Octaviani, N. F., et al. (2023)
Vol. 1, No. 2 (December 2023), pp. 105-113

DOI : 10.22373/ijes.v1i2.4148
ISSN 3046-885X

IJES
Indonesian Journal of Environmental Sustainability

Published by : Center For Environmental Studies UIN Ar-Raniry Banda Aceh

MICROBIAL FUEL CELL (MFC) BY ELECTROACTIVE BACTERIA AS A RENEWABLE ELECTRICAL ENERGY SOURCE IN INDONESIA

Nazla Fauziyah Octaviani, Nisa Kartika, Anggita Rahmi Hafsari*

Department of Biology, Faculty of Science and Tehcnology, UIN Sunan Gunung Djati Bandung, Indonesia

**Email Correspondence:* anggitarahmi@uinsgd.ac.id

Received : 17 August 2023 Accepted : 26 September 2023 Published : 30 December 2023

ABSTRACT

The uncontrolled nature of fossil fuels and their ecological consequences have moved emphasis to renewable energy and fuel cells, particularly in the transportation industry. The generation of energy from electrons generated from metabolic reactions aided by bacteria is studied in this paper. Microbial fuel cells (MFC) are an environmentally beneficial method of generating electricity while also purifying wastewater, with up to 50% chemical oxygen requirement elimination and power densities ranging from 420 to 460 MW/m^2. This paper focuses on the technology that generates electricity by utilizing the metabolic power from electroactive bacteria as a renewable energy source. The method to collect data is a literature study. The result is seven species of electroactive bacteria potential from 7 articles, which can be used to generate MFC. In summary, using electroactive bacteria as MFC as a renewable energy source is possible because many sources of organic materials can be used as carbon sources for MFC, such as organic waste.

Keywords : Bacteria, Electroactive, MFC, Renewable Energy

ABSTRAK

Sifat bahan bakar fosil yang tidak terkendali dan dampak ekologisnya telah mengalihkan penekanan pada energi terbarukan dan sel bahan bakar, khususnya di industri transportasi. Pembangkitan energi dari elektron yang dihasilkan dari reaksi metabolisme yang dibantu oleh bakteri dipelajari dalam makalah ini. Sel bahan bakar mikroba (MFC) adalah metode yang bermanfaat bagi lingkungan untuk menghasilkan listrik sekaligus memurnikan air limbah, dengan menghilangkan kebutuhan oksigen kimia hingga 50% dan kepadatan daya berkisar antara 420 hingga 460 MW/m^2. Tulisan ini berfokus pada teknologi pembangkitan listrik dengan memanfaatkan tenaga metabolisme bakteri elektroaktif sebagai sumber energi terbarukan. Metode pengumpulan data adalah studi literatur. Hasilnya adalah tujuh spesies bakteri elektroaktif potensial dari 7 artikel yang dapat dimanfaatkan untuk menghasilkan MFC. Kesimpulannya, pemanfaatan bakteri elektroaktif sebagai MFC sebagai sumber energi terbarukan dimungkinkan karena banyak sumber bahan organik yang dapat digunakan sebagai sumber karbon MFC, seperti sampah organik.

Kata kunci : *Bakteri, Elektroaktif, MFC, Energi Terbarukan*

Introduction

Electrical energy has a vital role for humans in supporting their survival and

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ISSN 3046-885X

one of the primary energies whose needs will continue to grow due to the growth and development of population and economy in the world (Ependi & Hafsari, 2023). Electrical energy in 2011 was used around 10.668 million TOE or 82% of total demand then increased to around 14.898 million TOE by 2035 (Alfian et al.). *Electric Power Annual* 2022 reports about 60% of fossil fuels such as coal, petroleum, natural gas, and other gases are used as power generation and about 18% comes from nuclear energy. The need for fossil energy sources will continue to increase from year to year by 4.6% and is expected to triple higher by 2030 (Energy Information Administration, 2023) (Sofyan et al., 2015).

The Indonesian National Electricity Company shows that Indonesia's needs in the use of energy in the form of electricity is 20354.41 MW (Mega Watt) per day, but the national electricity company (PLN) currently only produces 53317.53 MW. This causes 10, 211 villages in Indonesia have not been able to benefit from this electrical energy. Another factor that causes many regions in Indonesia has not been electrified is the geographical condition and economic conditions of rural communities so that (Nurulita et al., 2020) (Agency for the Assessment and Application of Technology, 2014). The energy crisis that is currently unresolved requires new innovations that are environmentally friendly and cheap.

