Emerging Frontiers of Microbes as Liquid Waste Recycler

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Abstract

There is a worldwide energy crisis due to massive energy demand and restricted assets. This demand of energy is increasing continuously and exponentially with the increase in population. The nourishment of energy demand should be at least without affecting the environment. The human population is mainly dependent on non-renewable energy resources, especially petroleum products causing deterioration of environment, which will be exhausting in the next few decades. On the other hand, non-exhausting, self-sustainable, environment friendly, and bio-renewable energy sources are underutilized. The non-renewable energy sources are not only getting exhausted after a certain time but also cause carbon emissions to the environment, as one of the agendas in COP 27 (Conference of the parties) held in Egypt. This focuses on sustainable fuel of clean energy projects with zero carbon emission without hampering the climate condition

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further with the continuously increasing population. Therefore, this chapter focuses on all these issues along with the renewable and sustainable energy sources utilizing organic liquid waste, produced from households, industry, agriculture, dairy, etc., and converting it to energy through a novel technology called microbial Fuel cell (MFC), representing a new form of renewable energy, generating bioelectricity through oxidation of waste. Thus, MFCs have the potency to treat liquid wastewater along with bioenergy generation, and various other applications. A portion of the difficulties and future points of view concerning the energy recuperation from liquid wastewater utilizing MFCs are also discussed.

Keywords

Microbial fuel cell · Liquid waste · Bioremediations · Bioelectricity

1.1 Introduction

The energy requirement is continuously increasing throughout the world. In this regard, fossil fuels have catered a significant portion of the energy demand. Subsequently, this has resulted in depletion of fossil fuel resources as the fossil fuel energy reservoir is in a fixed quantity. Additionally, the combustion of fossil fuels generates lots of greenhouse gas which is an alarming situation for the environment. As a result, looking for low-cost, environmentally friendly alternative energy sources has become a primary concern (Logan 2004).

Addressing waste management and global climate change issues, sustainable development is vital. With exponentially increasing energy demand and finite fossil fuel resources, new alternative sustainable energy solutions are required. In this context, achieving energy demand-treatment of municipal and industrial wastewater is also essential (Gavrilescu and Chisti 2005; Mohan et al. 2007; Li et al. 2014). One of the revived bio-electrochemical concepts and promising technology that is proposed to deal with these aspects is microbial fuel cell (MFC), which principally produce electricity from the anaerobic oxidation of biodegradable organic wastes (Madakka et al. 2020; Pant et al. 2013; Patil et al. 2012). Microorganisms are capable of converting an enormous type of biodegradable natural wastes (organic compound) into CO_2 (carbon dioxide), water, and energy (Potter 1911). MFCs are microbially produced energy and provide a habitat for their growth and metabolic activities (Logan 2004). A general layout of a two-chambered MFC is specified within the anodic compartment, microorganisms can bring forth oxidative conversions, and simultaneous chemical or reductive microbial processes can occur in the cathodic compartment. Electrodes of both compartments are usually separated by a proton or cation exchange membrane and interconnected through an external circuit with an external resistor or load (Rabaey and Verstraete 2005).

1.2 What Is Liquid Waste?

Liquid waste or wastewater is a significant problem in the world. Liquid waste may include wastewater, fats, oils, grease, used oil, fluids, solids, gases, sludge and hazardous home liquids. These wastes are hazardous or potentially harmful to human health and the environment. They can be released by commercial items assigned as "liquid industrial waste, for example, cleaning liquids or pesticides as a result of the manufacturing process" (Friedman 1981). According to the environmental protection agency (EPA), liquid waste is any waste material that approves the definition of a liquid and must pass through a 0.45-μm filter at a pressure differential of 75 psi.

1.2.1 Sources of Liquid Wastes and Their Pollutants

Any product, by-product or type of residue that cannot be used profitably is called waste. A waste outcome is viewed as a pollutant when it harms the environment. Also, waste and pollutants are intricately correlated. In simple words, pollutants are generally waste, but all wastes are not pollutants. Liquid waste may originate from various human activities like- Industrial waste, manufacturing industries, agriculture, dairy, energy production, transport, house building, and domestic activities, as shown in Fig. 1.1.

1.2.1.1 Industrial Waste

In industrial waste, effluents are waste products in liquid forms resulting from various industrial processes. They are released by industries such as petrochemical complexes, fertilizers factories, oil refineries, paper pulp factories, textile, sugar and steel mills, tanneries, distilleries, coal washeries, synthetic material plants for drugs, fibres, rubber plastics etc. (Abbas et al. 2014a, b; Soni et al. 2020; Yadav et al. 2020). The industrial and mills include metals (copper, zinc, lead, mercury etc.), detergents, petroleum, alcohols, acids alkali, phenols, carbamate, cyanide, arsenic, chlorine and many other inorganics and organic toxicants (Devi et al. 2023). All these chemicals discharged from industry are toxic to living beings. They may cause death and sub-lethal effects on the liver, kidneys, reproductive, respiratory and nervous systems (Yadav et al. 2021).

1.2.1.2 Manufacturing Waste

These activities generate a wide variety of waste depending on the nature of raw materials, products, the design and the mode of operation. Generally, manufacturing industries using biological materials (e.g., breweries, food processing, and dairy) generate biodegradable waste of biological substances (Kumar et al. 2020). Microorganisms can frequently use and recycle these biological substances. On the other hand, non-biodegradable raw materials are also used in several sectors, often not biodegradable. They may linger in the environment until it is changed or decomposed by chemical or physical factors (Leow et al. 2018).

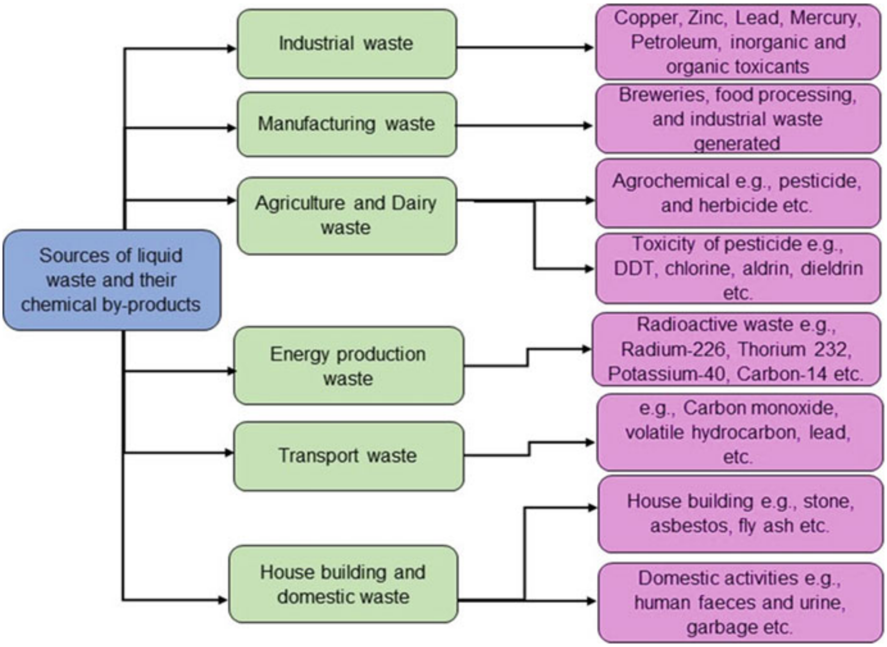

Fig. 1.1 Source of liquid waste with their waste release (*DDT* dichlorodiphenyltrichloroethane)

1.2.1.3 Agriculture and Dairy

These activities produced crop residues and manure, which are biodegradable. Most of the pesticides used in agricultural sectors are non-biodegradable. In addition, plastics and copper in feed additives and waste from fossil fuels are recalcitrant to biodegradation. The ammonia gas released from manure and fertilizers to the environment contributes to acid rain. In addition, the discharge of nitrate and phosphate chemicals into surface water and water bodies is not only leading to the formation of massive algae blooms but also contaminating groundwater, making it unfit for drinking (Badgujar and Bhanage 2018).

Agrochemical

Agrochemicals, such as chemical fertilizer, pesticides and herbicides, contribute to heavy metal and pollution. Pesticides and weedicides are used by human beings to control Crop diseases by pests or to kill weeds and increase crop productivity. These toxic chemicals have created health hazards for livestock, wildlife, fish, other aquatic organisms, birds, mammals and humans. Ecological pesticides and herbicides have created two major serious problems which were not previously anticipated. In the first place, many of them have persisted and accumulated in the environment and have harmed or contaminated numerous animals or plants not intended to be targeted. Secondly, these directly and indirectly affect human health (Rai et al. 2020; Saleh et al. 2020).

