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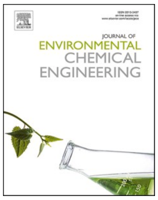

Biodiversity in microbial fuel cells: Review of a promising technology for wastewater treatment

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ABSTRACT

Microbial variety has many functions, and most bacteria can be employed as a biocatalyst in a Microbial Fuel Cell (MFC). MFC is an anaerobic bioreactor that transfers chemical energy in organic compound chemical bonds to electrical energy through catalytic reactions of microorganisms. Various microorganisms in the form of a community or consortium have a higher ability to transfer electrons to the anode and increase the degradation of the organic compound than pure cultures. Scientists have known that bacteria may produce electricity by breaking down organic substrates for years. Today, the presence of the energy crisis and batik industry has reignited interest in MFCs among university academics as a technique to convert biomass to hydrogen without releasing net carbon into the atmosphere. Batik wastewater can be used as a substrate for MFC to generate renewable energy (electricity) and bioremediation of chromium. This study reviews a diverse community of bacteria in microbial fuel cells, which may be used to remediate industrial effluent.

1. Introduction

The use of fossil fuels, notably oil and gas, has grown recently, resulting in a global energy crisis [1]. Using renewable bioenergy is one strategy to address the current global warming problem. A lot of attention is being paid to alternative electricity-producing methods. In recent years, academic researchers have been particularly interested in a technology known as microbial fuel cells (MFCs), which use microbes to catalyze the conversion of energy held in chemical bonds in organic compounds to electrical energy [2–5]. Bacteria can produce electricity in MFCs while simultaneously biodegrading organic materials or trash [6,7]. Thus, using MFCs that utilize microbes can be an alternative to electricity generators in the present and the future.

Microbes in the anodic chamber of an MFC oxidize additional substrates, producing electrons and protons in the process. Carbon dioxide is produced during oxidation. However, no net carbon emission occurs because the carbon dioxide in renewable biomass is derived from the atmosphere during the photosynthetic process. Microbes in the anodic chamber absorb electrons and protons during the dissimilative process of oxidizing organic substrates [8]. To generate electric current, microbes must be kept segregated from oxygen and any other end terminal acceptor other than the anode, which mandates the use of an anaerobic anodic chamber.

Recent years have seen rapid advancements in MFC research, with the number of journal publications doubling in the previous three years as more scientists enter the field. Various reviews on MFC, each with a unique taste or emphasis, examined MFC’s design [9], characterization, and performance. Rabaey et al. [8] examined microbial metabolism in MFCs from the standpoint of microbial physiologies. Lovely et al. [10] focused on the potential use of MFC systems dubbed Benthic Unattended Generators (BUGs) to remote power filtering or monitoring devices [11] and compared MFCs to standard anaerobic digestion technology to

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produce biogas as a green energy source. Chang et al. [12] investigated the characteristics of electrochemically active bacteria used in mediator-free MFCs and the rate-limiting electron transport pathways. Bullen et al. [13] compiled various experimental results on MFCs. Zhuwei et al. [1] detailed the present state of the art in MFC, emphasizing recent advances in MFC reactor design, performance, and optimization of critical operational parameters. This study demonstrates a diverse array of bacteria in microbial fuel cells, which may be used to remediate industrial effluent.

2. Microbial fuel cell evolution

In theory, any microbe might be used as a biocatalyst in MFC. Potter pioneered the MFC concept in 1910 [14]. With the help of platinum electrodes, energy was generated using *E. coli* and *Saccharomyces* as MFC [15]. It drew little attention until the 1980 s, when it was discovered that incorporating electron mediators may significantly improve current density and power output. Unless the bacteria in the anodic chamber are anodophiles, they cannot transport electrons straight to the anode.

Most of the outer layers of microbial species are composed of non-conductive lipid membranes, peptidoglycans, and lipopolysaccharides that hinder direct electron transfer to the anode. Electron mediators expedite the transfer [16]. Trapping electrons from within the membrane can rapidly decrease oxidized mediators. The mediators travel through the membrane, delivering electrons to the anode and oxidizing them in the anodic chamber's bulk solution. This cyclic process increases power generation by increasing the rate of electron transport. A good mediator should exhibit the following properties [17]– (i) the ability to cross the cell membrane easily; (ii) the ability to grab electrons from the electron carriers of electron transport chains; (iii) a high electrode reaction rate; (iv) good solubility in the anolyte; (v) non-biodegradable and non-toxic to microbes; and (vi) low cost.

And how effectively do cells eliminate oxidized mediators? In comparison to other aspects, power savings are more critical. While the lowest redox mediator would theoretically have the lowest anodic redox and maximize the redox difference between the anode and cathode (i.e., provide the most significant voltage difference), it would not necessarily be the most efficient at extracting electrons from the microbes' reduced intracellular systems (NADH, NADPH, or reduced cytochromes). A mediator with a higher Eo redox value than one with the lowest redox value will have a more significant total power [17]. Synthetic exogenous mediators include dyes and metallorganics such as neutral red (NR), methylene blue (MB), thionine, meldola's blue (MelB), 2-hydroxy-1, 4-naphthoquinone (HNQ), and Fe (III EDTA) [2,17–21].

However, the toxicity and instability of synthetic mediators preclude their application in MFCs. Certain microbes can utilize endogenous mediators, chemicals naturally occurring in the environment, such as microbial metabolites. Humic acids, anthraquinone, and sulfur oxyanions (sulfate and thiosulphate) can transmit electrons from the cell's inner membrane to the anode [22]. A breakthrough occurred when it was discovered that microorganisms could carry electrons directly to the anode [23,24]. These bacteria have a high Coulombic efficiency and are highly stable in their operational state [24,25]. *Shewanella putrefaciens* [26], *Geobacteraceae sulferreducens* [27], *Geobacter metallireducens* [28], and *Rhodoferax ferrireducens* [24] are bioelectrochemically active bacteria that can form a biofilm on the anode surface and conduct electrons directly through the membrane.

Biofilms growing on the cathode's surface may contribute to electron transmission between bacteria and electrodes. When bacteria in a biofilm are employed, the anode acts as the ultimate electron acceptor in their dissimilatory respiratory chain. Cathodes can act as electron donors for *Thiobacillus ferroxidans* suspended in a catholyte in an MFC system with microorganisms in both the anodic and cathodic chambers [29]. G. metallireducens and *G. sulfurreducens* [30], and other sweater biofilms [31] may all operate as ultimate electron acceptors by collecting electron sources. MFCs without mediators are advantageous in wastewater treatment and energy generation because they eliminate the cost associated with a mediator [17].

3. Microorganisms that serve as the fuel source for microbial fuel cells

Numerous bacteria can transmit electrons to an anode formed during organic matter metabolism. A partial list of bacteria and associated substrates are listed in Table 1. Marine sediment, soil, wastewater, freshwater sediment, and activated sludge all contain a high concentration of these microorganisms [32,33]. Numerous recent papers have discussed the screening and identification of microbes and the establishment of a chromosomal library for bacteria capable of generating electricity through the decomposition of organic matter [28], [34,35]. Table 1 shows the recent paper about microbes used as biocatalysts in MFCs in the form of pure and mixed cultures.(Table 2).

