PRODUCTION OF BIOENERGY USING MICROBIAL FUEL CELL

SANA MAQSOOD, ZURIAT JABBAR, HANNANA MARYAM AND SIKANDER ALI*

Institute Of Industrial Biotechnology, Government College University, Lahore, Pakistan

*Corresponding author e-mail: dr.sikanderali@gcu.edu.pk

Abstract

Microbial Fuel Cell (MFC) is an excellent emerging technology for energy generation using a wide variety of substrates including organic and inorganic matter of wastewaters, industrial sludge or renewable biomass. MFC uses microbial catalytic activity to convert biodegradable energy into bioelectric energy. Moreover it is also advantageous in the field of wastewater treatment. The problem with these systems is that energy production is low and not continuous. Researchers have been working from last decade to resolve these problems and to increase energy production. For further improvements, an understanding of microbiology and substrates used in these systems is required. This research review gives a brief account of the commonly used microorganisms in MFC. Different substrates that have been used so far like glucose, acetate, wastewaters, dyes and other inorganic substrates with current density produced by them are also discussed. At the end, applications of MFC are also described.

Key words: Microbial fuel cells, wastewaters, bioelectric energy

1. Introduction

Fossil fuels have been a great source for energy production (Akdeniz, Çaglar, & Gullu, 2002) but it negatively effects the natural environment due to release of carbon dioxide resulting in global warming and atmospheric pollution (Rahimnejad, Ghoreyshi, Najafpour, Younesi, & Shakeri, 2012). So, we require an alternative technology for energy production that can produce carbon dioxide at lower rates. Fuel cell can be used for this purpose as it does not produce polluting gases as well as it is efficient way of energy generation (Peighambardoust, Rowshanzamir, & Amjadi, 2010). In developing countries there are two major issues one is energy production with atmosphere friendly method and other is waste material that can be wastewater from food factories, sewerages, brewering, chocolate industry, and domestic wastewater. Water treatment plants can help but their installation cost, maintenance and high energy requirement can cause failure of water treatment. Both of these problems i.e. energy production and wastewater treatment can be solved if we use this wastewater as a substrate for energy production. For this purpose we can use biological fuel cell. Biological fuel cell produces electricity by using naturally available biomass. This technology is highly efficient, cost effective and does not produce toxic gases (Williams, & Koslow, 1966). Biological fuel cell works by using catalytic activities of microorganism or enzymes which oxidizes the substrate that can be waste products of human living, this cause production of electrons that move towards anode through external circuit resulting in production of electrical energy (Rao, Richter, Von Sturm, & Weidlich, 1976; Barton, Gallaway, & Atanassov, 2004).

There are two classes of biological fuel cells on the basis of biocatalyst. Enzymatic fuel cells use enzymes as a biocatalyst and the second class uses microbial catalytic activity and are known as microbial fuel cell (MFC). MFCs are just same as any other fuel cell in which two electrodes, anode and the cathode, are connected through external wire system and separated by proton exchange membrane. Schematic diagram of a simple microbial fuel cell is shown in Figure 1. Main difference is the substrate that is waste material or organic material in case of MFC. When organic material is oxidized on the anode, electron and proton are released. Electric current is produced when electrons flow to the cathode via external circuit. On the cathode, electrons react with electron acceptor that can be oxygen or nitrate (Delaney et al., 1984; Logan, & Regan, 2006; Logan, 2009). Electrons flow from anode to cathode via external circuit while protons diffuse via proton/ion exchange membrane that forms internal circuit. How much energy is produced, it depends on rate of electrons flowing through the circuit and the electrochemical potential difference between electrodes.