Pesticides

The toxicity of pesticides is because of Organo-chlorine pesticides (i.e., Dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane, Chlordane, aldrin, Dieldrin, etc.). The reason for this is that sodium, potassium, and magnesium ions decrease adenosine triphosphate activity in the neuromuscular junctions of animals, particularly insects and influence the sensory system in the large zones of axon cockroaches. DDT is also known to affect the efflux of potassium ions from the axons. DDT and other organochlorine pesticides are absorbed from the intestinal tract from the alveoli of the lungs and also through the skin. If the pesticides are in solution, the high concentration of DDT causes brain damage, centrilobular liver necrosis, and liver enlargement in small mammals (Mojiri et al. 2020).

1.2.1.4 Energy Production Using Fossil Fuels

The usage of enormous amounts of water across numerous power plants is essential for energy generation. The majority of power plants in the world generate energy by burning fossil fuels for boiling water. Those results in producing an excess steam inside the plant, the produced stream is used for spinning turbines. Water is also needed for the mining of coal, refining transportation fuels, and extracting petroleum sources. In once-through coal plants, the used water is typically released right back into the source (rivers, lakes, streams, and oceans) which increases the water temperature and causes thermal pollution, which alters life cycle of marine ecosystem (Jin et al. 2019). Thermal pollution of water is extremely harmful for both people and environment. Also, combustion of fossil fuels liberates carbon dioxide and significant amount of carbon monoxide, various oxides of sulphur, nitrogen and water vapours. Carbon dioxide produced during combustion is recycled by photosynthesis, but its increasing concentration in the atmosphere results in global warming. Oxides of sulphur and nitrogen cause acid rain, affecting the natural ecosystem (Tyagi and Lo 2013).

Radioactive Wastes

Radioactive isotopes or radionucleotides are forms of an element with unstable atomic nuclei. They decompose with ionizing radiation in the form of Alpha or beta particles or gamma Rays. Many radioisotopes, such as radium- 226, Uranium – 235 or 238, Thorium-232, potassium-40 or carbon- 14, occur naturally. Other radioisotopes, such as Cesium, Cobalt, Iodine, Krypton, Plutonium, and Strontium, are generated industrially as fission products from atomic bomb effects, such as nuclear reactor, or other radiation-related work. Of the over 450 radioactive isotopes that can occur as fission products, only a few are of major ecological concern within the biotic community environment. These radioactive components may become scattered or collected relying on the organic movement of the component and time of radioactivity of the isotopes. However, isotopes may accumulate in human tissue just as plants, and animal radiation exposure from artificial sources are already sufficient to produce serious diseases such as leukaemia and bone tumours, genetic damage, and infant mortality (Petrangeli 2019; Kumaraswamy and Kashyap 2021).

1.2.1.5 Transport

This is the major contributor to atmospheric pollution by carbon monoxide, sulphur, nitrogen, volatile hydrocarbon, and lead. It also contaminates air, surface, and soil/ underground water with oil and oil products (Sobieraj et al. 2022).

1.2.1.6 House Building and Domestic Activities

These activities generate both non-biodegradable (e.g., stone, asbestos, synthetic, fly ash, etc.) and biodegradable (sewage and various waste components) wastes. The chief waste generated by domestic activities is human faeces, urine (a component of sewage), and garbage (consisting of food scraps, plastics, cardboard, tin bottles, etc.). While sewage is biodegradable, it is discharging water bodies. Without proper treatment, it leads to spreading diseases like diarrhoea, hepatitis, etc., reducing oxygen tension or reducing anoxia in water. Separation of these components of garbage would facilitate their biodegradation and recycling. Still, it is not practised mainly due to cost considerations, and the garbage is also dumped into large bits. These activities cause pollution by generating carbon dioxide, carbon monoxide, sulphur, nitrogen, etc. (Noor et al. 2020).

1.3 What Is the Problem Arising from Liquid Waste with Their Static Data?

Problems arising from liquid waste are the rise in urban movement and the act of releasing untreated wastewater. The uncontrolled development in urban zones has made arranging and expansion of water usage and made sewage systems troublesome and costly to complete.

It is a typical practice to release untreated sewage into waterways or put it into the farming area, causing significant health and economic risks. The number of families with access to drinking water gracefully has expanded the percentage associated with the urban sewage collection system.

The problem with the current treatment technologies is the lack of sustainability. The conventional centralized system flushes pathogenic bacteria out of the residential area, using large amounts of water, and often combines the domestic wastewater with rainwater, causing the flow of large volumes of the path (Sato et al. 2013).

According to sources of wastewater data: Aquastat, F. A. O. (2019), there is static data from various countries based on wastewater generated, wastewater treated, and wastewater reuse. Out of 196 countries, we could get complete information in 49 countries, partial information in 74, and no information in 73 countries. Also, based on wastewater production (112 countries), wastewater treatment (102 countries), and wastewater reuse (55 countries), various countries are mentioned graphically.

Graphically representation of the above data in the form of complete, partial, and no information in Fig. 1.2a and also no. of countries whose wastewater treatment and reuse are in Fig. 1.2b.

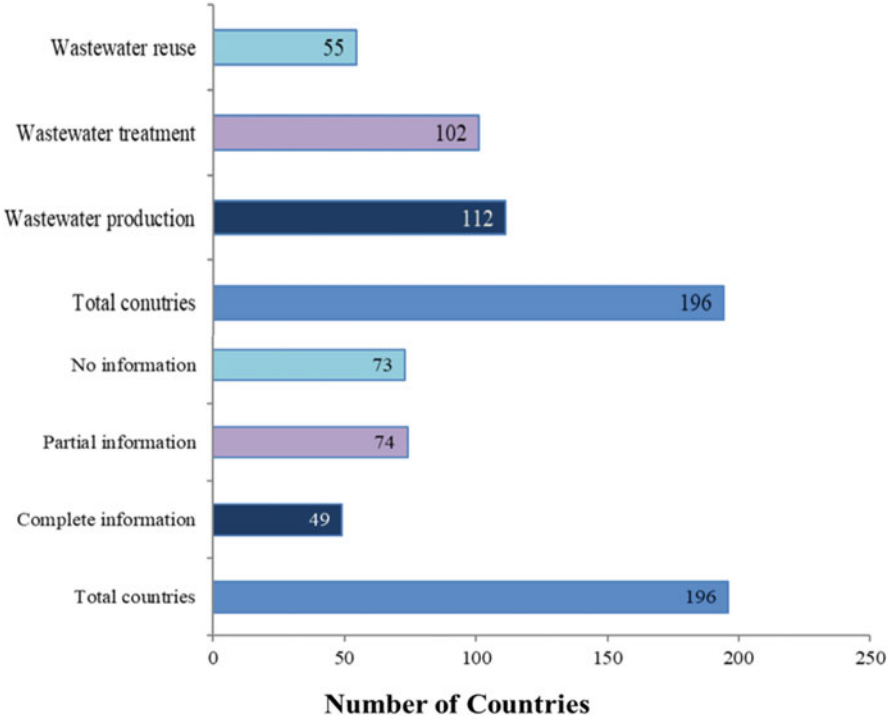

Fig. 1.2 The availability of complete, partial, or no data on wastewater production, treatment and use and Availability of data regarding each Aspect of wastewater production, treatment, and use at the country level. (Source of wastewater data—Aquastat, F. A. O. (2019))

The graph is a pie-chart by their continents, in which the continent produced more wastewater and treated and reused it. The figure below shows the three different graph-based on wastewater generated, treated, and reused. Figure 1.3a shows the wastewater generated in which continent south America produced 96.31%. It is the maximum generated wastewater and minimum generated by Oceania at 0.03%. Figure 1.3b shows the wastewater treated in the continent south America treated 95.7%, which is the maximum treated and minimum in Oceania at 0.05% in Fig. 1.3c shows the wastewater reuse maximum reuse by continent Asia at 43.73% and the minimum continent\South America 1.11% (all these values are approximate values).