An alternative that can be used to answer problems in Indonesia is the use of renewable energy. Renewable energy derived can come from unlimited sources such as, wind, solar and bacteria. The quantity of renewable energy sources is abundant, while fossil fuels, coal, gas, and oil and bacteria are included in renewable energy sources the formation of which takes hundreds of millions of years. Burningfossil fuels, produces energy that produces harmful greenhouse gases, such as CO_2 (Setyono et al., 2019). Research results from the Ministry of Energy and Mineral Resources of the Republic of Indonesia show that the use of fossils as energy can produce 20 billion tons of carbon emissions, while MFC can reduce carbon emissions by 48-94% (EBTKE Public Relations, 2022).

Previous research has explored the potential of bacteria that can generate electricity through Microbial Fuel Cells (MFCs) by utilizing the metabolism that occurs in bacteria. Bakteri that have been used in MFC (Microbial Fuel Cell) systems are Geobacteraceae sulferreducens, and Rhodoferax ferrireducens, Bacillus subtilis (Prayogo et al., 2017). Bacteria are simple or unicellular organisms and have several types based on their shape: bacilli, straight, cocci, spillus, and helix. Based on the resulting content, bacteria are divided into several classes, one of which is electroactive bacteria, such as Bioelectrochemical Systems (BES), which are used for biotechnological applications (Hafsari & Retired, 2020).

BES are electrical devices that rely on electrogenic bacterial activity and include a variety of devices with different purposes. BES reduces pollutants, recycles elements, synthesizes new products, and generates electricity. BES can also be used for biodegradation/removal of some contaminants with a circular economy model that can be utilized as fuel and converted into energy. There are different types of BES, which include different technologies, such as microbial fuel cells (MFCs), microbial electrolysis cells (MECs), and microbial electrosynthesis (MES) (Lovely, 2012) (Garbini et al., 2023)

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Microbial Fuel Cell (MFC) is an innovation that uses renewable energy and can produceelectrical energy through the degradation process of organic matter by microorganisms through catalytic reactions or bioelectrochemical mechanisms of microorganisms. The microorganisms involved in MFCs are derived from microorganisms with habitats in aerobic, facultative anaerobes, or obligate anaerobes. MFCs have several advantages, including high efficiency, flexible operational conditions, no additional energy requirements, and relevant applications in locations where adequate electrical infrastructure may not be available (Kumar et al., 2019) (Vidales et al., 2019)**.** The main components in the MFC series consist of the anode, cathode, and electronic equipment that supports this process. The anode is usually made of carbon, because it supports bacterial growth, is easy to connect with wires, and is affordable. This anode is usually placed inside the sediment, where the activity of microorganisms in the sediment becomes a source of electrical energy (Prakash et al., 2018).

Renewable electrical energy needs to be done through innovation in the use of bacteria that have the potential to produce electrical energy from their metabolic processes. This update is intended to solve the problem of the electrical energy crisis and support human survival in terms of meeting energy needs. This paper discusses a thorough analysis of recent developments in various fields of study and presents the discovery of electroactive bacteria in microbial fuel cell systems as a renewable energy source. This research objection is to review the use of electroactive bacteria using the MFC (Microbial Fuel Cell) as a renewable energy source.

Methods

The Library Research method or literature study is used to collect data. The data taken from scientific articles focused on the use of electroactive bacteria in MFC from 2014-2023. We collect data from search engines Google and Safari. The keywords in the search engine are MFCs, electroactive bacteria, and renewable electrical energy sources.

Results and Discussion

The literature study results using Google search engines and Safari, using the keywords MFCs, electroactive bacteria, and renewable electrical energy sources, found 7 articles from within and outside the country (Table 1). 7 species of electronic bacteria can produce electricity around 50-690 mW/m^2. These results suggest that bacteria can be used to generate electricity through MFC technology.

Table 1. Electricity generated from various types of electroactive bacteria

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ISSN 3046-885X

Bacteria	**Sources of Nutrition**	**Anode**	**Cathode**	**Result**	**Bibliography**
Geobacter sulfureducens	Acetate	Carbon paper	Catalyst pt	418 mW/m^2	(Mokhtarian, *et. al* 2012)
Shewanella oneidensis	Mud	Graphite	Graphite	690.9 mW/m^2	(Wahyuni, 2022)
Lactobacillus bulgaricus	Glucose	Graphite	Graphite	201.8 mW/m^2	(Novitasari, 2011)
Bacillus subtilis	Peat Water	Activated carbon	Activated carbon	270 mW/m^2	(Utami & Fatisa, 2019)
Escherichia coli	Peat Water	Activated carbon	Activated carbon	116 mW/m^2	(Utami & Fatisa, 2019)
Clostridium	Tofu Liquid Waste	Graphite fiber brush	Hydrophobic carbon fabric	94.5 mW/m^2	(Hidayat, *et. Al* 2020)
Lactobacillus plantarum	Sago stem	Graphite	Graphite	50.082 mW/m^2	(Rahmaniah, Ardi, & Fuadi, 2020)