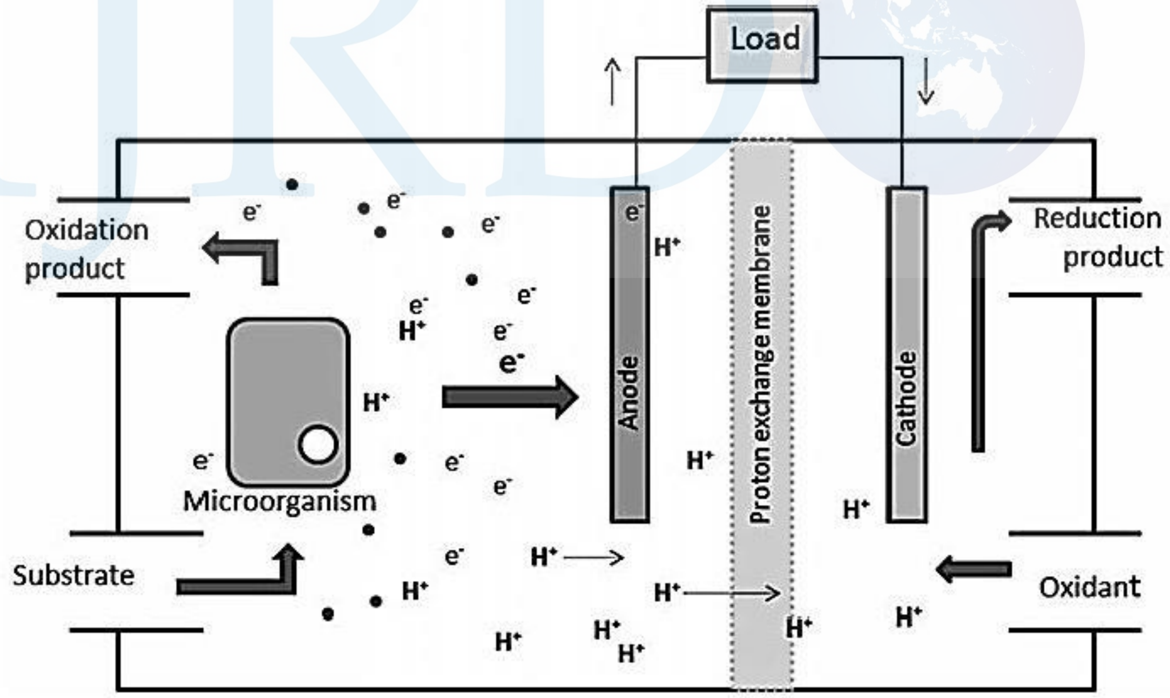

Figure 1. Schematic diagram of a simple microbial fuel cell

MFC can be mediator dependent or mediator free. Some microorganisms have lipid bilayer or lipopolysaccharide that can cause hindrance in movement of electrons, so mediator is used for electron movement that can be synthetic or natural. Synthetic mediators are Thionine, Methylene Blue, Neutral Red while Natural mediators are Anthraquione, Humic acid, Sulphate & Thiosulphate (Park, & Zeikus, 2000).

2. Brief History of Microbial Fuel Cells

Potter (1911) suggested that microbial fuel cell can be used for energy generation while he was working on *Escherichia coli* he showed that electricity can be generated from the cultures of *Escherichia coli*. In 1931, Cohen gave some additional knowledge by showing that on connecting microbial half fuel cells in a series could produce almost 35V but only 2mA current was generated. DelDuca used hydrogen as a reactant that was produced by a bacterium, *Clostridium Butyricum*, by fermentation of glucose. Due to fluctuating nature of the hydrogen production from the bacteria the cell functioned but it was unstable. The issue of fluctuating production of hydrogen by *Clostridium butyricum* was resolved in 1976 by Suzuki. He gave new idea for designing MFC that is in use even now days (Suzuki, Karube, & Matsunaga, 1978).

Advancement in the field of MFC research was done in early 1980s by M. J. Allen and H. Peter Bennetto. They explained fuel cell functioning and other factors related to MFC improvement in a number of papers (Kim, Hyun, & Park, 1999). Kim et al proposed that *Shewanella oneidensis* that Was formally known as *Shewanella putrefaciens*, the Fe (III)-reducing bacterium, was able to produce energy in a microbial fuel cell without addition of mediators (Allen and Bennetto, 1993). After Kim's publications, a number of bacteria were observed for their electrochemical activity and pure as well as mixed bacterial cultures were used in different MFC designs. Over last few decades, a lot of work is done on MFC designs. Now MFC can be used in developing countries for wastewater treatment as well as electricity generation. For making MFC economically viable, an understanding of requirements of MFC system should be focused. In the following section, we briefly outline microbes used in MFC and substrates that can be used in MFC.