1.3.1 Why We Focus on Liquid Waste and How It Is Treated

The focus is on liquid waste, especially wastewater, because, as we know, the availability of sewage and sources is enormous, as well as a by-product of any material it merges with either air, water, or soil. Also, we are using wastewater because most of the industrial and domestic effluents are in a liquid form. Severe

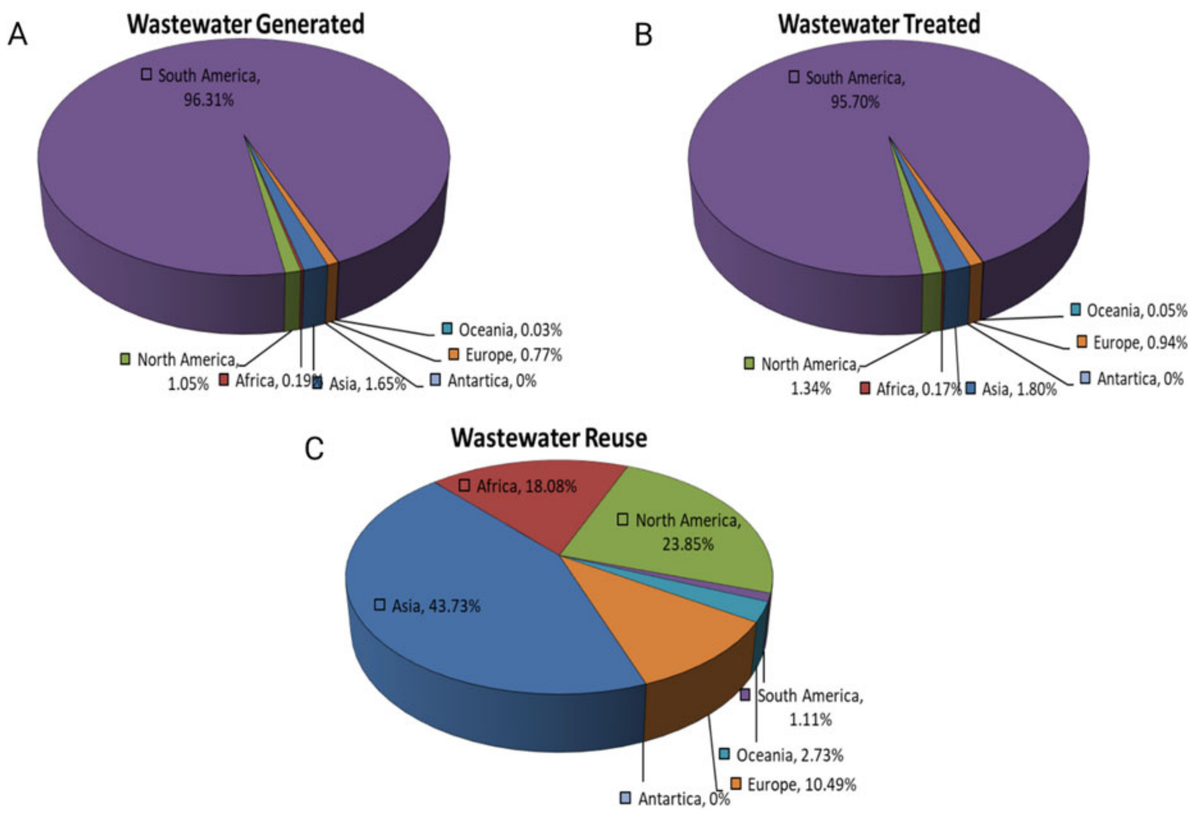

Fig. 1.3 **a**, **b**, and **c**- show the continent-wise wastewater generated, treated, and reused respectively. (Source of data: Aquastat, F. A. O. (2019))

outcomes occur when these effluent chemicals continuously discharge in the river and freshwater streams. How these chemicals or other by-products are treated or minimized in sewage waste is a question (Hussain et al. 2021).

Here, we are focusing on the liquid wastewater or sewage wastewater that will be treated by conventional and advanced methods.

1.3.2 Conventional and Advanced Methods for Liquid Wastewater

For the conventional methods, there are some physicochemical methods such as coagulation, flocculation, precipitation, adsorption, ion-exchange, electro-dialysis, and membrane separation that can be applied in wastewater treatment schemes

1.3.2.1 Coagulation and Flocculation

Coagulation and flocculation are significant physicochemical wastewater treatment activities that are used to remove turbidity particles and natural organic materials. Hydrolytic aluminium and iron salts are the most often used coagulants (Kimura et al. 2013). Optimal pH for $Al(OH)_3$ use is 4.5, and 8 for $Fe(OH)_3$

$Al_2(SO_4)_3 + 6H_2O = 2Al(OH)_3 + 3H_2SO_4$
$FeCl_3 + 6H_2O = Fe(OH)_3 + 3HCl$

The main disadvantage of these methods is the significant amount of chemical sludge produced. Furthermore, aluminium-based coagulants raise the residual aluminium concentration in purified water. This residual aluminium is connected with a number of issues, including increased turbidity, decreased disinfection efficiency, hydraulic capacity loss, and possible harmful impacts. This method, however, is not generally practical since it necessitates a pH rise post-treatment to prevent corrosion in water distribution networks, which increases the process's cost (Kimura et al. 2013).

Flocculation is the production of bridges between flocs followed by polymer binding of particles into big agglomerates or clumps. Filtration or flotation can then be used to remove the agglomerates. Flocculants may be made from a variety of materials, including polyferricsulfate (PFS) and polyacrylamide (PAM) (Fu and Wang 2011). Despite some turbidity, some flocculants, such as mercaptoacetyl chitosan (MAC) and flocculants based on Konjac graft-poly (acrylamide)-co-sodium xanthate, may efficiently remove heavy metal ions from wastewater. It is impossible to use a universal flocculent due to the differences in particle characteristics (Zinicovscaia and Cepoi 2016). Therefore, flocculent can be divided into several groups:

- Non-ionic, with -OH and COOH groups (natural polymers: starch, gums, glues, and alginates).
- Anionic, with -COOH and SO_3H groups.

- Cationic, with -NH_2 and =NH groups. Because anionic species are less costly than cationic species, they make up the majority of accessible synthetic flocculants.
- Amphoteric, with anionic and cationic groups (proteins).

Inorganic flocculants frequently result in the creation of significant amounts of sludge, whereas natural polymers are biodegradable and more effective.

1.3.2.2 Precipitation

Chemicals react with heavy metal ions to generate insoluble precipitate, which is then removed from the water by sedimentation or filtering (Fu and Wang 2011). Precipitation is most commonly used to remove metal ions, phosphorus compounds, and radioactive materials. Because of its simplicity, low cost, and automated pH control, hydroxide treatment is the most often utilized precipitation procedure. Ca $(OH)_2$ and NaOH compounds are used as precipitants. The mechanism of heavy metal removal by chemical precipitation can be presented by the following equation:

$$M^{2+} + 2(OH)^{-} \leftrightarrow M(OH)_2 \downarrow .$$

The major drawback of hydroxide precipitation is the creation of large amounts of low-density sludge, which causes dewatering and disposal issues. Sulphide precipitation has been shown to be superior than hydroxide precipitation. The main advantages are the high degree of metal removal even at low pH and the possibility of selective metal removal and recovery. Metal sulphide sludge also has greater thickening and dewatering qualities than metal hydroxide sludge. The process’s limitations include the generation of hazardous H2S vapours and sulphide colloidal precipitates (Fu and Wang 2011). Sometimes precipitation is used in combination with coagulation.

1.3.2.3 Ion-Exchange

Ion exchange is one of the most often used heavy metal removal procedures in the world. The key benefits of the ion exchange process are metal recovery, greater selectivity, and smaller sludge quantities (Zinicovscaia and Cepoi 2016). The concept is the exchange of ions in a chemically comparable amount between the solid (resin) and liquid (electrolytic solution) phases without any structural change to the resin (Kurniawan et al. 2006). The most common cation exchangers can be divided in the following groups:

- Strong acidic resins with sulfonic acid groups (−SO3H),
- Weak acid resins with carboxylic acid groups (−COOH),
- Strong basic anionites containing –NH2 groups,
- Weak basic anionites containing amino groups.

Ion exchange techniques are effective for the treatment of wastewater with metal concentrations in the range of <10–100 mg/L, or even higher than 100 mg/L (Kurniawan et al. 2006).

1.3.2.4 Adsorption

Adsorption is well regarded as an efficient and cost-effective method of pollution removal from wastewater. The concentration of molecules on the surface of a sorbent characterizes the process (Owlad et al. 2009). Adsorption has considerable benefits such as low cost, high availability, profitability, flexibility in design and operation, and process reversibility (Fu and Wang 2011), which is especially relevant from an economic and environmental viewpoint. Because of its huge micropore and mesopore volumes and high surface area, activated carbon is one of the most often utilized sorbents for the removal of organic contaminants from wastewater. Activated carbon is categorized into four categories based on the manufacturing process: powder-activated carbon, granular-activated carbon, activated carbon fibrous, and activated carbon cloth, each of which has a distinct purpose (Owlad et al. 2009). Since activated carbon is a costly sorbent, it cannot be used in complex wastewater treatment systems. As a result, there is a huge potential for the creation of low-cost sorbents made from natural materials or specific waste products from industrial or agricultural activities that are cheap, plentiful, and have extremely low economic expenses (Zinicovscaia and Cepoi 2016). Conventional methods, such as coagulation, precipitation, and adsorption, are used to reduce high concentrations of various organic compounds and metal ions to regulatory required levels. Membrane technology is more efficient when pollutant concentrations are low.