MFC is commonly used to identify and study a specific electron transfer mechanism. The electron transfer mechanism involves the digestion of macromolecules by heterotrophs and produces organic acids. Several reports show a symbiotic relationship between heterotrophic anaerobic or facultative anaerobic fermenting species that utilize various substrates to produce short-chain fatty acids. Anodophiles (direct conducting types) tend to have a narrow range of substrate utilization and little digesting capability. So they benefit from the association, allowing the anodophile to obtain electrons from macromolecular carbon energy substrates, removing fatty acids, and avoiding end product inhibition by the fermenter.

In addition, using MFC as a producer of electrical energy can use a mixed culture of microbes as a biocatalyst. This happens because mixed cultures are more able to adapt to the environment and increased inter-microorganism metabolism, which increases the transfer of electrons and protons at the cathode, the electrogenic properties of microbes, and the complex syntrophic relationships between species in the MFC [36,37]. Unlike the case with a pure culture which is at risk of decreasing the resistance of the transfer of electrons and electricity produced quickly. This can be seen from the research conducted by [6] that pure culture makes 0.28 mA of electrical power for 14 days compared to mixed cultures, capable of producing 0.7 mA of electrical power for 24 days. Thus, using mixed cultures is assumed to be superior to using MFC as a producer of electrical energy.

Understanding MFC's work requires an understanding of the anodic electron transfer mechanism. As previously stated, microbes carry electrons to the electrode via an electron transport system composed of various components in the bacterial extracellular matrix or electron shuttles dissolved in the bulk solution. Generally, electrons are transferred directly to the final electron acceptor, Fe_2O_3, by contact with mineral oxides and metal-reducing bacteria [38,39]. *Geobacter* sp. is a dissimilatory metal-reducing species that generates biologically useable energy in the form of ATP under anaerobic conditions by dissimilating metal oxides in soils and sediments.

Because the anode, like the solid mineral oxides, serves as the final electron acceptor in mediator-free MFCs made with metal-reducing bacteria primarily from the genera Shewanella, Rhodoferax, and Geobacter, the anodic reaction is identical in this approach (Fig. 1). *S. putrefaciens*, *G. sulferreducens*, *G. metallireducens*, and *R. ferrireducens* all use this process to transport electrons to the solid electrode (anode) [34,38,39].

Although dissimilatory metal-reducing bacteria run most true mediator-free MFCs, *Clostridium butyricum* has been described as an exception [7,40]. While anodophiles can transmit electrons straight to the anode during the initial phases of biofilm growth, mediators such as dye molecules and humic compounds have some effect on mediator-free MFCs. Mn^{4+} or neutral red (NR) added to the anode considerably improves the performance of MFCs utilizing the anodophile *S. putrefaciens* [41]. For bacteria incapable of transporting electrons to the anode, mediators are critical for electron transport. The basic techniques are as

Table 1
Microbes used in MFCs.

Microbes	Substrate	Applications	Reference
Pure Culture			
Bacillus subtilis	Glucose	Electron transfer is caused by excreted redox compounds (mediators) in the broth, which are influenced by microbial physiology	[35]
Rhodoferax ferrireducens	Glucose, Xylose sucrose, Maltose	Mediator-less MFC	[22,36]
Klebsiella pneumonia	Glucose	HNQ as mediator biomineralized manganese as electron acceptor [37,38]	
Pseudomonas aeruginosa	Glucose	Phycocyanin and phenazine-1-carboxamide as a mediator	[8,39]
Escherichia coli	Glucose and Sucrose	Mediators such as methylene blue needed	[14,40, 41]
Gluconobacter oxydans	Glucose	Mediator (HNQ, resazurin, or thionine) needed	[42]
Actinobacillus succinogenes	Glucose	Neutral red or thionin as an electron mediator	[6,43,44]
Erwinia dissolven	Glucose	Ferric chelate complex as mediators	[19]
Lacobacillus plantarum	Glucose	Ferric chelate complex as mediators	[19]
Streptococcus lactis	Glucose	Ferric chelate complex as mediators	[45]
Proteus mirabilis	Glucose	Thionin as a mediator	[5,46]
Mixed Cultures			
Klebsiella, Citrobacter, Enterococcus faecalis, Lactobacillus lactis, and *Escherichia shigella*	Tryptone and Glucose	Produce electricity high as 36,41 mw/m^2 isolated from a hot spring water environment	[47]
Bacillus subtilis and Bacillus cereus	Glucose	Decolorize textile wastewater in 71,7% and produce electricity high as 673 mV/143.4 mg in 7 days	[48]
Bacteroidetes, Proteobacteria, Firmicutes, Actinobacteria and *Acidobacteria*	Sucrose and Glucose	Replacing expensive platinum as a cathode catalyst in MFCs	[49]
Escherichia coli, Saccharomycopsis fibuligera, and mixed culture of *E. coli* and *S. fibuligera*	Peptone and Glucose	It showed high BOD$_5$ and COD removal after 48 h at 76.57% and 77.22%, respectively, and generated 5.49 mA of current, 757 mV of voltage, and the electrical energy produced was 9.216 × 10 − 5 kWh	[50]
Arcobacter, Aeromonas, Pseudomonas, Acinetobacter, Cloacibacterium, and *Shewanella* sp.	Glucose	Degrade 2,4-dichlorophenol and produce electricity high 156 mA/m^2 current density with 41% phenolic degradation	[51]
Alcaligenes faecalis, Enterococcus gallinarum, Pseudomonas aeruginosa	Glucose	Self-mediate consortia isolated from MFC with a maximal level of 4.31 W m^{-2}	[39]

Table 2
Basic components of microbial fuel cells.

Items	Materials	Remarks
Anode	Graphite, graphite felt, carbon paper, carbon cloth, Pt, Pt black, reticulated vitreous carbon (RVC)	Necessary
Cathode	Graphite, graphite felt, carbon paper, carbon cloth, Pt, Pt black, RVC	Necessary
Anodic chamber	Glass, polycarbonate, Plexiglas	Necessary
Cathodic chamber	Glass, polycarbonate, Plexiglas	Optional
Proton exchange system	Proton exchange membrane: nafion. Ultrex, polyethylene, poly (styrene-co-divinylbenzene); salt bridge, porcelain septum, or solely electrolyte	Necessary
Electrode catalyst	Pt, Pt black, MnO$_2$, Fe^{3+}. Polyaniline, electron mediator immobilized on the anode	Optional

follows (Fig. 2).

They collect electrons from microorganisms and discharge them onto the surface of the anode. The electrons are transmitted between the anode and the bacteria via mediators. *Actinobacillus succinogenes*, *Desulfovibrio desulfuricans*, *E. coli*, *Proteus mirabilis*, *Proteus vulgaris*, and *Pseudomonas fluorescens* require external mediators, although some organisms may create their own. For example, *Pseudomonas aeruginosa* utilizes pyocyanin molecules as electron shuttles.