One MFC mechanism generally uses a double compartment, where the two mechanisms are arranged in series, then the anode chamber and cathode are joined together through a salt intermediary. This intermediate bridge is made by mixing KCl and agar, where K+ ions have a larger radius than H+ ions, which in turn, protons (H+) can diffuse towards the cathode chamber. Each MFC system in the series circuit works independently, resulting in higher currents and potential differentials. In addition, the *Microbial Fuel Cell* system can be used using different types of electrodes, namely carbon and zinc electrodes. Carbon and zinc are used as part of the cathode, while carbon is the primary material at the anode. The use of electrodes in MFCs is influenced by the surface area of the electrode used as the anode. The anode is made of carbon, with a carbon surface that has a size of 1.36 x 10-3 m^2. The selection of the appropriate type of electrolyte solution in the cathode chamber also affects the resulting potential difference. This is because MFCs involve redox reactions and require oxidizing agents strong enough to capture electrons from the anode space. The use of serially arranged double- compartment MFC systems also affects the resulting potency difference (Bosire et al., 2016)

Electroactive bacteria that can transfer electrons extracellularly are also known as exoelectrogenic bacteria, exoelectrogens, electrochemically active bacteria, anode respiration bacteria, or electrical bacteria. The microorganism known as electroactive bacterium capable of extracellular electron transfer (EET) are 100 species. They interact with other microbial species, minerals, or extracellular dissolved electron acceptors and donors that cannot enter the cell electrically. Prokaryotic cells in this system coordinate their development, activity, and mobility through beneficial cell-to-cell interactions (Hafsari & Purnawan, 2020). As a result, complex biofilms with highly organized multicellular and multispecies structures form. Cells are linked together and embedded in a matrix composed primarily of proteins, nucleic acids, and carbohydrate polymers in biofilms. Extracellular polymeric compounds facilitate cell-to-cell contact and electron transfer (EPS (Garbini et al., 2023)

The way bacteria work in MFC involves the conversion of soluble organic substrates into protons (H+), CO_2, and electrons, which are then converted into electrical energy with the help of bacteria as electron acceptors. The Nutrition Source of Bacteria in MFC. Nutrients are needed as a source of carbon that can be metabolized by bacteria into an energy source (Hafsari, 2020). In table 1 it can be seen that the source of nutrients used by bacteria consists of acetate, mud, glucose, peat water, tau waste and sago stem. These bacteria undergo substrate metabolism, converting them into H+ ions in the anode chamber, CO_2, and electrons. These electrons then flow into the cathode chamber through the circuit, generating an electric current. In the cathode chamber, oxygen undergoes a reduction reaction by H+ ions and electrons, producing air (Santoro et al., 2017)

Microbes that have produced energy through metabolic processes will transfer the electrons produced. This electron transfer uses a mediator that accepts intracellular electrons and ejects them to the electrode surface in a reduced state. MFC uses organic substrates because they are easily found in nature and have minimal environmental impact, because they can process potential organic waste into more valuable resources. These organic substrates can come from various sources, such as glucose, fats, proteins, cellulose, and simple organic acid compounds such as lactic, acetic, and butyrate. Several types of waste, such as tofu production waste treated by microbes and microalgae (Spirulina platensis), manure treated by Escherichia coli, corn plant waste treated by Shewanella and kitchen waste treated by several species of microalgae, have shown the potential to produce electric power with varying power densities (Zhao et al., 2017) (Zheng & Nirmalakhandan, 2010) (Wang et al., 2017)

Electroactive microorganisms use redox networks and structural proteins to transfer electrons between the plasma membrane and extracellular minerals. These proteins generally work together in building pathways that physically and electrically connect the redox reactions of metal ions associated with external minerals with intracellular metabolic processes. For example, EET pathways of gram-negative Proteobacteria Geobacter sulfureduksi, and Shewanella oneidensis have been extensively investigated. These bacteria belong to the class of dissimilated metal-reducing microorganisms, which are groups of microorganisms (consisting of both bacteria and archaea) that can perform anaerobic respiration by utilizing metal as a terminal electron acceptor (Bajracharya et al., 2016).