1.3.2.5 Membrane Filtration

Membrane filtration has received a lot of attention in recent years because it can be used to remove pollutants from various sources. The use of membrane technology in an existing industrial process may reduce costs and overall energy consumption. Existing membrane processes include ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

Ultrafiltration (UF)

UF is a procedure for separating heavy metals, macromolecules, and suspended particles from solution employing a permeable membrane with pore sizes ranging from 5 to 20 nm and separating substances with molecular weights ranging from 1000 to 100,000 Da (Fu and Wang 2011). The primary benefits of UF procedures are the lack of chemical usage and the high quality of the end product (pathogen elimination of 90–100%). Regardless, the method is hampered by the expensive expense of the membrane.

Reverse Osmosis (RO)

RO is a pressure-driven membrane technology that allows water to flow through while polluting metal ions are trapped. RO is more successful in removing metal ions from inorganic solutions. Furthermore, the procedure works in a wide pH range of 3–11 and pressure range of 4.5–15 (Fu and Wang 2011). RO also necessitates the employment of high-pressure pumps to drive the water through the semi-permeable membranes, resulting in a reject stream that contains 95–99% of the dissolved salts. The needed pressure is proportional to the concentration of salts in the water. The method's benefits include minimal cost and excellent efficiency. The primary drawbacks of RO are the high-power consumption caused by the pumping pressures and the costly membrane repair.

Nanofiltration (NF)

NF is a technology that is midway between UF and RO and is appropriate for particles with molecular sizes ranging from 0.0001 to 0.001 μm. NF permits monovalent ions to flow through while rejecting a substantial percentage of divalent cations and multivalent ions. The advantages of NF include its high efficiency, low energy consumption, and ease of use. There have been several studies on the removal of heavy metals by NF and RO membranes (Zinicovscaia and Cepoi 2016) (Fig. 1.4).

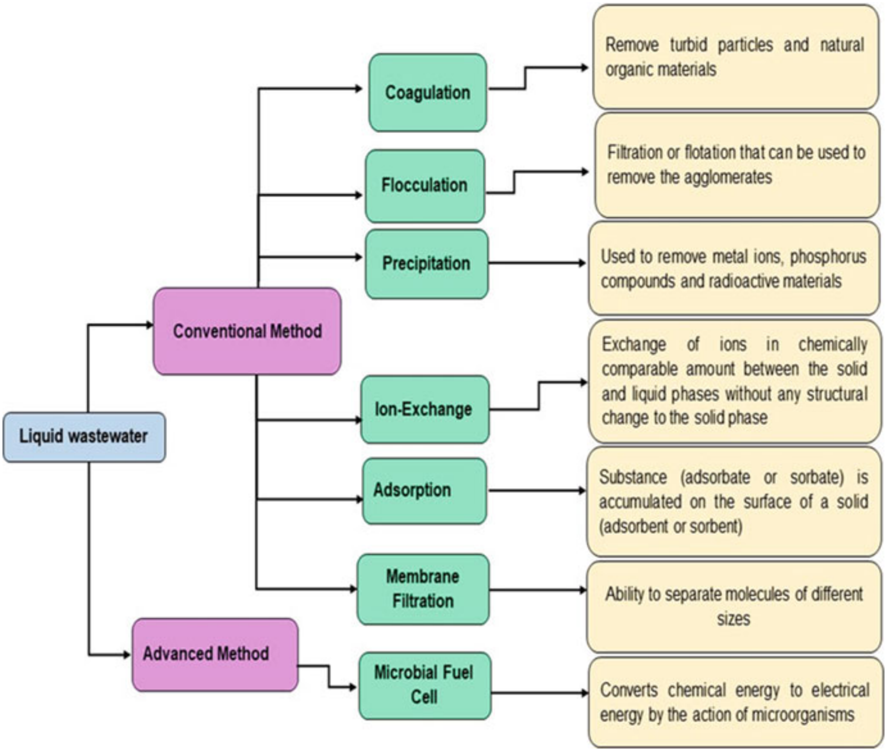

Fig. 1.4 Conventional and advanced methods for liquid wastewater remediation

1.3.2.6 Advanced Method for Liquid Wastewater

The MFC is used as an advanced method because it has become an innovative renewable energy resource by degrading organic pollutants in wastewater. It is described in Sect. 1.5 of this chapter based on its physical components and its working mechanism.

1.4 Role of Microbes

The microorganisms involved in aerobic and anaerobic digestion and their activities are the same as those found in nature. The organic material (biodegradable components) is oxidized to carbon dioxide and water along with the production of biomass and nitrogenous compounds. In wastewater, however, the organic materials are in much higher concentration than in nature. Therefore, the microbial populations and activities are increased accordingly, providing a large surface area for biofilm formation and oxygen exchange in fixed-film processes (Solanki et al. 2020).

1.4.1 Aerobic Microbes

Various microorganisms occur in aerobic digestion systems. These are bacteria, protozoa, fungi, viruses, cyanobacteria, and algae.

Bacteria are the most common organisms; their number may be more than 10^{12} cells/mL to 10^9 cells/mL).

1.4.1.1 Aerobic Oxidation

Many heterotrophic bacteria are responsible for the Aerobic oxidation of organic molecules. Some important bacteria are, *Sarcina, Pseudomonas, Streptococcus, Salmonella, Escherichia, Staphylococcus, Shigella, Aerobacter,* etc. (Liu et al. 2021*)*.

1.4.1.2 Nitrification

Ammonium released from protein/ amino acid degradation is toxic to fish and is undesirable in river waters. Ammonium is converted to nitrate by nitrifying bacteria (*Nitrosomonas* and *Nitrobacter)*. Nitrate is much less toxic than ammonia but also causes the eutrophication of river water. The presence of access nitrate in drinking water may lead to a condition called Blue Baby syndrome in very young ones. The nitrification bacteria are slow to multiply. Therefore, when wastewater contains a high level of ammonia, care must be taken to maintain a high population of bacteria, and organic loading must be carefully regulated (Sadhukhan et al. 2022).

1.4.1.3 Denitrification

The nitrate is ultimately removed from the waste by denitrifying bacteria (e.g., *Alcaligenes, Achromobacter, Micrococcus, Pseudomonas,* etc.). These bacteria convert nitrate into nitrogen, which is liberated in the atmosphere. Denitrifying bacteria are strictly anaerobic; therefore, denitrification is often achieved by an anaerobic stage following aerobic digestion or by alternating aerobic and anaerobic conditions. Denitrification may also produce various oxides of nitrogen in addition to nitrogen (Dubeux and Sollenberger 2020).

1.4.2 Anaerobic Microbes

The anaerobic digestion processes involve a wide variety of organisms, of which bacteria are the most predominant. These microorganisms digest organic molecules, like lipids, carbohydrates, protein, etc., into methane and carbon dioxide (Laurens and Nelson 2020; Verma et al. 2018).

Sulphate is used as an electron acceptor by bacteria like *Desulphovibrio* during the oxidation of organic compounds, and they reduce sulphate to sulphur.

Denitrifying bacteria oxidized organic substrates and their nitrate as an electron acceptor and liberated nitrogen in the process. At neutral pH, nitrogen is the primary product of this process. But at acidic pH, mainly nitrogen oxides are formed (Zhang et al. 2012).

Methanogenic bacteria contain several cofactors not found in other bacteria. Three such Cofactors are involved in reducing carbon dioxide to methane in a stepwise fashion, beginning with methanopterin followed by methanofuran and Coenzyme M (CoM). In the end, the last reaction is catalysed by factor 430 (F430), the prosthetic group of CoM (De Mandal et al. 2020).

The **ATP generation** in methanogens is assumed to involve a proton motive force. According to one model, hydrogen is oxidized by hydrogenase on the surface of the plasma membrane to generate hydrogen ions which drive ATP synthesis. Subsequently, the hydrogen ion is used to reduce carbon dioxide inside the cells. This process also uses up the electrons generated during hydrogen oxidation by hydrogenase (De Mandal et al. 2020).

