosorption is the process of removing any chemical from a mixture using biological material [18]. Organic and inorganic substances, as well as insoluble and soluble substances, exist. Inorganic and organic pollutants from fluid streams, such as metals, are among the substances addressed. Biosorption is the removal of metalloid species, metals or compounds, and particles utilizing biological materials, with an emphasis on metals and associated elements, according to researchers.

10.4 *Biodegradation and bioremediation*

The biodegradation process is defined as the breakdown of a substance into its components [19]. Biodegradable plastic gets broken down in the environment using this method. Biodegradation is carried out spontaneously by microorganisms (bacteria and fungi). Bacteria and fungi decompose organic materials in order to recycle nutrients. The most effective decomposers are those that utilize oxygen via aerobic respiration. Microbes like these can be boosted in activity by the correct balance of oxygen, moisture, and other nutrients. Many decomposers live by digesting substrate foods like plastics and then converting them to harmless metabolites.

Bioremediation is the technique of removing harmful pollutants through biological processes. Bioremediation is the process of removing biodegradable materials from their original use area as well as from distant places [20]. Bioventing, rhizofiltration, biostimulation land-farming, bioaugmentation, and composting are all instances of bioremediation. The microorganisms that do bioremediation are known as bioremediators. Bioremediation is simply described as a procedure in which organic wastes breakdown biologically to non-harmful compounds under-regulated settings. The pH, quantity of oxygen available at the location, type of soil, temperature, and number of microorganisms capable of digesting the contaminants are all elements that influence bioremediation [21]. *Mycobacterium*, *Sphingomonas*, *Alcaligenes*, *Rhodococcus*, *Pseudomonas*, and other microorganisms are liable for the breakdown of polyaromatic chemicals, insecticides, and hydrocarbons.

11 Advance Wastewater Treatment

As people, communities, and corporations seek methods to maintain vital resources available and usable, advanced wastewater treatment technologies have piqued their attention throughout the world [22]. As society deals with the effects of a growing population, urbanization, industry, and the depletion of potable water, advanced wastewater treatment is required. Wastewater treatment does not always handle wastewater effectively, which can lead to a variety of difficulties, such as odor and health risks. New wastewater treatment methods are being used to address these issues. In order to achieve the goal of resource recovery or resource conservation, it is possible to improve the quality of wastewater beyond the limitations of conventional approaches by adopting advanced treatment processes for wastewater treatment. Advanced wastewater treatment facility effluents can also be recycled, either directly or indirectly, to increase the quality of the available domestic water supply [23].

11.1 *Membrane bioreactors for wastewater treatment*

Membrane bioreactors are wastewater treatment systems that combine a suspended growth biological treatment method, such as activated sludge, with membrane separation method, like low-pressure microfiltration or ultrafiltration membranes [24] as shown in Figure 6. The membranes are utilized to separate solids from liquids, which is a crucial function. In activated sludge facilities, secondary and tertiary clarifiers as well as tertiary filters have traditionally been utilized to achieve this. The two most prevalent types of MBR systems are pressure-driven and vacuum (gravity-driven) systems. With hollow fiber or flat sheet membranes placed in the bioreactors or a subsequent membrane tank, immersed vacuum or gravity systems are frequently used. Pressure-driven systems are in-pipe cartridge systems and are located outside the bioreactor. Membrane Bioreactors combine membrane filtration with conventional biological treatment techniques (such as activated sludge) to efficiently remove organic and suspended particles [25]. These systems can also deliver a high amount of nutrient removal if they are constructed properly. Membranes are immersed in an aerated biological reactor in an MBR system. During the MBR wastewater treatment process, particles and liquids are separated using microfiltration (MF) or ultrafiltration (UF) membranes. Depending on their size or electrical charge, fluid components are separated using membranes, which are two-dimensional materials. The ability of a membrane to permit the movement of specific compounds is referred to as semi-permeability (sometimes also called permselective). The chemical makeup of the separated components is not changed throughout this physical operation. Retentate describes substances that are rejected, whereas permeate describes substances that flow through membrane pores.