MFCs with mixed cultures have a strong track record. The use of complex mixed cultures (anodic microcosms) enables a much broader range of substrates. When MFCs are mixed, their substrate specificity is far broader than that of pure cultures. When an MFC is injected with sea sediments or anaerobic sludge, mixed cultured microorganisms are present in the anode chamber. In the same chamber, electrophiles or anodophiles coexist with groups that utilize natural mediators in mixed culture MFCs (with anaerobic sludge) [14], establishing a correlation between power production and sulfur component concentrations. Because sludge contains naturally occurring quantities of S-containing material, they discovered that the sulfate/sulfide-mediated system generated 70–80% of the power, while electrophiles generated just 20%− 30%.

The materials used as components of the MFC affect the electrical energy they produce. The electricity in the MFC is provided by external resistors placed between the anode and cathode and the membrane to ensure the transport of ions from one chamber to another. Currently, most materials that make up the anode, cathode, and membrane come from carbon, increasing the resistivity and resistance of electron transfer, which risks decreasing stability and electric power [42]. Thus, some researchers recommend inexpensive anode materials derived from Cu, TiO$_2$, Ni, dan Si materials along with membrane materials in the form of ionic liquid (IL) membranes which can reduce resistivity while reducing the cost of assembling MFC [43,44]. The characteristic of ionic liquids can ensure the selective transport of only protons and no other cations through the membrane so that microbial activity is not affected by the carrier of cations in textile wastewater [45]. Thus, by paying attention to the aspects of the MFC component material, the pH gradient between rooms on the MFC device must be stable so that the metabolic process and electron transfer run smoothly.

4. Microbes found in batik wastewater

Microorganisms in batik wastewater are diverse and can be obtained in various ways, including sample dilution, isolation, microorganism identification using gram staining and biochemical tests, pure culture (multiplication of indigenous microorganisms), and isolates [46] measuring reducing activity. *Bacillus* sp., *Pseudomonas* sp., *Geobacillus* sp. [47], *Lactobacillus delbrueckii* [48], *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Pantoea* sp. [49], *Escherichia coli*, *Klebsiella pneumoniae*. Other microbes such as the consortia *Sargassum* sp. and *Saccharomyces cerevisiae* [50], *Aspergillus* sp. [51], *Saccharomyces cerevisiae* [49], and *Pleoratus ostreatus* [52], as well as *Aspergillus* sp. [51], were also discovered. *Pleurotus ostreatus* bacteria reduce the levels of BOD and COD, but *Lactobacillus delbrueckii* bacteria decolorize synthetic colors. Due to the presence of gram-negative bacteria in batik

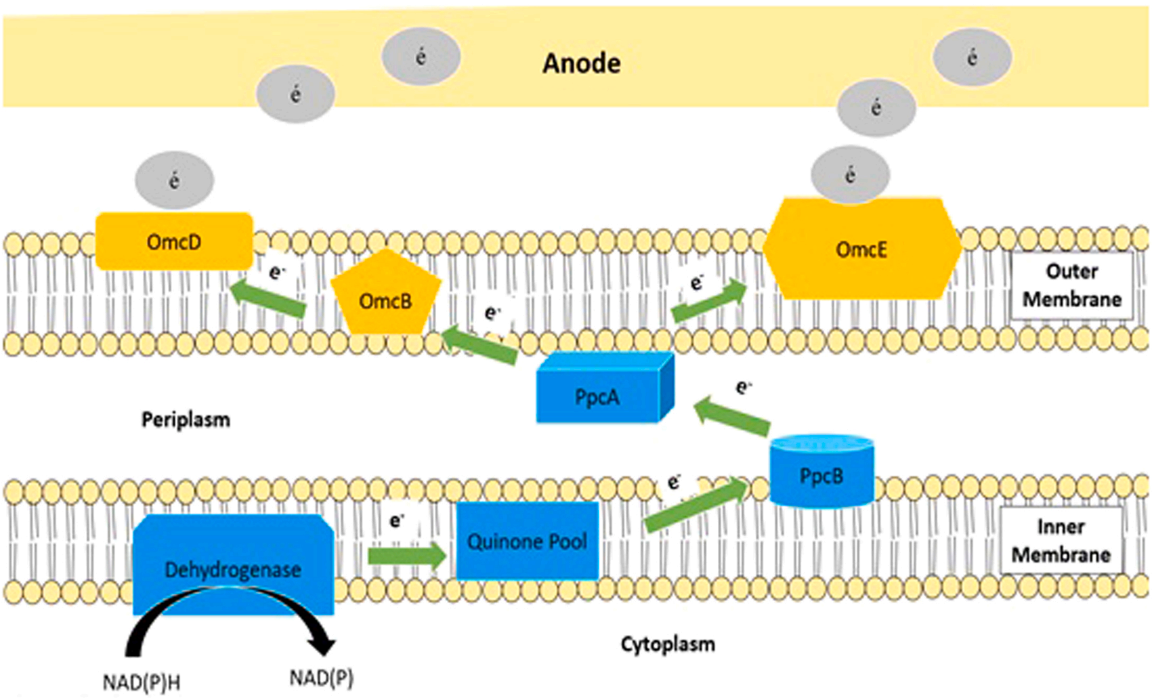

Fig. 1. Components thought to be involved in electron transfer from cells to the anode in MFCs based on metal-reducing microorganisms (*Geobacter* spp).