1.4.3 Use of Mixed Microbial Culture

When two distinct microorganisms work together, xenobiotic substances can be entirely degraded. In contrast, neither of them could accomplish this degradation on their own. *Acinetobacter*, for instance, has plasmid-borne genes for the dihydroxylation of one of the rings of 4-chlorobiphenyl, cleavage of the meta ring, and subsequent degradation to yield 4-chlorobenzoate. However, it is unable to degrade this product further. *Pseudomonas putida* strains use the Ortho Pathway to break down the 4-chlorobenzoate ring, producing acetyl-CoA and succinate in the process, but they are unable to use 4-cholorobiphenyl. Acinetobacter and *Pseudomonas putida*, all together, decompose the xenobiotic 4-chlorophenyl entirely but are not able to degrade it alone (Marghade et al. 2021).

One bacterium can provide the nutrients needed by another for growth. For instance, *Nocardia cyriacigeorgica* can break down cyclohexene but cannot make biotin. When *Pseudonocardia* species break down cyclohexene, and *Nocardia* cells are lysed, *Pseudomonas* uses these products to grow and release biotin species strains, but it is unable to break down cyclohexene itself. In turn, the biotin encourages Nocardia's growth and cyclohexene's breakdown. Therefore, cyclohexene would be broken down if these two strains were together, but neither one could do it alone (Nawaz et al. 2011; Marghade et al. 2021).

Due to microbial interactions, the biological treatment system, or the microbial population utilized for xenobiotic breakdown, is more stable and typically achieves greater biodegradable rates (Adkins 2019).

1.4.4 Bioremediation

Bioremediation strategies utilize natural frameworks to deal with toxins and are environmentally reliable and a substitute for normal decay. These procedures regularly include bioaccumulation, biosorption, bioaugmentation, and biodegradation (Devi et al. 2022; Kashyap et al. 2019; Solanki et al. 2019)**.** Bioaccumulation is characterized as the ability of the live biomass to assemble the contaminant, which depends on biomass's resilience and take-up limits. The limitation of this procedure is that microbial development is restricted when the toxin focuses are excessively raised for bioaccumulation and such microbial cells need metabolic vitality (Robinson et al. 2001). Biosorption, for the most part, includes the adsorption wonders, any place the pollutants (adsorbate) are adsorbed against regenerative and eco-accommodating adsorbents/biosorbents. The limitation of this strategy is that it cannot be utilized for treating voluminous effluents since the issues are related to removing adsorbed biomass (Kuhad et al. 2004). Bioaugmentation is the strategy for presenting picked species which might be endogenous or exogenous to an intricate domain with contaminations (Joshi et al. 2017). The disadvantage of the bioaugmentation strategy is that the presented bacterial strain might be fruitless to develop or live as they endure some serious hindrances with the ecological toxin (Nzila et al. 2016). Biodegradation is a modest and compelling method of regarding wastewater as it is cheap, eco-accommodating, and naturally appropriate and has less slop-creating properties (Saratale et al. 2011).

1.4.5 Bioremediation by Bacterial Strains

Bioremediation of natural contaminants is founded on microorganisms ordinarily present at the destinations or on microbial inoculants created in the lab and presented at the locales. Certain bacterial, fungal, and algal species are also equipped to collect toxic inorganic contaminants. However, there is no practical strategy for eliminating these microorganisms from the dirt after sequestering the inorganic particles. Therefore, bioremediation of inorganic contaminants is basically founded on appropriate bacterial species. The biological management processes using a wide range of microorganisms (bacteria, fungi, yeast, and algae) can overcome the limitations because it is cost-effective, produces a reduced amount of sludge, and is eco-friendly to conventional physico-chemical treatment. Different trophic groups of bacteria (i.e., *Pseudomonas, Staphylococcus, Halomonas,* etc.) have been reported to accomplish a higher extent degradation of many pollutants under the most favourable conditions compared to other microbes. The bacterial method may be able to degradation of the chemical effluents in anaerobic and aerobic conditions or engage a combination of the two (Verma et al. 2021).

Tables 1.1 and 1.2 show bacterial remediation of various chemical and heavy/toxic chemicals usually present in liquid waste, which causes chemical illness and are harmful to the environment.

1.5 Role of Microbial Fuel Cells (MFCs) in Wastewater Treatment

MFC (biofuel device) is a bio-electrochemical device that converts chemical energy into electrical energy by using microorganisms that act as a degradation catalyst of wastewater. The chapter mainly focuses on the use of sewage or liquid waste to produce bioenergy with the help of microorganisms (Obileke et al. 2021).

1.5.1 Basic Components of MFCs with Their Factors Affecting Efficiency

A regular/basic MFC comprises an anodic and cathodic chamber isolated by a proton exchange membrane (PEM)/salt bridge. The cathodic chamber usually opens directly to the air, which is shown in Fig. 1.5.

1.5.1.1 Electrode Material

As a conductivity electrode, platinum, platinum black, graphite, carbon paper, graphite felt, and other materials are used. The same electrode material will be used in both chambers. The type of material that would be used in the electrode material will be shown vital effects on efficiency. For better-performing electrode material use will consistently improve the presentation of MFCs on account of various material outcomes in various enactment polarization losses (Saran et al. 2022).

1.5.1.2 pH Buffer and Electrolyte

pH buffer and electrolyte used in the cathode chamber are platinum, platinum black, polyaniline, phosphate, etc. In the event that no buffer is utilized in working MFCs, at that point there will be a self-evident no pH difference between anode as well as cathode chamber. The use of electrolyte is to create a pH discrepancy which expands

Table 1.1 Microorganisms' tendency to remediate their respective chemicals

Chemical	Microorganisms	References
Sodium (Na^+)	*Rhodobacter sphaeroides, Rhodovulum* sp.	Sasaki et al. (2017)
Calcium (Ca^{2+})	*Bacillus licheniformis SRB2*	Zhao et al. (2019)
	Sporosarcina pasteurii, Bacillus megaterium	Chaparro-Acuña et al. (2018)
Magnesium (Mg^{2+})	*Bacillus licheniformis SBR2*	Zhao et al. (2019)
Aluminium (Al^{3+})	*Vibrio alginolyticus*	Purwanti et al. (2019)
Iron (Fe^{3+})	*Rhodobacter capsulatus, Pelobacter carbinolicus, Geobacter sulfurreducens, Gallionella capsiferriformas strain ES-2*	Gnanaprakasam et al. (2017)
Nitrogen ammonical (NH_4^+)	*Nitrosomonadales* convert NH_4^+ to NO_2^-, *Nitrospirales convert* NO_2^- *to* NO_3^-, *Chlorella vulgaris, Bacillus cereus, Pseudomonas putida*	Maharjan et al. (2020)
		Gómez-Guzmán et al. (2017)
Carbonate (CO_3^{2-})	*Cyanobacteria, Synechococcus Prochlorococcus*	Kamennaya et al. (2012)
Chloride (cl^-)	*Escherichia coli*	Owoseni et al. (2017)
Fluoride (F^-)	*Bacillus flexus PN4*	Sakthi Thesai et al. (2020)
	Providencia vermicola KX926492	Mukherjee et al. (2017)
Sulphate (SO_4^{2-})	*Salmonella typhimurium, Clostridium pasteurianum*	Gnanaprakasam et al. (2017)
	Desulfovibrio sp, *Desulfotomaculum* sp.	Piacenza et al. (2018)
Sulphite (SO_3^{2-})	*Chromatium vinosum* (as hydrogen sulphite degrade)	Syed et al. (2006)
Nitrate (NO_3^-)	*Massilia brevitalea, Psychrobacter glacincola, Arthrobacter defluvi, Pseudomonas antarctivca, Rhodobacter* sp.	Gnanaprakasam et al. (2017)
	Chlorella vulgaris, Bacillus cereus, Pseudomonas putida	Gómez-Guzmán et al. (2017)
Nitrite (NO_2^-)	*Nitrospora* sp., *Bradyrhizobium, Nitrospira moscoviensis*	Gnanaprakasam et al. (2017)
Phosphate (PO_4^{3-})	*Pseudomonas* sp. *JPSB12, Enterobacter* sp. *TPSB20, Flavobacterium* sp. *TPSB23*	Paul and sinha (2015)
	Chlorella vulgaris, Bacillus cereus, Pseudomonas putida	Gómez-Guzmán et al. (2017)
	Accumulibacter	Zou et al. (2014)
Silica (SiO_2)	*Rhodococcus* sp. *BH4*	Lee et al. (2020)
Potassium (K^+)	*Sapindus mukorossi*	Jassal et al. (2015)

Table 1.2 Microorganisms' tendency to remediate their respective chemicals/heavy metals