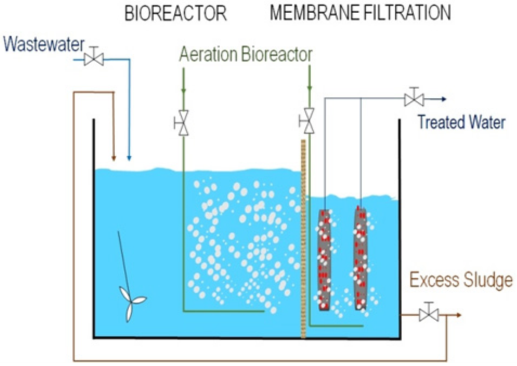


Figure 6: Schematic diagram of membrane bioreactors.

The membrane bioreactor (MBR) is a popular wastewater treatment technique that is perhaps the most practical. The application of microfiltration or ultrafiltration membrane to completely retain activated sludge within the bioreactor decouples hydraulic retention time (HRT) from solids retention time (SRT) [26]. MBR may now operate at high mixed liquor suspended solids (MLSS) concentrations and extended SRTs thanks to this decoupling. Due to the high MLSS concentration and lengthy SRT, the MBR technology has been identified as being adequate in wastewater treatment from various sources and can swiftly respond to variations in wastewater properties. Despite its efficacy, the MBR technology has been shown to have many flaws and technological problems. Membrane fouling and poor micropollutant removal are two of the disadvantages. Membrane fouling usually happens because of soluble microbial products (SMP) and extracellular polymeric substances (EPS), which is still a major hurdle to MBR implementation.

11.2 *Electrochemical membrane bioreactors (EMBR)*

An electrochemical method can be combined with MBR to overcome the problems mentioned above. This integrated method is a new wastewater treatment technique with a better output [27]. In such systems, mechanisms including electroosmosis, direct oxidation, electrophoresis and electrocoagulation, can all work together to maximize pollutant removal while lowering membrane fouling. EMBR has been used to eliminate pollutants (e.g., COD) and reduce fouling. According to published literature, operating conditions like HRT, SRT and current density influences the performance of EMBR [28]. However, rigorous analysis of the influence of operating circumstances on performance, mixed liquor characteristics, and membrane fouling in the EMBR is necessary. In an EMBR, nitrogen and phosphorus can be removed or recovered through a series of bio-electrochemical processes, such as nitrification, bioelectrochemical denitrification, volatilization and diffusion of ammonia nitrogen and phosphate precipitation.

A conventional EMBR consists of a cathodic chamber and an anodic chamber. The anodic chamber, which is where electrons from influent organic matter metabolism are driven to the anode, can be manufactured not only according to MFC design rules, but also from an existing unit utilizing conductive materials [29]. Electron acceptors, such as nitrate/nitrite and oxygen have been utilized on the cathode side. To transport H^+ from the anodic chamber to the cathodic chamber, a number of proton exchange routes are used, including an ion exchange membrane, nonwoven cloth, and perforated plexiglas plate and reactions take place as shown in Figure 7. The membrane module in an EMBR can be standalone or coupled with the cathode, referred to as a filtering biocathode [30]. Table 4 provides a quick overview of components in EMBR and material of constructions.