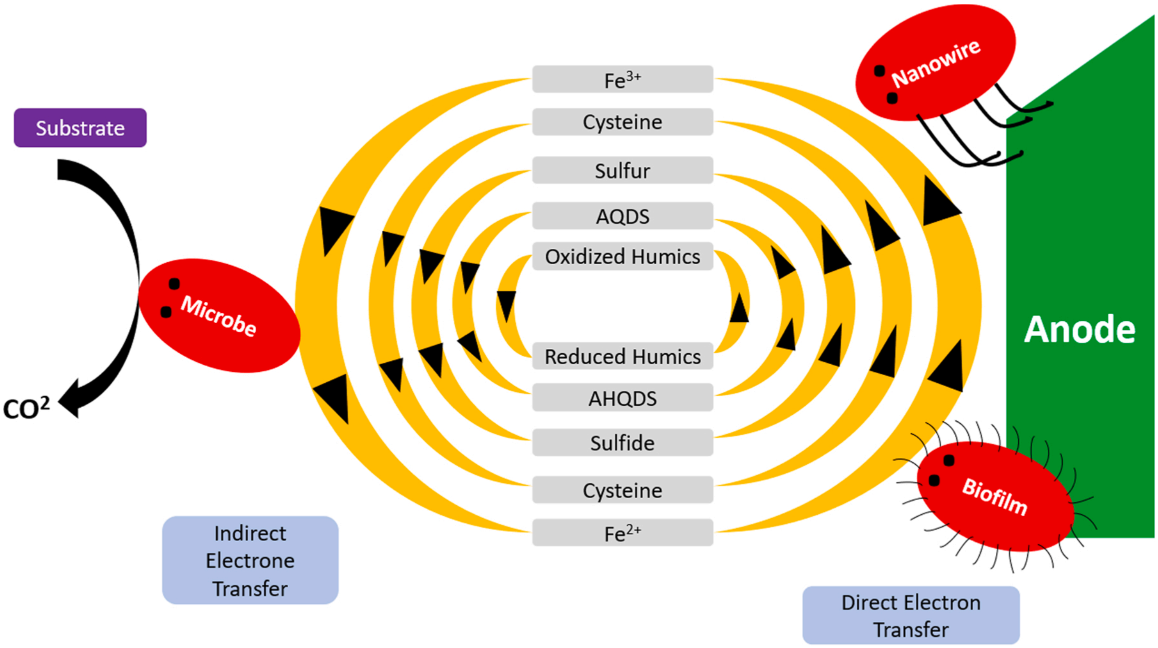

Fig. 2. Model for various compounds acting as electron shuttles between a bioelectrochemical active microorganism and the anode.

wastewater and their capacity to evolve more rapidly to develop resistance, heavy metals such as hexavalent chromium (Cr(VI)) are absorbed through sulfate transport channels in cell membranes and bacterial cytoplasm [53]. Numerous bacteria isolated from batik wastewater communicate enzymatically and cooperatively to lower heavy metal levels [54]. Multiple bacteria in the liquid waste enable it to break down heavy metals effectively and efficiently.

A consortium of microorganisms in the form of bacteria that may digest hexavalent chromium includes *Mesophilobacter, Methylococcus, Agrobacterium, Neisseria, Xantobacter, Deinococcus, Sporosarcina*, and *Bacillus*, which are effective in lowering BOD levels by 85.71% in batik wastewater. This is because of the decomposition of organic matter in batik wastewater due to the action of the azo reductase enzyme produced by a consortium of bacteria such as *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Klebsiella pneumoniae*, and *Escherichia coli*. This consortium effectively reduces the decolorization level of azo dyes [54,55]. Due to the exchange of ions in the cell membrane wall with heavy metal [54], the consortium of microorganisms is also effective in reducing hexavalent chromium (Cr(VI)) in batik wastewater by 73.03%, from an initial concentration of 74.298–20.04 ppm. Hexavalent chromium (Cr VI) can be reduced by azoreductase or chromate reductase enzymes producing microorganisms. This reduction helps in rapid growth and reproduction rates.

The consortium of microorganisms was created by merging individual organisms tha previously propagated through pure culture on a laboratory scale. The microbes were then mixed to evaluate their capability for degrading an environment contaminated with heavy metals. The interaction of microbes in the environment cannot be predicted unless observed in the lab and can boost the final result of heavy metal degradation compared to single isolates [56]. This happens because the work of enzymes from each type of microorganism can complement each other to survive using the available nutrition sources in the growth medium [57]. Consequently, the consortium of microorganisms is regarded as a more effective bioremediation agent than a single isolate.

5. Wastewater treatment

MFCs were explored in wastewater treatment as early as 1991 [58]. MFCs can be charged with various organic compounds found in municipal wastewater. The amount of energy generated by MFCs during the wastewater treatment process may minimize the amount of electricity required by a traditional approach that aerates activated sludges and uses a great deal of electricity. MFCs significantly reduce the amount of solid waste that must dispose of by 50–90% [59]. Additionally, it can degrade organic molecules such as acetate, propionate, and butyrate to CO_2 and H_2O. Because a greater diversity of organics may biodegrade more organics, a hybrid including electrophiles and anodophiles is extremely beneficial for wastewater treatment. Certain bacteria utilized in MFCs have an unmatched capacity for sulfide elimination, which is required for wastewater treatment [60]. MFCs have a high degree of operational stability due to their ability to foster the growth of bio-electrochemical active microorganisms during wastewater treatment. Due to scaling problems, continuous flow and single-compartment MFCs and membrane-less MFCs are favored for wastewater treatment [61,62]. Sanitary wastes, food processing wastewater, swine wastewater, and corn stover are all suitable biomass sources for MFCs due to their high organic matter content [63–66]. In some cases, up to 80% of COD can be removed [65,67], while up to 80% of Coulombic effectiveness has been recorded [26].

The liquid waste treatment process at MFC involves waste degradation and decolorization processes. The transfer of electrons from waste substrates and electricigens can degrade existing specific compounds such as azo compounds, phenols, and heavy metals to become more straightforward and less dangerous. Batik and textile liquid waste can be handled using living cells through bioaccumulation and bioaugmentation. Increasing MFC in waste handling can be done by bioaugmentation using carbon source substrates (glucose, cellulose, and hemicellulose) or microbes. In addition, in overcoming textile waste pollution, the electricity generated by the MFC can detect the presence of waste toxicity which is also often collaborated with CW (Constructed Wetland), known as MFC-CW, which in its application is still in the development stage [68]. The utilization of MFC can increase the efficiency of textile waste decolorization by neutralizing the pH of the waste and reducing the levels of BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), and TS (Total Solid). Based on the results of research conducted by [69] shows that the electric power generated by MFC in textile waste is directly proportional to the reduction in BOD, COD, and TS levels and increases the pH level of the waste with removal percentages of 74.7%, 79, 6%, and 66.7%.

Discharging untreated wastewater from batik textile industries has caused enormous addition of chromium metal ions in the water. The hexavalent chromium (Cr VI) compounds have toxic effects on humans, animals, plants, and microorganisms. In humans, the effects of chromium range from skin irritation to DNA damage and cancer development [70]. A lasting and continuative exposure to chromium, even at low concentration, can damage the skin, eyes, blood, respiratory, and immune systems [71]. It causes asthma, nasal ulcers, convulsions, acute gastroenteritis, and damage to the liver and kidneys [70]. On a cellular level, the genotoxic effect of chromium leads to oxidative stress, DNA damage, and tumor development [72]. People exposed to high levels of chromium are more likely to suffer lung and nasal sinus cancer. Both of these cancers have a high mortality rate. Cr VI has been linked to male infertility and stunted child development [73].

6. The advantages of MFC as a wastewater treatment and electricity energy producer

MFCs can degrade organic and inorganic compounds (heavy metals) from wastewater and power electricity generation. The paramount importance of improving the efficacy of MFC is to select suitable microbes and materials for forming electricity (such as anode, cathode, and electrode catalyst) from batik and textile wastewater. It can be similar to batteries or fuel cells, which use the organic compound as substrates to generate electricity. Microorganisms in microbial fuel cells (MFC) can reduce COD levels by up to 50% and power densities in the range of 420–460 mW/m^2 [74]. MFCs joined to form vertical cascades, where the fluid output from the first row of the MFC serves as the input of another MFC in the cascade. This helps in the rapid reduction of COD. Reactor design and configuration are critical in boosting microbial fuel cell performance (MFCs). Separated anode chambers into two portions in a dual anode chamber microbial fuel cell modified by varying organic loadings demonstrated a superior understanding of the integrated MFCs for wastewater treatment [71]. In addition, the increase in electricity produced by the MFC is directly proportional to the degradation and decolorization of the waste. This can be seen from the results of research by Krithika et al. [36], which showed that samples of textile waste containing *Direct Yellow 12*, *Direct Blue 15*, and *Direct Red 23* dyes on MFC before and after being inoculated with the microbial consortium for seven days had electric power 150 mV and 637 mV. There was an increase in the percentage of decolorization by 71.7%. Thus, using MFC as an energy producer and remediation can be an effective solution in dealing with the energy crisis and environmental pollution.