Chemical	Microorganism	Reference
Arsenic	*Pseudomonas chengduensis As11, Bacillus flexus As12*	Jebelli et al. (2018)
	Pseudomonas putida strain WB, Geobacter lovleyi, Bacillus selenatarsenatis, Hydrogenophaga sp. *strain CL3, Sinorhizobium, Arthrobacter aurescens, Stenotrophomonas* sp. *strain MM7*	Gnanaprakasam et al. (2017)
	Klebsiella pneumonia, Enterobacter sp.	Abbas et al. (2014a, b)
	Corynebacterium glutamicum	Mateos et al. (2006)
Boron	*E. coli, Enterococcus faecium*	Heim et al. (2015)
	Candida tropicalis, Rhodotorula mucilaginosa, Micrococcus luteus, Bacillus thuringiensis, B. cereus, B. megaterium, B. pumilus, Pseudomonas aeruginosa, Aspergillus versicolor	Laçin et al. (2015)
	Lysinibacillus sp. *21019, B. horneckial DSM23495, Microbacterium* sp. *CRRI-B*	Raja and Omine (2013)
	Variovarox, Shewanella, Mycobacterium, Rhodococcus, B. simplex	Miwa and Fujiwara (2009)
Cadmium	*Lactobacillus plantarum CCFM8610*	Zhai et al. (2017)
	Pseudomonas sp. *M3*	Abbas et al. (2014a, b)
	Pseudomonas aeruginosa strain KUCd1	Sinha and Mukherjee (2009)
Lead	*Pseudomonas aeruginosa ATCC27853*	Babiker et al. (2020)
	Providencia alcalifaciens strain 2EA	Naik et al. (2013)
Cadmium +Lead	*Bifidobacterium longum46, Lactobacillus fermentum ME3, Bifidobacterium lactis Bb12*	Halttunen et al. (2007)
Chromium	*Lactobacillus plantarum MF042018*	Ameen et al. (2020)
	Klebsiella pneumoniae strain MS 1.5, Mangrovibacter yixingensis strain MS2.4	Sanjay et al. (2020)
	Lactobacillus rhamnosus MTCC 1408, L.casei MTCC1423	Mishra et al. (2012)
	Bacillus coagulans, Desulfomacculum reducens, E. coli, Pseudomonad, P.ambigua G-1, P. putida, Enterobacter cloacae, E. coli ATCC33456, Alcaligens eutrophus AE104, P. fluorescens, B. mycoids, Shewanella oneidensis strain MR-1	Singh (2008)
Copper	*Enterococcus faecium*	Yilmaz et al. (2010)
	Geobacter metallireducens, Geobacter sulfurreducens	Fang and Achal (2019)
Cyanide	*Pseudomonas pseudoalcaligenes CECT5344,*	Luque-Almagro et al. (2016)
	Bacillus pumilus	Kandasamy et al. (2015)

(continued)

Table 1.2 (continued)

Chemical	Microorganism	Reference
Manganese	*Pseudomonas putida strain MnB1, Pseudomonas* sp. *strain SK3*	Kitjanukit et al. (2017)
Selenium	*Lysinibacillus* sp., *Azospirillum* sp., *Burkholderia fungorum, Bacillus cereus, Bacillus safensis JG-B5T, Alishewanella* sp. *WH16–1, Stenotrophomonas maltophilia SeITE02*	Sinharoy and Lens (2020)
	Aeromonas sp.*VS6, Citrobactor freundiiKS8Pseudomonas flurescens K27, Enterobacter cloacae SLS1a-1, R. spharoids, R.rubrum S1*	Piacenza et al. (2018)
	Pseudomonas stutzeri NT-1	Kuroda et al. (2011)
Mercury	*Pseudomonas aeruginosa ATCC27853*	Babiker et al. (2020)
	Vibrio fluvialis	Saranya et al. (2017)
	Pseudomonas sp. *B50A*	Giovanella et al. (2016)
	Cupriavidus metallidurans strain MSR3	Rojas et al. (2011)
	Pseudomonas putida spi3	Von canstein et al. (1999)
Zinc	*Bacillus megaterium EMCC 1013, Rhizobium rhizogenes EMCC1743, Rhizobium leguminosarum EMCC1130, Azotobacter vinelandii, Nocardiopsis dassenvillei*	El-Barbary and El-Badry (2019)
	Bacterium VMSDCM	Mishra et al. (2014)
Antimony	*Sinorhizobium* sp. *GW3*	Li et al. (2019)
	Cupriavidus, Moraxella sp. *S2*	Li et al. (2018)
Tellurium	*E. coli, Lactococcus lactis, R. capsulatus, R.rubrum G9, R. capsulatus, P.fluorescens K27, D.gigas, P.aeruginosa ML4262, Stearothermophilus, Mycobacteruim tuberculosis, B.beveridgei, B.selenitireduceus, S.barnesii, Shewanella frigidimarins ER-Te-48, Bacillus* sp. *GT-83,*	Piacenza et al. (2018)
	Pseudoalteromonas sp. *strain EPR3*	Bonificio and Clarke (2014)
	Stenotrophomonas maltophilia TI-1Ochrobacterum anthropi TI-2, Ochrobactrum anthropi TI-2	Kagami et al. (2012)

the main motivation of the proton spreading from the anode to the cathode chamber, which at last forms an equilibrium (Saran et al. 2022).

1.5.1.3 Proton Exchange Membrane (Salt Bridge)

PEM, which uses materials like Nafion, Ultrex, porcelain septum, and others, can alter the internal resistance and concentration polarization loss of MFCs, which in turn affects the power output of the MFCs. Nafion is the most well-liked due to its very selective proton permeability (Obileke et al. 2021).

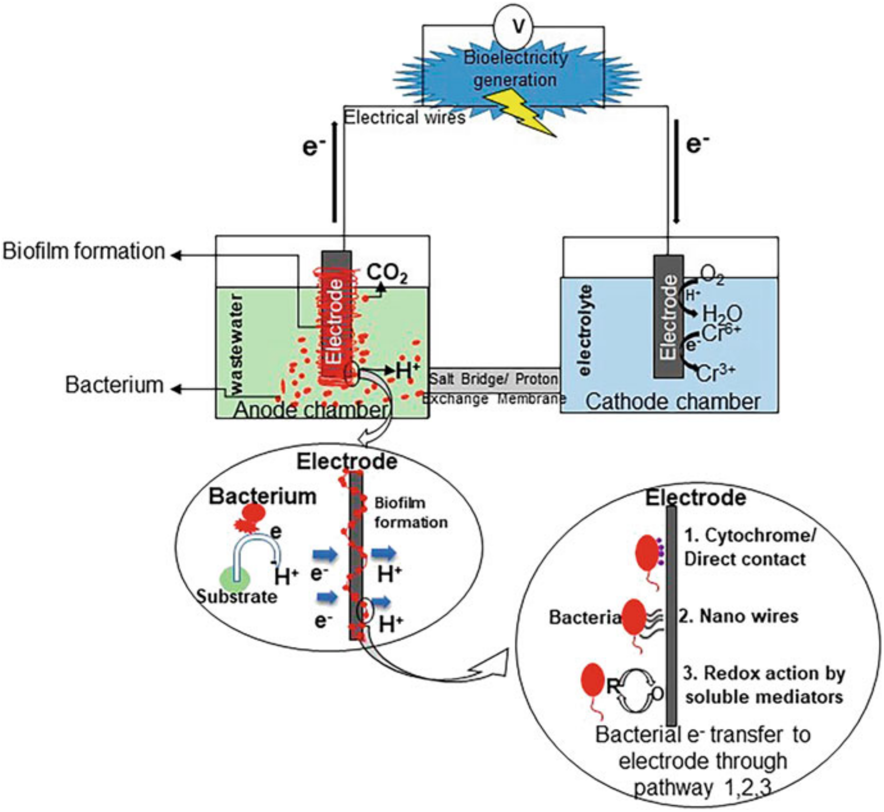

Fig. 1.5 Microbial fuel cell with its basic components. (CO_2 carbon dioxide, O_2 oxygen, e^- electron, H^+ proton/hydrogen ion, Cr^{6+} *and* Cr^{3+} chromium ion)

1.5.1.4 Operating Condition in the Anodic Chamber

Glass, polycarbonate, plexiglass, etc., are used for the chamber. The kind of substrate, concentration, and feed rates are crucial variables in determining how effectively MFCs work. Power density changes with the varied substrates by using a single microbe or a mixed microbial consortium. In batch or continuous flow mode MFCs, the substrate concentration determines the amount of electricity produced (Obileke et al. 2021).

1.5.1.5 Operating Condition in the Cathodic Chamber

The same type of material (glass, polycarbonate, plexiglass, etc.) will be used for both chambers. In the cathode chamber, oxygen is the most commonly used electron acceptor. Power output depends on the concentration level of electron acceptors.