3. Microorganisms in Microbial Fuel Cell

MFC uses catalytic activity of microorganisms on some substrates for generation of electric current. Microorganisms used in the MFC cause oxidation of organic substrates resulting in release of electrons and protons. At the cathode, protons react with the electrons and a chemical like oxygen that has ability to be reduced at the cathode surface this chemical is known as catholyte. Mechanism of generating electric current by MFC is just like that of a chemical fuel cell; difference is in use of microbes as a catalyst at the anode. Catalysts are used to increase the rate of a reaction without being involved or affected by the reaction. Energy required for microbial growth in a MFC system is provided by the oxidation of the substrate and it creates an energy loss. Since conditions provided by the anode associated microorganisms remain favorable for energy generation, a MFC has the ability to generate electricity indefinitely.

Table 1. Microorganisms that can be used in MFC

Microbes	Substrate	Applications	Refernces
Actinobacillus succinogenes	Glucose	Neutral red or thionin as electron mediator	Park & Zeikus, 2000
Aeromonas hydrophila	Acetate	Mediator-less MFC	Pham et al., 2003
Alcaligenes faecalis, Enterococcus gallinarum, Pseudomonas aeruginosa	Glucose	Self-mediate consortia isolated from MFC with a maximal level of 4.31 W m^{-2}.	Logan & Regan, 2006
Clostridium butyricum	Starch, glucose, lactate, molasses	Fermentative bacterium	Park et al., 2001

A number of microorganisms can be used in association with anode in MFC systems. Some microorganisms which are commonly used are presented in Table 1. Biofilm is the term that is used for bacteria associated with any surface. In case of anode associated biofilm, organism may have direct association or can be indirectly associated with anode with the help of other members of the electrode community. One of the members of electrode community is *Brevibacillus* sp. PTH1. Power produced by *Brevibacillus* sp. PTH1 is low but it can be enhanced when co-cultured with a *Pseudomonas* sp. (Boon et al., 2008). Other microorganisms which are able to produce power current in pure culture involve representatives of the *Firmicutes* (Park et al., 2001) and *Acidobacteria* (Bond et al., 2005) and *Hansenula anomala* (Prasad et al., 2007). These organisms can produce current of varying degrees by direct or indirect anode interaction.

4. Substrates used in MFCs

Efficiency of MFC to convert waste material into useful bioenergy mainly depends on type and components of waste material. Chemical nature of substrate and concentration of its component is of great importance. Substrate is important as it is source of carbon and other nutrients. A wide range of substrates can be used in MFCs for generation of electricity including simple compounds and a mixture of organic matter present in wastewater. Table 2 shows some substrates that can be used in MFC system. .Removal of toxic material from the wastewater is the main objective of MFC. It ensures safe effusion that do not harm natural environment. Activated sludge process (ASP) has been the pillar of treating sewerage and industrial wastewater since the last century. But this process is energy demanding. According to a research, in USA electricity requirements to supply oxygen in ASPs is almost equal to 2% of that required for total electricity consumption in USA (Electric Power Research Institute, 2002). But with some modifications the waste material can be used as substrate for the preparation of some biochemicals and energy (Kleerebezem and van Loosdrecht, 2007). Furthermore, primary objective of treatment of waste is to make it able to reuse and recovery of energy. Some substrates that have been commonly used in MFC are briefly discussed.

Acetate

Initial substrate that has been the substrate of choice for electricity generation is acetate. Acetate is a simplest substrate that is extensively used as carbon source to induce electrochemical activity of bacteria (Bond, Holmes, Tender, & Lovley, 2002). Despite of its inertness at room temperature towards microbial reactions and fermentation, it is still commonly used as a substrate. Furthermore, acetate is the final product of many metabolic pathways including the Entner–Doudoroff pathway for glucose metabolism and cheap and readily available (Biffinger, Byrd, Dudley, & Ringeisen, 2008). According to one research acetate has ability to produce energy as much as 66% higher than that of produced by butyrate (Liu, Cheng, & Logan, 2005). When performance of four different substrates was compared it was noted that acetate was on the top with highest power output (Chae, Choi, Lee, & Kim, 2009). In a study done by (Liu, Zhang, & Su, 2009), they compared MFC based on acetate substrate with the MFC in which substrate was a protein-rich wastewater, electric power produced by acetate based MFC was more than 2-fold maximum as compared to the MFC that was based on protein-rich wastewater. A number of substrates can be used due to diversity in microbial community and these complex substrates can be converted to relatively simpler compounds like acetate that can be used as donator of electron for power generation.