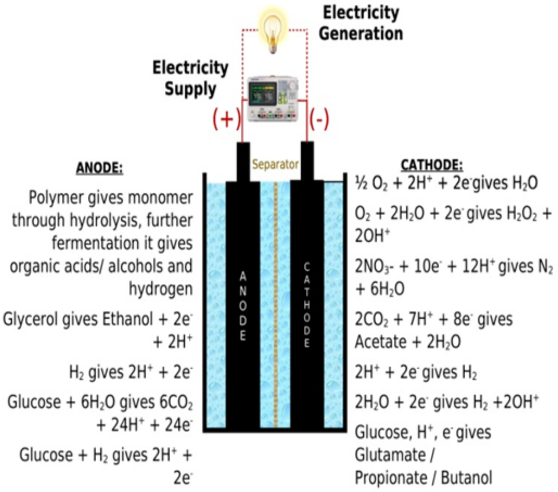


Figure 7: Overview of chemical reactions taking place in EMBR System

Table 4: Various components used in construction of EMBR system

Part	Material Used
Anode	Granular graphite, carbon/graphite felt, activated carbon, graphite brush, activated carbon fiber, carbon cloth, and iron mesh [31]
Cathode	Polyester nonwoven coated with multiwalled carbon nanotubes, Stainless steel mesh, PPY/PT membrane, carbon/graphite felt, PANi-PA membrane, iron mesh
Electron donors	Acetate, sucrose, glucose, organic matters
Electron acceptors	Dissolved oxygen, nitrate/nitrite, carbon dioxide, air/oxygen.
Membrane modules	Stainless steel mesh, nylon mesh, AQDS/PPY/PT membrane, graphite felt, PANi-PA membrane MF membrane, porous nickel-based hollow fiber membrane, polyester nonwoven coated with multiwalled carbon nanotubes

11.3 *Mechanism of EMBR*

An electrochemical membrane bioreactor (EMBR) is made up of a filtration membrane that separates suspended particles from dissolved organic and inorganic components and a bioreactor that biodegrades them as depicted in Figure 8. Combining these two technologies has resulted in the development of new electrochemical membrane bioreactors (EMBRs) that retrieve energy from contaminated water while collecting treated water for reuse [32]. Membrane modules were used as separators or filters between the cathode and anode in these reactors, and in certain cases, as the cathode itself. The bacteria consumed the substrates, resulting in the production of protons and electrons at the anode, and the freshwater was drained by the separator and cathode. The electrodes and external circuit carried electrons to the cathode, where they were mixed with oxygen from the air or aeration, as

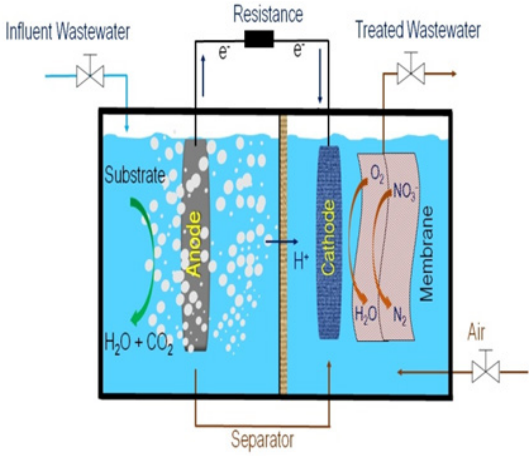


Figure 8: Schematic diagram of EMBR system.

well as protons that diffused from the anode. This combination, compared to separate MFCs or MBRs, would save money on reactors while providing high-quality effluent, high nutrient (especially nitrogen) removal efficiency, and a set quantity of electricity [33]. Electrochemical processes might augment other pollution removal techniques in an EMBR, such as activated sludge biodegradation and membrane filtering. As a result, understanding the principles of electrochemical processes is critical. Direct anodic oxidation happens when an electron is transferred from an organic pollutant to the surface of anode without any precipitation. However, due to the accumulation of organic contaminants on the anodic surface as well as dissolution/sacrifice of anode, the anode may degrade and potentially deactivate. The degree of anode degradation and/or deactivation is determined by the characteristics of anode material, as well as the concentration and attributes of organic contaminants. Many researchers have carried out a research work on electrochemical membrane technologies and summary of their findings is presented in Table 5.