1.5.2 Mechanisms of MFCs

As we know, MFC is a bioelectrochemical device that converts chemical energy into electrical energy by the use of microorganisms which utilize the substrate (liquid waste). Also, MFCs simultaneously reuse wastewater and generate electricity. The electricity production from microbes is described as a regular/basic MFC comprising an anode and cathode compartments separated/ distant by a PEM/salt bridge. Microbes in the anode chamber metabolize the organic compounds or substrate, which acts as an electron donor. The metabolism of these organic compounds generates electrons and protons. The electrons first transfer to the anode surface and second migrates via an electrical circuit to the cathode. On the other hand, the flow of protons first migrates to the electrolyte or buffer solution via the PEM/salt bridge. This electron and proton are consumed in the cathode reduction by the electron acceptors and, after that, bioelectricity generation (Chaturvedi and Verma 2016).

1.5.3 Types of MFCs

They are broadly classified as a mediator and mediator-less MFC.

1.5.3.1 Mediator MFCs

A large portion of the microbial power devices is electrochemically indolent. The mediators strengthen the electrons moving from MFCs to the electrode, such as thionine, methyl viologen, methyl blue, humic acid, or another chemical that enhances the electron transfer. Also, most of the mediators accessible are expensive and toxic.

1.5.3.2 Mediator-Less MFCs

This type of MFCs does not require a mediator but electrochemically active bacteria to transfer an electron to the electrode. These electrons are conveyed straightforwardly from the bacterial respiratory catalyst to the electrode. Mediators- less MFCs are a later region of study. Because many aspects determining optimal efficiency, such as bacteria strain, type of PEM, pH, and so on, are poorly understood, Mediators-less MFCs are a later area of study (Kumar et al. 2017).

1.5.4 Research Organization on MFCs

1.5.4.1 International Status

During the last couple of decades, extensive basic/ fundamental research work has been carried out in many institutes worldwide, a glimpse of which is presented here. The accelerated rate of publication, particularly during the last decade, is quite evident in Fig. 1.5, presented below.

The research in Bio-Energy & Environmental Biotechnology at the Energy and Biotechnology Department of Ecological and Biological Engineering of Oregon State University includes electricity generation using MFCs and Hydrogen production using microbial electrolysis cells (MECs). Currently, the group focuses on reactor design, membrane/cloth selection, electrode development, isolation of exoelectrogens, and system optimization to improve power generation and hydrogen production from various waste biomass. In May 2009, the Department of Earth Sciences at the University of Southern California, Los Angeles, published a paper titled "Electricity production coupled to ammonium in a microbial fuel cell" (He et al. 2009).

MFCs offer great promise for simultaneous wastewater treatment and renewable energy generation. The Penn State group, led by Dr. Bruce Logan, focuses primarily on MFC architecture and factors that will lead to successful scale-up designs. They used air-cathode and aqueous (dissolved oxygen) cathode systems to understand better factors that limit power generation and examine how power density can be increased while using low-cost yet effective materials.

Below is a list of various international institutes working on MFCs.

- Penn State University (USA)—The Logan Group.
- Medical University of South Carolina (MUSC) (USA)—May Lab.
- Gwangju Institute of Science and Technology (Korea) The Energy and Biotechnology Laboratory (EBL).
- Harbin Institute of Technology (HIT) (China) School of Municipal and Environmental Engineering, Advanced Water Management Centre.
- The University of Queensland, St. Lucia, Australia.
- Istituto per l'Ambiente Marino Costiero (IAMC) IST-CNR Section of Messina, Messina, Italy.
- Department of Earth Sciences, University of Southern California, Los Angeles, California.
- Dépt. deGénie Chimique, Ecole Polytechnique de Montréal, Centre-Ville, Montréal, QC, Canada.
- School of Chemical Engineering and Advanced Materials, Merz Court, Newcastle University, Newcastle upon Tyne, UK.
- US Naval Research Laboratory Washington, DC (USA)—The Ringeisen Group.

1.5.4.2 National Status

R&D on biofuel has started more recently (since the year 2000) in India. The rate of publication has accelerated during the last few years, as shown in Fig. 1.6. It is evident that there are only a few institutes which are involved in biofuel cell development, as listed below:

- Indian Institute of Chemical Technology, Bioengineering and Environmental Centre (BEEC), Hyderabad, India.
- Biotechnology Department, IIT Madras, Chennai, India.
- Indian Institute of Technology Delhi, New Delhi.

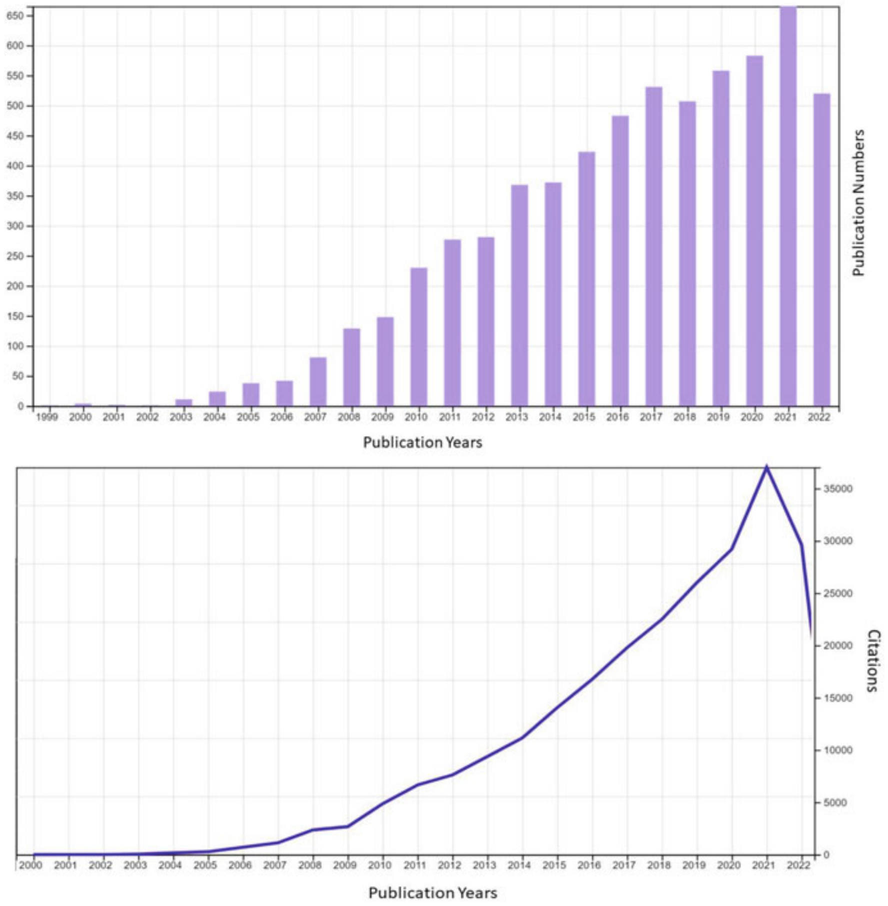

Fig. 1.6 Histogram shows the year-wise worldwide research publication on microbial fuel cells with their citation analysis

- Indian Institute of Technology Bombay, Mumbai.
- Vellore University.
- Department of Civil Engineering, Indian Institute of Technology, Kharagpur.
- Central Electrochemical Research Institute, Karaikudi, Tamilnadu, India (Ministry of New and Renewable Energy, Government of India 2016).

The last few years have seen considerable research activity in India's biofuel cells, mainly via R&D work sponsored by the MNRE, DST, CSIR, etc. PEM Fuel cell uses an extensive range of materials. Such materials are electrocatalysts, catalyst support, gas diffusion media, microporous materials, hydrophobic materials, hydrophilic materials, different types of carbon, electrolyte, sealants, and conducting coating materials as shown in Fig 1.7 and Table 1.3.