4.1. Glucose

Glucose is the second substrate that is generally used in MFC operation. According to a study done by (Kim, Choi, Jung, & Kim, 2000), there should be some carbon source in the medium for microorganism when using *Proteus vulgaris* in MFC system. But when glucose and galactose were compared, initiation of cells in the MFC by glucose was short termed. (Rabaey, Lissens, Siciliano, & Verstraete, 2003) showed that a glucose fed batch MFC in which the cathode oxidant was 100mM ferric cyanide produced a maximum frequency of current of 216 W/m3. (Lee, Parameswaran, Kato-Marcus, Torres, & Rittmann, 2008) compared the efficiency of energy conversion (ECE) of glucose and acetate as substrates in MFC and he reported that the ECE of acetate was 42%, but with glucose it was only 3% resulting low current as well as power density. Moreover, due to its fermentable nature it can be treated as a substrate having lower Coulombic efficiency (CE) in comparison to other compounds with lower molecular weight, just as acetate (Chae et al., 2009).

4.2. Synthetic wastewater

Many researchers have used chemical and synthetic wastewater having distinct composition for generation of bioenergy as it is feasible and sustainable process and also because its pH and conductivity can be easily controlled. (Mohan, Mohanakrishna, Reddy, Saravanan, & Sarma, 2008) showed that feasibility of bioenergy generation from the wastewater depends upon substrate loading rate so they used varying loading rates of synthetic wastewater in same MFC to get different results. Different media were used to grow microbes containing mediators, like reduced sulphur containing wastewater and cysteine, that are able to act like electron donor and can boost energy generation but for a small period of time, thus performance of the system was not defined (Aldrovandi et al., 2009). By using a minimal salt media having glucose or acetate as an electron donor, this can be avoided. Effect of composition of wastewater on MFC performance was checked by (Rodrigo, Canizares, García, Linares, & Lobato, 2009). They used two different synthetic wastewaters that have same pollutants like peptone and glucose and organic loading was also same (315 mg/dm3). They fed MFCs by using different ratio of gradually biodegradable substrate and electricity was produced more efficiently owing to intermediates produced that favored electricity production.

4.3. Starch processing wastewater

Starch processing wastewater (SPW) can also be used as substrate as it is a source of nutrients. It consists of high amount of carbohydrates, starch, protein and sugars that can be changed to a variety of advantageous products. SPW was used as a fuel to enrich a microbial consortium for electricity production. (Lu, Zhou, Zhuang, Zhang, & Ni, 2009) used SPW as a fuel to operate a MFC and he obtained a maximum voltage output. But the Coulombic efficiency was only 7%. They reported that the diffusion of oxygen to the anode can be the reason behind this low CE causing oxidization of other electron acceptors and biomass production.

4.4. Dye wastewater

Largest chemical class of synthetic dyes is Azo dyes. Azo dyes are present in the effluent of different industries including dye-manufacturing industries and textile industries in huge amount. These dyes should be removed from the effluent before discharge as these dyes are extremely dangerous for environment and can cause problems like light blockage and can interfere transfer of oxygen into water bodies which is unfavorable for aquatic life (Pant, Singh, Satyawali, & Gupta, 2007). Moreover, some of Azo dyes are also toxic in nature. Recently, some researchers tried to use these dyes as a fuel (substrate) in MFC resulting in elimination of toxic dyes from industrial effluent as well as generation of bioenergy. (Sun, Hu, Bi, & Cao, 2009a) showed that the removal of active brilliant red X-3B, a model Azo dye, from industrial effluent can be increased using glucose as a co-substrate. Though their decolorization was not inhibited by higher dye concentrations, but, higher concentrations of ABRX3 affected the energy production from glucose. The reason can be the competition for electrons from the carbon sources between azo dye and the anode. So, mixture of two types of wastewaters as a substrate in MFC can serve for dye containing wastewater treatment. It can save cost as well as energy.

4.5. Cellulose and chitin

Cellulose and chitin are economical and convenient as substrate for generation of bioenergy. These substrates are a major component of organic matter in industrial wastewaters. There are only a few studies on use of these substrates in MFCs. To use cellulose for electricity generation in MFC, the microbe must have ability to hydrolyze cellulose anaerobically and it must be active electrochemically so that it can use anode as an electron acceptor and at the same time it can oxidize metabolites produced by hydrolysis of cellulose. In a recent study, (Rezaei, Richard, & Logan, 2009) showed the effects of varying size on maximum power production; its duration and CE. They used chitin particles of varying size. They narrated that the largest (0.78 mm) particles produced current density that was lower than that of produced by small particles (0.28 mm, 0.46 mm). So, the power production is limited when solid substrates like chitin and cellulose are used. This may be because particulate material has low rate of hydrolysis.