A number of natural microbial communities in batik waste can improve the performance of the MFC device. This is because, so far, various local genera of microorganisms isolated or inoculated from batik waste have been able to increase the electric potential and the degradation of their toxicity. Although the disadvantage of MFC is that it requires a relatively high cost of MFC components, it can be minimized by using materials derived from relatively inexpensive carbon and natural microbes such as *Bacteroidetes, Proteobacteria, Firmicutes, Actinobacteria,* and *Acidobacteria* [75]. Various types of local indigenous microbes in batik wastewater that can degrade and recover energy in the form of electricity in the MFC have been compared with *Bacillus subtilis* [46,76], *Pseudomonas aeruginosa* [55,77], *Bacillus cereus*, *Klebsiella pneumoniae* [77], *Escherichia coli* [78,79], dan *Pseudomonas* sp. [80]. The effectiveness and performance of MFCs are affected by the concentration and species of microorganisms, the transfer of electrons from microbes to the electrodes, proton exchange membranes (PEM), and electron mediators [36,81]. Therefore, in the future, MFC utilization can use batik waste as an energy producer and minimize its toxicity.

7. The future of MFC in wastewater treatment

Alternative renewable sources, such as geothermal, wind, solar, hydroelectric biomass, and nuclear energy, have been intensively sought and developed. Although numerous researchers have proposed a variety of energy solutions as well as ways to remediate water sources [82,83], no single option can completely replace fossil fuel and eliminate water contamination. It appears that integrated energy choices are more practicable for supplying energy for specific tasks and diverse circumstances. Hoang et al. [82], Ledezma et al. [84], and Selvaraj et al. [85] have reported that the discovery that bacteria can contribute to the production of power from wastewater and biodegradable biomass wastes has received increased attention.

Due to their excellent efficiency in the production of oxygen as an effective electron acceptor, photosynthetic microalgae have been included in MFC as the photosynthetic-cathodic chamber for the achievement of self-sustainability. Hernández et al. [86] reported that photosynthetic-cathodic chambers enhance energy output, permit simultaneous CO_2 removal, and increase high cathode efficiency, in addition to being efficient in solar energy conversion. In addition, microalgae are known to remove inorganic contaminants (such as nitrogen and phosphorus) typically found in agricultural and home anaerobic digester effluent [87]. In conjunction with nitrate reduction, microalgae may serve as electron acceptors (i.e., mediators) at the cathode, bridging the potential gap between oxygen ($E0 = +820$ mV) and nitrate ($E0 = +430$ mV). These ideas are promising options for bioelectricity production and pollution reduction [83,88,89]. In addition, they have a significant potential for concurrently producing high-value products such as biomass, lipids, and pigments with various uses [90–94].

Nookwam et al. [94] reported the convergence of bioelectricity, biodiesel feedstock production, and wastewater treatment. Due to suitable microbial communities, an MFC fed with AD effluent from the rubber sector at an optimal OLR produced maximum energy and efficiently eliminated contaminants. MFC with photosynthetic microalgae in a cathodic chamber has been demonstrated to produce microalgal biomass with a high lipid content and deliver oxygen. The mass of MFC is produced, and stacked in large stacks, for treating large volumes at a significant continuous flow system. The smaller the MFC, the higher the power density. The future of MFC will be thousands of manufactured small-scale MFC.

MFCs designed in the vertical cascade were able to treat wastewater progressively and enhance bioelectricity production. Ongoing initiatives and obstacles include pilot-scale adoption, application with various wastewaters, and integration with other biofuels and bioproduct processes. MFC can be joined together to form cascades, where the output from the first row of the MFC becomes the fluidic input of another MFC in cascade formation. The length of a cascade is adjusted to match the BOD reduction required. Cascade can be lengthened or shortened until all the BOD in a sample is removed. With BOD removal, the longer the cascade, the greater the extraction of the BOD.

8. Conclusion and future perspectives

MFC holds an excellent future for treating the batik industry's liquid waste and generating electricity. Using MFC can help minimize the toxicity of batik liquid waste and generate electricity that supports production in small and medium-scale batik and textile industries, which may provide new insight into future MFC optimization. Additionally, the batik liquid waste can be used to isolate the bacteria that were employed as MFCs. *Bacillus* spp., *Pseudomonas* spp., *Geobacillus* spp., *Lactobacillus delbrueckii, P. putida, P. aeruginosa, Klebsiella pneumoniae, Pantoea* sp. and the consortia of *Sargassum* sp. *Saccharomyces cerevisiae*, *Aspergillus* spp., and *Pleurotus* ostreatus have been reported. Implementing MFC to treat batik wastewater is expected to be used as an alternative, renewable, environmentally friendly, and non-toxic source of power generation. The consortia for MFC should emphasize the development of microbial mixed cultures and components of MFC constituents.

Ethics approval

The present study does not involve experiments involving human or animal.

Consent to publish

All authors are aware of this submission and have consented to the publication of this study.

Consent to participate

All authors have given their consent for participation in this submission and possible publication of this study.

Code availability

Not applicable

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CRediT authorship contribution statement

Vita Meylani and R. Z. Sayyed; Conceptualization, Writing – original draft, Formal analysis. **Endang Surahman, Ahmad Fudholi, Waleed Hassan Almalki and Noshin Ilyas;** Review and editing and revision.

Declaration of Competing Interest

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

Data availability

No data was used for the research described in the article.

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References

[1] D. Zhuwei, L. Haoran, G. Tingyue, A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy, Biotechnol. Adv. 25 (5) (2007) 464–482.

[2] R.M. Allen, H.P. Benetto, Microbial fuel-cells: electricity production from carbohydrates, Appl. Biochem. Biotechnol. 39 (1993) 27–40.

[3] G.C. Gil, et al., Operational parameters affecting the performance of a mediator-less microbial fuel cell, Biosens. Bioelectron. 18 (4) (2003) 327–334.

[4] H. Moon, J.S. Chang, B.H. Kim, Continuous electricity production from artificial wastewater using a mediator-less microbial fuel cell, Bioresour. Technol. 97 (4) (2006) 621–627, 2006.

[5] Y. Choi, E. Jung, S. Kim, S. Jung, Membrane fluidity sensoring microbial fuel cell, Bioelectrochemistry 59 (1–2) (2003) 121–127.