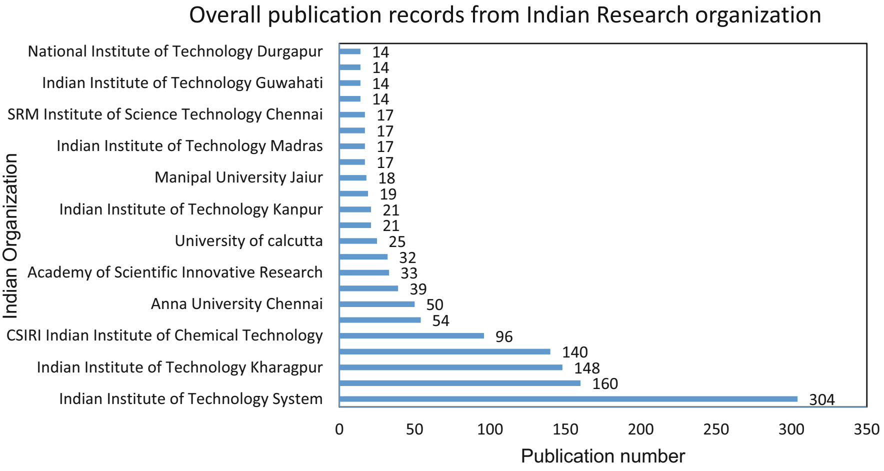

Fig. 1.7 Total number of research publications on microbial fuel cells from different institutes of India (https://www.webofscience.com)

Table 1.3 Depiction of various work organizations and the various forms of work they execute

Work organizations	Nature of work
IIT-M, NCCR, IIT-B, IIT-G, IIT-K, IIT-Kh, IIT-R, IIT-H, IISc, BESU, CSIR-CECRI, CSIR-NCL, CSIR-NPL, CFCT-ARCI, CIPET, CSIR-CSMCRI, BITS-Goa, TU, AIIST, PSGIAS, Anna University, UoH, DTU, and many other Universities	• Basic Science • Catalysts, Membrane, Bipolar plate • Modelling
BHEL, CSIR-CECRI, CFCT-ARCI, IIT-B, SSF (closed), ISRO Labs & Def. Labs	• Stack and System • Application demonstration
Tata, M&M, TVS, REVA, NMRL, some CSIR Labs, IITs, BPCL, RIL	• System integration using bought-out stacks for demonstration • Demonstration of indigenously

IIT Indian Institute of Technology, *CSIR* Council of Scientific and Industrial Research, *TU* Tamilnadu University, *BITS* Birla Institute of Technology and Science, *DTU* Delhi Technical University

1.5.5 Application on Microbial Fuel Cell

Although MFCs have been studied as an alternative energy source, their application is restricted to certain zone only. With further upgrades in configuration, cost-viability, and execution proficiency are dependent on these close-to-term applications, as shown in Fig. 1.8. It is conceivable to scale up and use MFCs as an environmentally friendly power asset. The clearest utilization of MFCs is the abundance of power. They can be used in the rural area and the urban segment. Even though power generation using energy components has not been very successful on a small scale, large-scale application can be successful. These have a conversion efficiency of fuel to the power of request of 70% or more and are not limited to

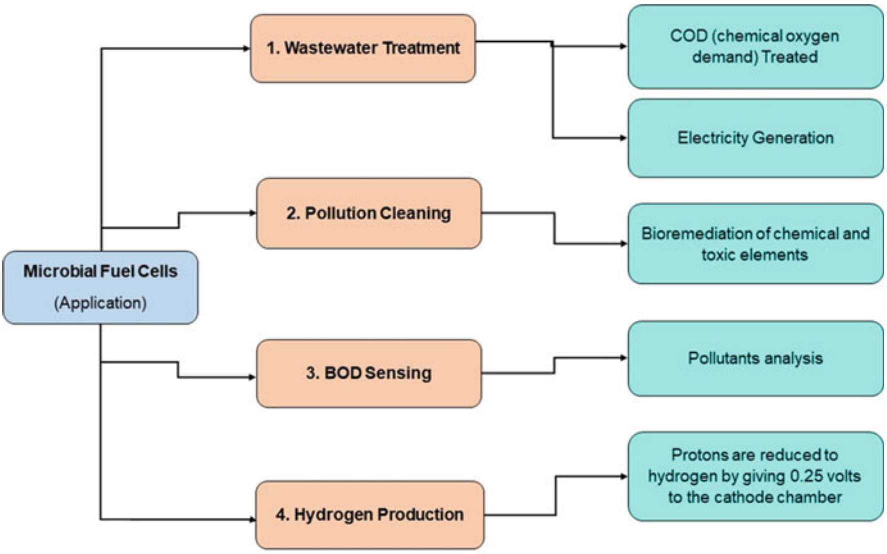

Fig. 1.8 Applications of microbial fuel cells in different areas

the Carnot cycle. Higher energy recovery of 80% to 97% has been accounted for. An ideal approach is to use is to store the electricity in a rechargeable battery.

1.5.5.1 Wastewater Treatment

The microbes can generate power while also decomposing effluents. MFCs are straightforwardly under genuine thought as gadgets to deliver electrical force all through the treatment of mechanical, agribusiness, and metropolitan wastewater. When microorganisms oxidize natural compounds in the wastewater, electrons are delivered, yielding a consistent quantity of electrical current. Suppose the power age in this framework can be extended. In that case, MFCs may give another strategy to offset the operating costs of wastewater treatment plants, making advanced wastewater treatment more moderate in both making and industrialized nations. Moreover, MFCs are also mentioned to create less waste when contrasted with the high-sway treatment measure (Li et al. 2014).

1.5.5.2 Cleansing Contaminated Lakes and Rivers

MFCs can be used in the bioremediation of water containing characteristic contaminations, for example, toluene and benzene mixes found in gas. The MFCs configuration is changed so the power device floats on the head of contaminated water. The anode is lowered in the water where natural toxic feed the microorganisms, and the cathode float on topor head of the water. Normal pollution is the degeneration of carbon dioxide and water, purifying the contaminated lake or stream. The MFCs can be excused in distant common water waterways, many equivalents to the remote sensor (Chen et al. 2022).

1.5.5.3 Biological Oxygen Demand (BOD) Sensing

Another possible use of the MFCs innovation is to use it as a sensor for contamination examination and in situ measure noticing and control. Biological oxygen demand (BOD) is the proportion of split oxygen expected to meet the metabolic necessities of high-impact life structures in water rich in natural issues, for instance, sewage. The related association between the coulombic yield of MFCs and the centralization of adapting characteristic impurities in wastewater makes MFCs possibly usable as BOD sensors. An MFC-type BOD sensor can be saved operational for over 5 years without extra help for more organizational life length than such a BOD sensor detailed in the literature (Do et al. 2020).

1.5.5.4 Hydrogen Production

Hydrogen creation by modified MFCs fragmenting away at natural waste may be fascinating for other options. In such a gadget, anaerobic conditions are kept up in the cathode chamber, and an additional voltage of 0.25 volts is to the cathode. Under such conditions, protons are decreased to hydrogen on the cathode. Such adjusted MFCs are named bio-electrochemically helped microbial reactors. (Vishwanathan et al. 2013).

1.6 Challenges of MFCs

MFCs, a promising innovation for power generation by utilizing waste material, experience numerous difficulties that obstruct their commercialization. A fraction of the significant void openings of this innovation are as per the following: -

- The power density obtained by xenobiotics and waste is very low compared to pure carbon sources. This hinders its applicability in waste management and electricity generation for day-to-day purposes. (Chaturvedi and Verma 2016).
- Pure carbon sources cannot be routinely employed for electricity generation because they are expensive compared to waste. (Chaturvedi and Verma 2016).
- The material used for a cathode/ anode and membrane during the scaling up of MFCs is costly and suppresses its commercialization.

1.7 Conclusions and Future Prospects

1.7.1 Conclusions

Wastewater is perceived as making a significant commitment to natural contamination. MFCs are an innovation for the creation of power from the metabolism of the microorganism. In this chapter, we interact with considerable liquid waste and its xenobiotic substances, such as a chemical parameter hazardous compound that is extremely dangerous to the environment and toxic to the organism.

MFCs are used for power generation and are transformed into less toxic compounds, which exhibited its other possible use in waste management and pollution control. A large number of microorganisms and a waste assortment of the substrate (including xenobiotics) have been utilized in the creation of power. A significant drawback of this innovation is that power output is very low, and scaling up reductions in power output. This is the principal motivation behind why this innovation has not yet been popularized. Thus, a great deal of work is required so this innovation gets proficient, appropriate, and generally acknowledged.

1.7.2 Future Prospects

MFCs are a promising innovation for generating energy using natural substances, particularly from a diverse natural waste source. In any case, there are sure disadvantages, which have impeded making it more material when reasonable applications are concerned. The major drawback of MFCs and possible solutions which can help to enhance the efficiency of MFCs. Drawbacks like low power density can be improved by isolating microorganisms that can transfer electrons to the anode or by generating recombinant strain that shows more excellent electron transfer rates. For electron transfer, many reports have confirmed that a relatively pure culture, a consortium of bacterial cultures, will improve electron transfer. Also, many bacterial cultures produce mediators which efficiently transfer electrodes to the anode. Another drawback is the limited surface area of the electrodes where microorganisms adhere. Studies have been performed on MFC reactors and have resulted in designing more efficient laboratory-scale MFCs. These include the use of air cathode, stacked reactor, and cloth electrode assemblies.

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