4.6. Sunlight

An alternative source of energy for MFC is sunlight. According to a study done by (Rosenbaum, Schroder, & Scholz, 2005) a 'living solar cell' using the microbe *Chlamydomonas reinhardtii* is able to produce hydrogen using sunlight. This hydrogen is then oxidized to produce current. So, modern approach is to use phototrophic MFCs for the conversion of solar energy into electric energy either by using photosynthetic microorganisms or by living plants. The plant MFCs in rice paddy fields have been reported to produce electricity by rhizosphere populations by oxidizing organic carbon delivered to the rhizosphere (Kaku, Yonezawa, Kodama, & Watanabe, 2008). Photosynthetic algal MFC is another kind of phototrophic MFC. (Strik, Terlouw, Hamelers, & Buisman, 2008b) reported that it can produce a maximum power of 110 mW/m2 surface area of photobioreactor. The waste material containing organic matter that was produced in the algal photobioreactor through photosynthesis was provided to a MFC for generation of electricity.

Table 2: Different Substrates Used In Microbial Fuel Cells (MFC)

Substrate type	Source inoculum	Concentrations	Current density (mA/cm^2)
Acetate	Pre-acclimated bacteria from MFC	1g/L	0.8
Azo dye in the presence of glucose	Mixture of aerobic and anaerobic Sludge	300 mg/L	0.09
Cellulose particles	Pure culture of *Enterobacter Cloacae*	4 g/L	0.02
Domestic wastewater	Anaerobic sludge	600mg/L	0.06
Glucose	Mixed bacterial culture maintained on sodium acetate for 1 year (*Rhodococcus* and *Paracoccus*)	6.7Mm	0.7
Protein-rich wastewater	Mesophilic anaerobic sludge	1.75 g/L COD	0.008
Sucrose	Anaerobic sludge from septic Tank	2674mg/L	0.19
Synthetic wastewater	Granular sludge from a upflow anaerobic sludge blanket (UASB) reactor	16 g COD/day	0.017

4.7 Inorganic substrates

In addition to all substrates stated above, many other substrates can also be used. (Huang and Logan, 2008) showed the effectiveness of energy generation and treatment of paper recycling plant wastewater using MFC and obtained a maximum current density of 672 mW/m2 after making minor changes in the wastewater by adding phosphate buffer. However, when unaltered wastewater was used, only 144 mW/m2 current was produced that can be due to low solution conductivity. (Luo, Liu, Zhang, & Jin, 2009) used MFC using phenol as a substrate to study degradation of phenol. When he used phenol as a sole substrate in an aqueous air cathode, electricity was generated during degradation of phenol. But the power produced by using phenol was lower than that of glucose. Recently, (Kim and Chang, 2009) reported that carbon mono oxide can be used for energy generation. The CO fermenter produced acetate that was supplied to a MFC for electricity generation. Although the production as a result of this conversion was quite low, it verified that syn-gas like carbon mono oxide can be converted to electricity by microbial process.

1. Application

The main applications of MFCs are classified in the following forms:

5.1. Generation of bioelectricity

Remarkable application of MFC is bioenergy production by using a wide range of substrates, and system architectures with bacteria, though the power levels in all these systems were relatively low (Logan, 2008), but it is preferable for continuous and long-term power applications as it has no safety issues. (Bettin, 2006) reported the applications of MFC for biomedical purposes. According to his study, we can generate power from MFC using any substrate for biomedical devices like pacemaker. For cardiac stimulation, it is possible to generate 25mW of power from MFC. But, large amount of surface area is required. Basic goal of MFCs is to produce a sufficient current for the application in small electrical appliances. In a study done by (Rahimnejad et al., 2012) they used fabricated stacked MFC to generate power enough to turn on ten LED lamps and one digital clock for a span of 2 days.

5.2. Biohydrogen production

Production of biohydrogen is one of the major applications. In MFCs, electrons and protons combine at the cathode and form hydrogen that can be stored and used for later use. According to a study, increase in additional voltage and removal of oxygen at cathode can facilitate the process. Substrate for the process is not limited, domestic wastewater can also be used. For the BEAMR process, high-strength wastewaters appear to have the most immediate promise for H2 recovery (Logan & Regan, 2006). MFCs can be source of renewable hydrogen that Can fulfill overall hydrogen requirements in a hydrogen economy (Mohan et al., 2008).