Several researchers have proved that in *Microbial Fuel Cell* (MFC) systems, bacteria can produce electrical energy through their metabolic processes. Types of bacteria often used in MFC research include *Pseudomonas sp, Geobacteraceae sulferreducens, Geobacter metallireducens, Rhodoferax ferrireducens,* and even Bacillus *subtilis bacteria. B. Subtilis* can degrade this organic matter by releasing enzymes, which in their partners release electrons. These electrons can be used as a source of electrical energy (Wahyuni et al., n.d.).

DOI : 10.22373/ijes.v1i2.4148
Vol. 1, No. 2 (December 2023), pp. 105-113
ISSN 3046-885X

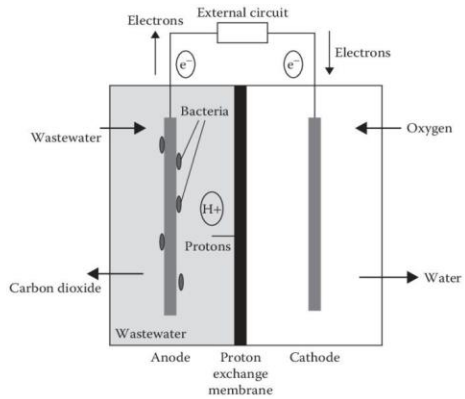

Image Source: (Roy et al., 2023)

The anodic space, cathodic space, and proton exchange membrane are depicted in the figure above (PEM). Microorganisms form electrons and protons in the MFC anodic space, which is kept at anaerobic conditions. Carbon dioxide is produced as a byproduct of oxidation. Electrons are absorbed by the anode and transferred to the cathode. An external circuit is used to pass electrons. Protons, on the other hand, reach the cathodic space via PEMs or salt bridges. They react with O2, which generally acts as an electron acceptor, to produce water in the cathodic space. Continuous electric current production can be accomplished by separating microorganisms from oxygen or electron acceptors other than the anode. To ensure these conditions. Changes in the type of microorganisms, membranes, anodic surface modifications, changes in bacterial genes, and other methods have been tried to increase the system's power generation capacity and efficacy in treating liquid waste. The performance of the MFC largely depends on the features of its construction. Other parameters affecting MFC performance include substrate supply, temperature, microbial or community species used, anolite composition, anode, cathode, and MFC separator material. The three most essential components of an MFC are the anode, cathode, and PEM. Several anode and cathode materials have been used to improve or change MFC capacity and performance over time (Roy Et Al., 2023).

Microbial Fuel Cell (MFC) is a system that can generate electricity by utilizing the metabolic activity of microorganisms. The use of microbial fuel cells can help reduce environmental contaminants such as wastewater, reduce carbon dioxide in the atmosphere by using them to rebuild fuel, and potentially provide a renewable energy source. Microbial fuel cells generate electricity through the use of microorganisms. MFCs can be used in wastewater treatment plants because they can convert organic matter in wastewater into electricity while removing pollutants. In addition, there are several disadvantages of using MFC, namely the cost of manufacturing MFC materials and electricity production which are challenges. The instability that occurs through low rates of microbial growth limits the application of MFCs. (Clark et al., 2016) (Riscahya et al., 2021).

Conclusion

DOI : 10.22373/ijes.v1i2.4148
ISSN 3046-885X

From literature study we found seven electroactive bacteria can generating electricity through various metabolic processes. These electrogenic bacteria include Geobacteraceae sulferreducens, Geobacter metallireducens, Rhodoferax ferrireducens, Bacillus subtilis, Shewanella oneidensis MR-1, and various other microorganisms. Renewable electrical energy generated using Microbial Fuel Cells (MFCs) has several benefits, namely processing organic waste, reducing environmental contaminants such as wastewater, reducing carbon dioxide in the atmosphere by using it to rebuild fuel, and potentially providing a renewable energy source.

References

Alfian, N., Aurelia, M., Mulyanto, K. B., &; Sholikah, U. (n.d.). The potential of Syzygium oleina as an alternative electricity producer with the plant-microbial fuel cell method.

Bajracharya, S., Sharma, M., Mohanakrishna, G., Dominguez Benneton, X., Strik, D. P.B. T. B., Sarma, P. M., &; Pant, D. (2016). An overview on emerging bioelectrochemical systems (BESs): Technology for sustainable electricity, waste remediation, resource recovery, chemical production and beyond. *Renewable Energy*, *98*, 153–170.

Bosire, E. M., Blank, L. M., &; Rosenbaum, M. A. (2016). Strain- and Substrate-Dependent Redox Mediator and Electricity Production by Pseudomonas aeruginosa. *Applied and Environmental Microbiology*, *82*(16), 5026–5038.