[6] F. Fakhirruddin, A. Amid, W.W.A. Wan Salim, A.S. Azmi, Electricity generation in microbial fuel cell (MFC) by bacterium isolated from rice paddy field soil, E3S Web Conf. 34 (January) (2018) 12–20.

[7] S.E. Oh, B.E. Logan, Hydrogen and electricity production from food processing wastewater using fermentation and microbial fuel cell technologies, Water Res 39 (19) (2005) 4673–4682.

[8] K. Rabaey, W. Verstraete, Microbial fuel cells: novel biotechnology for energy generation, Trends Biotechnol. 23 (6) (2005) 291–298.

[9] B.E. Logan, B. Hamelers, R. Rozendal, U. Schroder, J. Keller, S. Freguia, Microbial fuel cells: methodology and technology, Env. Sci. Technol. 40 (17) (2006) 5181–5192.

[10] D.R. Lovley, Microbial fuel cells: novel microbial physiologies and engineering approaches, Curr. Opin. Biotech. 17 (3) (2006) 327–332.

[11] T.H. Pham, K. Rabaey, P. Aelterman, P. Clauwaert, N. De Schamphelaire, L. Boon, W. Verstraete, Microbial fuel cells in relation to conventional anaerobic digestion technology, Eng. Life Sci. 6 (3) (2006) 285–292.

[12] I.S. Chang, H. Moon, O. Bretschger, J.K. Jang, H.I. Park, K.H. Nealson,). Electrochemically active bacteria (EAB) and mediator less Microbial fuel cells,", J. Microbiol. Biotechnol. 16 (2) (2006) 163–177.

[13] R.A. Bullen, T.C. Arnot, J.B. Lakeman, F.C. Walsh, Biofuel cells and their development, Biosens. Bioelectron. 21 (11) (2006) 2015–2045.

[14] I. Ieropoulos, J. Greenman, C. Melhuish, J. Hart, Energy accumulation and improved performance in microbial fuel cells, J. Power Sources 145 (2) (2005) 253–256.

[15] M.C. Potter, Electrical effects accompanying the decomposition of organic compounds, Proc. R. Soc. Ser. B 84 (571) (1911) 260–276.

[16] F. Davis, S.P.J. Higson, Biofuel cells-recent advances and applications, Biosens. Bioelectron. 22 (7) (2007) 1224–1235.

[17] I.A. Ieropoulos, J. Greenman, C. Melhuish, J. Hart, Comparative study of three types of microbial fuel cells. Enzym, Micro Tech. 37 (2) (2005) 238–245.

[18] B.E. Logan, C. Murano, K. Scott, N.D. Gray, I.M. Head, Electricity generation from cysteine in a microbial fuel cell, Water Res. 39 (5) (2005) 942–952.

[19] I. Tokuji, K. Kenji, Bioelectrocatalyses-based application of quinoproteins and quinprotein-containing bacterial cells in biosensors and biofuel cells, Biochim Biophys. Acta 1647 (1–2) (2003) 121–126.

[20] C.A. Vega, I. Fernandez, Mediating effect of ferric chelate compounds in microbial fuel cells with *Lactobacillus plantarum, Streptococcus lactis,* and *Erwinia dissolvens*, Bioelectrochem Bioenerg. 17 (2) (1987) 217–222.

[21] D.H. Park, J.G. Zeikus, Electricity generation in microbial fuel cells using neutral red as an electronophore, Appl. Env. Microbiol 66 (4) (2000) 1292–1297.

[22] D.R. Lovley, Dissimilatory metal reduction, Annu Rev. Microb. 47 (1993) 263–290.

[23] B.H. Kim, H.J. Kim, M.S. Hyun, D.H. Park, Direct electrode reaction of Fe (III)-reducing bacterium, *Shewanella putrifaciens*. Enzym. Microb, Tech 30 (1999) 145–152.

[24] S.K. Chaudhuri, D.R. Lovley, Electricity generation by direct oxidation of glucose in mediators less microbial fuel cells, Nat. Biotechnol. 21 (2003) 1229–1232.

[25] F. Scholz, U. SchrÖder, Bacterial batteries, Nat. Biotechnol. 21 (2003) 1151–1152.

[26] J.R. Kim, B. Min, B.E. Logan, Evaluation of procedures to acclimate a microbial fuel cell for electricity production, Appl. Microbiol Biotechnol. 68 (2005) 23–30.

[27] D.R. Bond, D.R. Lovley, Electricity production by geobacter sulfurreducens attached to electrodes, Appl. Env. Microbiol. 69 (2003) 1548–1555.

[28] B. Min, S. Cheng, B.E. Logan, Electricity generation using membrane and salt bridge microbial fuel cells, Water Res 39 (9) (2005) 1675–1686.

[29] V. Prasad, D. Sivaram, T.K. Berchmans, S. Yegnaraman, Microbial fuel cell constructed with a microorganism isolated from sugar industry effluent, J. Power Sources 160 (2) (2006) 991–996.

[30] K.B. Gregory, D.R. Bond, D.R. Lovley, Graphite electrodes as electron donors for anaerobic respiration, Env. Microbiol. 6 (6) (2004) 596–604.

[31] A. Bergel, D. Feron, A. Mollica, Catalysis of oxygen reduction in PEM fuel cell by seawater biofilm, Electrochem Commun. 7 (9) (2005) 900–904.

[32] E. Zhang, W. Xu, G. Diao, C. Shuang, Electricity generation from acetate and glucose by sedimentary bacterium attached to the electrode in microbial-anode fuel cells, J. Power Sources 161 (161) (2000) 820–825.

[33] J. Niessen, U. Schroder, M. Rosenbaum, F. Scholz, Fluorinated polyanilines as superior materials for electrocatalytic anodes in bacterial fuel cells, Electrochem Commun. 6 (6) (2004) 571–575.

[34] D.E. Holmes, D.R. Bond, R.A. O'Neil, C.E. Reimers, L.R. Tender, D.R. Lovley, Microbial communities associated with electrode harvesting electricity from a variety of aquatic sediments, Microb. Ecol. 48 (2004) 178–190.

[35] J.H. Back, M.S. Kim, H. Cho, I.S. Chang, J. Lee, K.S. Kim, Construction of bacterial artificial chromosome library from electrochemical microorganisms, FEMS Microbiol Lett. 238 (1) (2004) 65–70.

[36] T. Krithika, R. Kavitha, M. Dinesh, J. Angayarkanni, Assessment of ligninolytic bacterial consortium for the degradation of azo dye with electricity generation in a dual-chambered microbial fuel cell. Environ, Challenges 4 (March) (2021), 100093.

[37] Y. Cao, et al., Electricigens in the anode of microbial fuel cells: Pure cultures versus mixed communities, Microb. Cell Fact. 18 (1) (2019) 1–14.

[38] D.R. Lovley, D.E. Holmes, K.P. Nevin, Dissimilatory Fe (III) and Mn (IV) reduction, Adv. Micro Physiol. 49 (1) (2004) 219–286.