5.3. Wastewater treatment

Wastewater treatment has been a worldwide problem. Many plants are installed but they are either difficult to manage or expensive. MFC can be used for wastewater treatment as substrate is free, no maintenance required and it can also convert organic and inorganic substrate present in wastewater into electricity. Several types of wastewaters like sanitary wastes, food processing wastewater, brewery wastewater, swine wastewater, synthetic wastewater and domestic wastewater have energy in the form of biodegradable organic matters. MFC technology that was designed in 1991 for effluent treatment is now suitable as an entirely new technology due to its ability to convert biodegradable organic material energy in electricity or hydrogen gas (Logan, 2008). High operational sustainability and low material costs are worthwhile characteristics for an efficient treating system.

5.4. Application of MFCs in biosensor

Another application of using MFC technology is as a sensor for pollutant analysis because current produced from MFC is directly proportional to the concentration of pollutants present in the organic material. Batteries have restricted lifetime and must be changed or recharged; thus, MFCs are suitable for powering electrochemical sensors. Use of MFCs as a biological oxygen demand sensor is now possible and this type of biological oxygen demand sensor has great operational sustainability and reproducibility and it can be kept operated for years.

2. Conclusion

As fossil fuels and petroleum sources are depleted, an alternative source of energy is required. Microbial fuel cell is an emerging technology as it is advanced source of bioenergy which has no toxic byproduct, needs no maintenance programs and is cost effective. Initially only acetate and glucose were used but now researchers are using many unconventional substrates. Using MFC technology is like "Hitting two birds with one stone" as it removes pollutants from the wastewater and can use its organic matter for energy generation. Though energy generation is low and not continuous but scientists are trying to improve its commercial applications. It is hoped that there will be more improvement in MFC system in coming years.

References

Akdeniz, F., Çaglar, A., & Gullu, D. (2002). Recent energy investigations on fossil and alternative nonfossil resources in Turkey. *Energy Conversion and Management*, *43*(4), 575-589.

Aldrovandi, A., Marsili, E., Stante, L., Paganin, P., Tabacchioni, S., & Giordano, A. (2009). Sustainable power production in a membrane-less and mediator-less synthetic wastewater microbial fuel cell. *Bioresource technology*, *100*(13), 3252-3260.

Allen, R. M., & Bennetto, H. P. (1993). Microbial fuel-cells. *Applied biochemistry and biotechnology*, *39*(1), 27-40.

Barton, S. C., Gallaway, J., & Atanassov, P. (2004). Enzymatic biofuel cells for implantable and microscale devices. *Chemical reviews*, *104*, 4867-4886.

Bettin, C. (2006). *Applicability and feasibility of incorporating microbial fuel cell technology into implantable biomedical devices* (Doctoral dissertation, The Ohio State University).

Biffinger, J. C., Byrd, J. N., Dudley, B. L., & Ringeisen, B. R. (2008). Oxygen exposure promotes fuel diversity for Shewanella oneidensis microbial fuel cells. *Biosensors and Bioelectronics*, *23*(6), 820-826.

Bond, D. R., & Lovley, D. R. (2005). Evidence for involvement of an electron shuttle in electricity generation by Geothrix fermentans. *Applied and environmental microbiology*, *71*(4), 2186-2189.

Bond, D. R., Holmes, D. E., Tender, L. M., & Lovley, D. R. (2002). Electrode-reducing microorganisms that harvest energy from marine sediments. *Science*, *295*(5554), 483-485.

Boon, N., Aelterman, P., Clauwaert, P., De Schamphelaire, L., Vanhaecke, L., De Maeyer, K., ... & Rabaey, K. (2008). Metabolites produced by Pseudomonas sp. enable a Gram-positive bacterium to achieve extracellular electron transfer. *Applied Microbiology and Biotechnology*, *77*(5), 1119-1129.

Chae, K. J., Choi, M. J., Lee, J. W., Kim, K. Y., & Kim, I. S. (2009). Effect of different substrates on the performance, bacterial diversity, and bacterial viability in microbial fuel cells. *Bioresource technology*, *100*(14), 3518-3525.

Cohen, B. (1931). The bacterial culture as an electrical half-cell. *Journal of Bacteriology*, *21*(1), 18-19.