11.4 *Factors affecting membrane fouling*

Membrane materials, sludge properties, hydraulic features, and operating parameters are the four categories of factors that impact membrane fouling [44]. Membrane fouling is further complicated by the interplay of various impacting variables [45]. Membrane fouling is determined by the properties of

Table 5: Recent studies in electrochemical membrane technology

Source of Pollutants	Parameters	Inferences
Aquaculture seawater	Membrane fouling resistance, SRT	Internal pore blockage is the primary source of the flow reduction [34].
Municipal wastewater	Membrane fouling and microbial activities	Membrane fouling was reduced in the EMBR system by increasing electrostatic repulsion between foulants and electro-generating reactive oxygen species for in-situ cleaning [35].
Synthetic domestic sewage	Fouling and electric field	When compared to the regular MBR, the removal efficiencies of COD and TP in the eMBR rose by 15.4%, 6.7%, and 39.7%, respectively [36].
Pharmaceutical wastewater	Biological performance and fouling mitigation	The biochar-added water AnMBR performed better when it came to treating pharmaceutical wastewater, with greater COD and AOX removal efficiency [37].
Pharmaceutical wastewater	Current density	For successful wastewater treatment and membrane fouling management, the size of the applied current density impacts not only microbiological survival but also the synergy between microbial and electrochemical activity [38].
Coal chemical industry wastewater	Performance and membrane fouling	EMBR can be used for preventing membrane fouling when used with an iron anode in the proper exposure mode [39].
Antibiotic wastewater	Performance and fouling	Antibiotic can be effectively removed from wastewater using EMBR [40].
High load wastewater	Antifouling and COD removal	A new antifouling conductive membrane integrating MnO_2 catalyst was generated in this study [41].
Pretreated coal gasification wastewater	COD removal	The combined process gives higher removal efficiency and superior fouling control performance indicated that it might be used to treat BPCGW on a large scale in the future [42].
Highly saline phenolic wastewater	Specific methanogenic activity	Different TM partitioning in the biomass matrix was caused by high salt concentrations, which were mostly bound to the exchangeable portion [43].

activated sludge as well as the reactor's hydrodynamic parameters. Simultaneously, operating parameters including sludge retention time (SRT), hydraulic retention time (HRT), food-to-microorganism (F/M) ratio, and wastewater properties impact sludge characteristics, which affect membrane fouling indirectly [46]. The MFC anode in the study carried out by Liu *et al.* [47] was the conductively modified AnMBR membrane, and a unique coupled system was built after that. The outcomes showed that membrane fouling can be greatly reduced by the MFC self-generated current. The study carried out by Wang *et al.* [48] used MFC-CMBRs with various external resistance to examine the coupling system's electrical energy utilization efficiency and the management of membrane fouling during the treatment of wastewater. The coupling system's nitrification and denitrification activity improved as a result of the electro-acclimated activated sludge treatment, and membrane fouling was successfully managed under low electricity supply.

12 Challenges and Future Recommendations

Due to its exceptional benefits, such as ease of control, high efficiency and no secondary pollutant, electrochemical membrane bioreactor technology has tremendous potential for further application in water treatment but still cost effectiveness and reuse of membrane still remain the main obstacles in electrochemical processes. The following future prospects, which researchers must work to stabilization of the reactor, application of different membranes, focus should be on continuous processes, optimizing and scaling up reactor.

13 Conclusions

Various wastewater treatment methods have been studied in this review paper and a brief description for every beginner researcher has been illustrated in the paper. From sampling, impurities and basic treatment methods to advance treatment methods have been described. Wastewater or sewage treatment, drinking water filtration, and wastewater reuse have all benefited from electrochemical techniques. This paper will assist upcoming new researchers to start their research by learning the basics from here and the necessity leading to innovations.

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Author Contributions

S.Y.: conceptualization, original manuscript writing, drafting, collection of data; S.K..: conceptualization, writing, editing and reviewing, creating diagrams, funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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