[39] M. Vargas, K. Kashefi, E.L. Blunt-Harris, D.R. Lovley, Microbiological evidence for Fe (III) reduction on early earth, Nature 395 (1) (1998) 65–67.

[40] H.S. Park, B.H. Kim, H.S. Kim, H.J. Kim, G.T. Kim, M. Kim, A novel electrochemically active and Fe (III)-reducing bacterium phylogenetically related to Clostridium butyricum isolated from a microbial fuel cell, Anaerobe 7 (6) (2001) 297–306.

[41] D.H. Park, J.G. Zeikus, Impact of electrode composition on electricity generation in a single-compartment fuel cell using *Shewanella putrefaciens*, Appl. Microbiol Biotechnol. 59 (2002) 58–61.

[42] J.E. Mink, J.P. Rojas, B.E. Logan, M.M. Hussain, Vertically grown multiwalled carbon nanotube anode and nickel silicide integrated high-performance microsized (1.25 μL) microbial fuel cell, Nano Lett. 12 (2) (2012) 791–795.

[43] C.R. Holkar, A.J. Jadhav, D.V. Pinjari, N.M. Mahamuni, and A.B. Pandit. A critical review on textile wastewater treatments: Possible approaches. J. Environ. Manage. 182, 351–366.

[44] C. Abourached, M.J. English, H. Liu,). Wastewater treatment by Microbial Fuel Cell (MFC) prior irrigation water reuse, J. Clean. Prod. 137 (2016) 144–149.

[45] S. Pandit, S. Ghosh, M.M. Ghangrekar, D. Das, Performance of an anion exchange membrane in association with cathodic parameters in a dual chamber microbial fuel cell, Int. J. Hydrog. Ener 37 (2012) 9383–9392.

[46] H.R. Fidiastuti, A.S. Lathifah, M. Amin, Y. Utomo, Studies of *Bacillus subtilis* NAP1 to Degrade BOD, COD, TSS, and pH: The Indigenous Bacteria in Indonesia Batik Wastewater, J. Phys. Conf. Ser. 1511 (1) (2020) 1–7.

[47] Wijiastuti, I.M. Artika, N. Nurhidayat, Isolation and selection of thermophilic bacteria as hexavalent chromium reducer from batik processing waste water, Curr. Biochem 2 (1) (2015) 22–31.

[48] M. Siti Zuraida, C.R. Nurhaslina, K.H. Ku Halim, Adsorption of colour from batik effluent by bacterial, *Lact. delbruckii* its Growth BEIAC 2013 - 2013 IEEE Bus. Eng. Ind. Appl. Colloq. 2013 (2013) 574–579.

[49] U. Fatmawati, Sajidan, Suranto, Potensi mikroorganisme sebagai agen bioremediasi dalam menurunkan kadar Cr(VI) pada limbah cair batik hasil pewarnaan, Semin. Nas. Pendidik. Biol. FKIP UNS 2010 266 2010 (2010) 266–276.

[50] Sunardi. Penurunan Kadar Krom (Vi) Dengan Sargassum Sp., Saccharomyces cerevisiae dan Kombinasinya Pada Limbah Cair Industri Batik. J. EKOSAINS, 3(1), 55–62.

[51] R.S. Dewi, R.S. Kasiamdari, E. Martani, Y.A. Purwestri, Efficiency of Aspergillus sp. 3 to reduce chromium, sulfide, ammonia, phenol, and Fat From Batik Wastewater, IOP Conf. Ser.: Earth Env Sci. 308 (1) (2019) 1–8.

[52] R.S. Dewi, M. Ilyas, A.A. Sari, Ligninolitic enzyme immobilization from *Pleurotus ostreatus* for dye and batik wastewater decolorization, J. Pendidik. IPA Indones. 8 (2) (2019) 220–229.

[53] R. Baldiris, N. Acosta-Tapia, A. Montes, J. Hernández, R. Vivas-Reyes, Reduction of hexavalent chromium and detection of chromate reductase (ChrR) in *Stenotrophomonas maltophilia*, Molecules 23 (2) (2018) 406.

[54] R.F. Dwisandi, F. Mutiara, E. Nurfauziah, V. Meylani, Effectiveness of indigenous local microorganisms in degrading hexavalent chromium (Cr(VI)) in Batik liquid waste. Biol, Environ. Pollut. 1 (1) (2021) 19–29.

[55] C.E. Halim, K. Abib, Y. Tjandra, V. Yosephi, A.K. Wardani, Pengaruh persentase pva-alginat beads terhadap tingkat dekolorisasi pewarna sintetis azo menggunakan konsorsium bakteri amobil, Chim. Nat. Acta 7 (2) (2019) 63–68.

[56] Y. Cheng, H.Y. Holman, Z. Lin, Remediation of chromium and uranium contamination by microbial activity, Elements 8 (2) (2012) 107–112.

[57] A. Asri, E. Zulaika, Sinergisme Antar Isolat *Azotobacter*, yang dikonsorsiumkan. J. Sains Dan. Seni ITS 5 (2) (2016) 57–59.

[58] W. Habermann, E.H. Pommer, Biological fuel cells with sulphide storage capacity, Appl. Microbiol Biotechnol. 35 (1991) 128–133.

[59] D.C. Holzman, Microbe power!, Env. Heal. Prop. 113 (11) (2005) 754–757.

[60] K. Rabaey, K. Van De Sompel, L. Maignien, N. Boon, P. Aelterman, P. Clauwaert, Microbial fuel cells for sulfide removal, Env. Sci. Technol. 40 (17) (2006) 5218–5224.

[61] J.K. Jang, T.H. Pham, I.S. Chang, K.H. Kang, H. Moon, K.S. Cho, Construction and operation of a novel mediator-and membrane-less microbial fuel cell, Process Biochem 39 (8) (2004) 1007–1012.

[62] Z. He, S.D. Minteer, L.T. Angenent, Electricity generation from artificial wastewater using an uflow microbial fuel cell, Env. Sci. Technol. 39 (14) (2005) 5262–5267.

[63] K. Rabaey, N. Boon, S.D. Siciliano, M. Verhaege, V. W, Biofuel cells select for microbial consortia that self-mediate electron transfer, Appl. Env. Micro 70 (9) (2004) 5373–5382.

[64] D.H. Park, M. Laivenieks, M.V. Guettler, M.K. Jain, Z. JG, Microbial utilization of electrically reduced neutral red as the sole electron donor for growth and metabolite production, Appl. Env. Microbiol 65 (7) (1999) 2912–2917.

[65] H. Liu, B.E. Logan, Electricity generation using an air-cathode single chamber microbial fuel cell in the presence and absence of a proton exchange membrane, Env. Sci. Technol. 38 (2004) 4040–4046.

[66] Y. Zuo, P.C. Maness, B.E. Logan, Electricity production from steam-exploded corn stover biomass, Energy Fuel 20 (2006) 1716–1721.