Delaney, G. M., Bennetto, H. P., Mason, J. R., Roller, S. D., Stirling, J. L., & Thurston, C. F. (1984). Electron-transfer coupling in microbial fuel cells. 2. performance of fuel cells containing selected microorganism—mediator—substrate combinations. *Journal of Chemical Technology and Biotechnology*, *34*(1), 13-27.

Du, Z., Li, H., & Gu, T. (2007). A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy. *Biotechnology advances*, *25*(5), 464-482.

Electric Power Research Institute, Water and Sustainability. 2002. Research Plan, vol. 1. Electric Power Research Institute, Palo Alto, CA.

Huang, L., & Logan, B. E. (2008). Electricity generation and treatment of paper recycling wastewater using a microbial fuel cell. *Applied microbiology and biotechnology*, *80*(2), 349-355.

Kaku, N., Yonezawa, N., Kodama, Y., & Watanabe, K. (2008). Plant/microbe cooperation for electricity generation in a rice paddy field. *Applied microbiology and biotechnology*, *79*(1), 43-49.

Kim, B. H., Kim, H. J., Hyun, M. S., & Park, D. H. (1999). Direct electrode reaction of Fe (III)-reducing bacterium, Shewanella putrefaciens. *Journal of Microbiology and Biotechnology*, *9*, 127-131.

Kim, D., & Chang, I. S. (2009). Electricity generation from synthesis gas by microbial processes: CO fermentation and microbial fuel cell technology. *Bioresource Technology*, *100*(19), 4527-4530.

Kim, N., Choi, Y., Jung, S., & Kim, S. (2000). Effect of initial carbon sources on the performance of microbial fuel cells containing Proteus vulgaris. *Biotechnology and Bioengineering*, *70*(1), 109-114.

Kleerebezem, R., & van Loosdrecht, M. C. (2007). Mixed culture biotechnology for bioenergy production. *Current Opinion in Biotechnology*, *18*(3), 207-212.

Lee, H. S., Parameswaran, P., Kato-Marcus, A., Torres, C. I., & Rittmann, B. E. (2008). Evaluation of energy-conversion efficiencies in microbial fuel cells (MFCs) utilizing fermentable and non-fermentable substrates. *Water Research*, *42*(6), 1501-1510.

Liu, H., Cheng, S., & Logan, B. E. (2005). Production of electricity from acetate or butyrate using a single-chamber microbial fuel cell. *Environmental Science & Technology*, *39*(2), 658-662.

Liu, Z., Liu, J., Zhang, S., & Su, Z. (2009). Study of operational performance and electrical response on mediator-less microbial fuel cells fed with carbon-and protein-rich substrates. *Biochemical Engineering Journal*, *45*(3), 185-191.

Logan, B. E. (2008). *Microbial fuel cells*. John Wiley & Sons.

Logan, B. E. (2009). Exoelectrogenic bacteria that power microbial fuel cells. *Nature Reviews Microbiology*, *7*(5), 375-381.

Logan, B. E., & Regan, J. M. (2006). Electricity-producing bacterial communities in microbial fuel cells. *TRENDS in Microbiology*, *14*(12), 512-518.

Logan, B. E., & Regan, J. M. (2006). Microbial fuel cells—challenges and applications. *Environmental Science and Technology*,5172-5180.

Lu, N., Zhou, S. G., Zhuang, L., Zhang, J. T., & Ni, J. R. (2009). Electricity generation from starch processing wastewater using microbial fuel cell technology. *Biochemical Engineering Journal*, *43*(3), 246-251.

Luo, H., Liu, G., Zhang, R., & Jin, S. (2009). Phenol degradation in microbial fuel cells. *Chemical Engineering Journal*, *147*(2), 259-264.

Mohan, S. V., Mohanakrishna, G., Reddy, B. P., Saravanan, R., & Sarma, P. N. (2008). Bioelectricity generation from chemical wastewater treatment in mediatorless (anode) microbial fuel cell (MFC) using selectively enriched hydrogen producing mixed culture under acidophilic microenvironment. *Biochemical Engineering Journal*, *39*(1), 121-130.

Mohan, Y., Kumar, S. M. M., & Das, D. (2008). Electricity generation using microbial fuel cells. *International Journal of Hydrogen Energy*, *33*(1), 423-426.