[67] B. Min, S. Cheng, B.E. Logan, Thermodynamic analysis of a single chamber microbial fuel cell, Water Res 39 (2005) 1675–1686.

[68] M. Tao, et al., Enhanced denitrification and power generation of municipal wastewater treatment plants (WWTPs) effluents with biomass in microbial fuel cells coupled with a constructed wetland, Sci. Total Environ. 709 (2020) 136–159.

[69] S.R. Mise, S. Saware, Electricity generation using textile wastewater by single chambered microbial fuel cell, Int. Res. J. Eng. Technol. 3 (2) (2016) 710–716.

[70] Wise J.T.F., Wang L., Xu J., Zhang Z., Shi X. The Nutritional Biochemistry of Chromium (III) Elsevier; Amsterdam, The Netherlands: 2019. Oxidative stress of Cr (III) and carcinogenesis; pp. 323–340.

[71] Mishra S., Bharagava R.N. (2016) Toxic and genotoxic effects of hexavalent chromium in the environment and its bioremediation strategies. J. Environ. Sci. Health Part C.,34:1–32. https://doiorg/10.1080/10590501.2015.1096883.

[72] M. Tumolo, V. Ancona, D. De Paola, D. Losacco, C. Campanale, C. Massarelli, V. F. Uricchio, Chromium pollution in european water, sources, health risk, and remediation strategies: an overview, Int J. Environ. Res Public Health 17 (15) (2020 28) 5438, https://doi.org/10.3390/ijerph17155438.

[73] R.S. Dewi, A. Mumpuni, R.A. Yusiana (2020). Chromium Removal of Batik Wastewater using Aspergillus sp. and Penicillium sp. IOP Conf. Series: Earth and Env Sci, 593, 012022 IOP Publishing https://doiorg/10.1088/1755–1315/593/1/012022.

[74] K.C. Obileke, H. Onyeaka, E.L. Meyer, N. Nwokolo, Microbial fuel cells, a renewable energy technology for a bio-electricity generation: a mini-review, Electrochem. Commun. 125 (2021), 107003.

[75] G. Samudro, T. Imai, Y.T. Hung, Enhancement of power generation and organic removal in double anode chamber designed dual-chamber microbial fuel cell (Dac-dcmfc), Water (Switz.) 13 (21) (2021) 1–17.

[76] P. Mani, F.V.T. B. Kyle, C.T. S, T. Keshavarz, G. Kyazze, Development of an electroactive aerobic biocathode for microbial fuel cell applications, Env. Microbiol Rep. 12 (5) (2020) 607–612.

[77] R.S. Dewi, R.S. Kasiamdari, E. Martani, Y.A. Purwestri, Decolorization and detoxification of batik dye effluent containing Indigosol Blue-04B using fungi isolated from contaminated dye effluent. Indonesian, J. Biotechnol. 23 (2) (2018) 54–60.

[78] I. Noviar, E. Munir, K. Nurtjahja, Preliminary study of local bacteria isolates in decolorizing liquid waste from boiling process of batik industry, IOP Conf. Ser. Earth Environ. Sci. 305 (1) (2019) 1–10.

[79] I. Noviar. (2019). Isolasi dan potensi bakteri pendekolorisasi limbah perebusan Batik. Universitas Sumatera Utara.

[80] B. Muchtasjar, H. Hadiyanto, M. Izzati, Microbial degradation of batik waste-water treatment in Indonesia, IOP Conf. Ser. Earth Environ. Sci. 314 (1) (2019) 1–5.

[81] A.C.J. Tacas, P.W. Tsai, L.L. Tayo, C.C. Hsueh, S.Y. Sun, B.Y. Chen, Degradation and biotoxicity of azo dyes using indigenous bacteria-acclimated microbial fuel cells (MFCs), Process Biochem. 102 (2021) 59–71.

[82] A.T. Hoang, et al., Microbial fuel cells for bioelectricity production from waste as the sustainable prospect of the future energy sector, Chemosphere 287 (3) (2022), 132285.

[83] A.T. Hoang, et al., Heavy metal removal by biomass-derived carbon nanotubes as a greener environmental remediation: a comprehensive review, Chemosphere 287 (1) (2022), 131959.

[84] P. Ledezma, J. Greenman, I. Ieropoulos, MFC-cascade stacks maximize COD reduction and avoid voltage reversal under adverse conditions, Bioresour. Technol. 134 (2013) 158–165.

[85] D. Selvaraj, A. Somanathan, G. Jeyakumar, Rajesh Banu, Kumar, Generation of electricity by the degradation of electro-Fenton pretreated latex wastewater using double chamber microbial fuel cell, Int. J. Energy Res 44 (15) (2020) 12496–12505.

[86] D. Hernández, B. Riaño, M. Coca, M.C. García-González, Treatment of agro-industrial wastewater using microalgae-bacteria consortium combined with anaerobic digestion of the produced biomass, Bioresour. Technol. 135 (2013) 598–603.

[87] B. Cheirsilp, T. Thawechai, P. Prasertsan, Immobilized oleaginous microalgae for the production of lipid and phytoremediation of secondary effluent from palm oil mill in fluidized bed photobioreactor, Bioresour. Technol. 241 (2017) 787–794.

[88] Y. Wang, et al., Cost-effective domestic wastewater treatment and bioenergy recovery in an immobilized microalgal-based photoautotrophic microbial fuel cell (PMFC), Chem. Eng. J. 372 (2019) 956–965.

[89] H. Hadiyanto, et al., Response surface optimization of microalgae microbial fuel cell (MMFC) enhanced by yeast immobilization for bioelectricity production, Chemosphere 287 (3) (2022), 132275.

[90] C. Yeesang, B. Cheirsilp, Low-cost production of green microalga Botryococcus braunii biomass with high lipid content through mixotrophic and photoautotrophic cultivation, Appl. Biochem. Biotechnol. 174 (1) (2014) 116–129.

[91] W. Tongprawhan, S. Srinuanpan, B. Cheirsilp, Biocapture of CO_2 from biogas by oleaginous microalgae for improving methane content and simultaneously producing lipids, Bioresour. Technol. 170 (2014) 90–99.

[92] B. Cheirsilp, Y.I. Mandik, P. Prasertsan, Evaluation of optimal conditions for the cultivation of marine Chlorella sp. as potential sources of lipids, exopolymeric substances, and pigments, Aquac. Int. 24 (1) (2016) 313–326.

[93] D. Sengmee, B. Cheirsilp, T.T. Suksaroge, P. Prasertsan, Biophotolysis-based hydrogen and lipid production by oleaginous microalgae using crude glycerol as exogenous carbon source, Int. J. Hydro. Ener 42 (4) (2017) 1970–1976.

[94] K. Nookwam, B. Cheirsilp, P. Maneechote, W. Boonsawang, C. Sukkasem, microbial fuel cells with photosynthetic-cathodic chamber in vertical cascade for integrated bioelectricity, biodiesel feedstock production, and wastewater treatment, Bioresour. Technol. 346 (2022), 126559.