Pant, D., Singh, A., Satyawali, Y., & Gupta, R. K. (2007). Effect of carbon and nitrogen source amendment on synthetic dyes decolourizing efficiency of white-rot fungus, Phanerochaete chrysosporium. *Journal of Environmental Biology*, *29*(1), 79.

Park, D. H., & Zeikus, J. G. (2000). Electricity generation in microbial fuel cells using neutral red as an electronophore. *Applied and Environmental Microbiology*, *66*(4), 1292-1297.

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

Peighambardoust, S. J., Rowshanzamir, S., & Amjadi, M. (2010). Review of the proton exchange membranes for fuel cell applications. *International Journal of Hydrogen Energy*, *35*(17), 9349-9384.

Pham, C. A., Jung, S. J., Phung, N. T., Lee, J., Chang, I. S., Kim, B. H., ... & Chun, J. (2003). A novel electrochemically active and Fe (III)-reducing bacterium phylogenetically related to Aeromonas hydrophila, isolated from a microbial fuel cell. *FEMS Microbiology Letters*, *223*(1), 129-134.

Potter, M. C. (1911). Electrical effects accompanying the decomposition of organic compounds. *Proceedings of the Royal Society of London. Series B, Containing Papers of a Biological Character*, *84*(571), 260-276.

Prasad, D., Arun, S., Murugesan, M., Padmanaban, S., Satyanarayanan, R. S., Berchmans, S., & Yegnaraman, V. (2007). Direct electron transfer with yeast cells and construction of a mediatorless microbial fuel cell. *Biosensors and Bioelectronics*, *22*(11), 2604-2610.

Rabaey, K., Lissens, G., Siciliano, S. D., & Verstraete, W. (2003). A microbial fuel cell capable of converting glucose to electricity at high rate and efficiency. *Biotechnology letters*, *25*(18), 1531-1535.

Rahimnejad, M., Ghoreyshi, A. A., Najafpour, G. D., Younesi, H., & Shakeri, M. (2012). A novel microbial fuel cell stack for continuous production of clean energy. *International Journal of Hydrogen Energy*, *37*(7), 5992-6000.

Rao, J. R., Richter, G. J., Von Sturm, F., & Weidlich, E. (1976). The performance of glucose electrodes and the characteristics of different biofuel cell constructions. *Bioelectrochemistry and Bioenergetics*, *3*(1), 139-150.

Rezaei, F., Richard, T. L., & Logan, B. E. (2009). Analysis of chitin particle size on maximum power generation, power longevity, and Coulombic efficiency in solid–substrate microbial fuel cells. *Journal of Power Sources*, *192*(2), 304-309.

Rodrigo, M. A., Canizares, P., García, H., Linares, J. J., & Lobato, J. (2009). Study of the acclimation stage and of the effect of the biodegradability on the performance of a microbial fuel cell. *Bioresource technology*, *100*(20), 4704-4710.

Rosenbaum, M., Schroder, U., & Scholz, F. (2005). Utilizing the green alga Chlamydomonas reinhardtii for microbial electricity generation: a living solar cell. *Applied Microbiology and Biotechnology*, *68*(6), 753-756.

Shantaram, A., Beyenal, H., Veluchamy, R. R. A., & Lewandowski, Z. (2005). Wireless sensors powered by microbial fuel cells. *Environmental Science & Technology*, *39*(13), 5037-5042.

Strik, D. P., Terlouw, H., Hamelers, H. V., & Buisman, C. J. (2008b). Renewable sustainable biocatalyzed electricity production in a photosynthetic algal microbial fuel cell (PAMFC). *Applied Microbiology and Biotechnology*, *81*(4), 659-668.

Sun, J., Hu, Y. Y., Bi, Z., & Cao, Y. Q. (2009a). Simultaneous decolorization of azo dye and bioelectricity generation using a microfiltration membrane air-cathode single-chamber microbial fuel cell. *Bioresource Technology*, *100*(13), 3185-3192.

Suzuki, S. H. U. I. C. H. I., Karube, I. S. A. O., & Matsunaga, T. A. D. A. S. H. I. (1978, January). Application of a biochemical fuel cell to wastewaters. In *Biotechnol. Bioeng. Symp.;(United States)* (Vol. 8). Tokyo Inst. of Tech., Yokohama, Japan.

Williams, K. R., & Koslow, R. (1966). An introduction to fuel cells. *Journal of Electrochemical Society*, *113*(6): 139C-140C.