BPPT (Agency for the Assessment and Application of Technology). (n.d.). *Energy Outlook Indonesia Energy Outlook 2014 Center for Energy Resources Development Technology Center*.

BRIN Public Relations. (2023, March 29). *The Prospect of Microbial Fuel Cell (MFC) Technology as an Alternative to Fossil Fuels*.

Clark, D. P., Nanette, & Pazdernik. (2016). *Microbial Fuel Cells*. Environmental Biotechnology.

Ependi, A. Z., &; Hafsari, A. R. (2023). Bioluminescent Bacteria as a Source of Future Renewable Light. *International Journal of Advanced Energy, Life Science and Environment Sustainability*, *3*(1).

EBTKE Public Relations. (2022, February 18). *Energy transition period towards net zero emissions*. Directorate General of New Renewable Energy and Energy Conservation.

Garbini, G. L., Barra Caracciolo, A., & Grenni, P. (2023). Electroactive Bacteria in Natural Ecosystems and Their Applications in Microbial Fuel Cells for Bioremediation: A Review. In *Microorganisms* (Vol. 11, Issue 5). MDPI.

Hafsari, A. R., & Purnawan, L. (2020). Molecular Identification and Phylogenic Analysis of Phosphate Solubilizing Bacteria Aneurinibacillus migulanus from Rhizosphere Imperata Cylindrica, Karst Citatah, Bandung Barat, Jawa Barat,

DOI : 10.22373/ijes.v1i2.4148
ISSN 3046-885X

Indonesia. *Journal of Physics: Conference Series*, 1665.

Hidayat, S., Aghnia, D. W., Kardena, E., & Helmy, Q. (2020). Kinerja Microbial Fuel Cell Dengan Variasi Hambatan Eksternal Dalam Menghasilkan Energi Listrik Dan Menyisihkan Senyawa Organik Pada Limbah Cair. *Jurnal Presipitasi*.

Kumar, S. S., Kumar, V., Sandeep K. Malyan, Jyoti Sharma, Thangavel Mathimani, Marshal S. Maskarenj, Prakash C. Ghosh, &; Arivalagan Pugazhendhi. (2019). Microbial fuel cells (MFCs) for bioelectrochemical treatment of different wastewater streams. *Fuel*, *254*.

Logan, B. E., Hamelers, B., Rozendal, R., Schröder, U., Keller, J., Freguia, S., Aelterman, P., Verstraete, W., & Rabaey, K. (2006). Microbial Fuel Cells: Methodology and Technology. *Environmental Science &; Technology*, *40*(17), 5181–5192.

Lovely D.R. (2012). Electromicrobiology. *Annual Review of Microbiology*, *66*, 391–409.

Lubis, A., Di, P., Conversion, T., Energy, K., Studies, B., &; Technology, P. (2007).

Lumbangaol, P. H. (2016). *Renewable Energy for Sustainable Development In Indonesia*.

Mokhtarian, N., Rahimnejad, M., Najafour, G., Daud, W. R., & Ghoreyshi, A. (2012). Effect Of Different Substrat on Performance of Microbial Fuel Cell. *African Journal of Biotechnology*, 1-7.

Novitasari, D. (2011). *Optimasi Kinerja Microbial Fuel Cell (MFC) untuk Produksi Energi Listrik Menggunakan Bakteri Lactobacillus bulgaricus.* Depok: Skripsi. Universitas Indonesia.

Nurulita, I., Elviantari, A., Dwilaksono, F., Manguntungi, B., & Budhi Kusuma, A. (2020). Green Electricity from Wetland Plants-Derived Microbial Fuel Cell for Indonesia's Coastal Region. In *Biologica Samudra* (Vol. 2, Issue 2).

Prakash, O., Pushkar, P., Mungray, A. K., Mungray, A & Kailasa, S. K., (2018). Effect of geometrical position of a multi-anode system in power output and nutritional variation in benthic microbial fuel cells. *Journal of Environmental Chemical Engineering*, *6*(1), 1558–1568.

Prayogo, F. A., Suprihadi, A., &; Raharjo, B. (2017). Microbial Fuel Cell (Mfc) Uses Bacillus Subtilis Bacteria with Septic Tank Waste Substrate and Its Effect on Waste Quality. In *Journal of Biology* (Vol. 6, Issue 2).

Rahmaniah, Ardi, S. B., & Fuadi, N. (2020). Aplikasi Teknologi Micobial Fuel Cell (MFC) Untuk Menentukan Energi Listrik Substrat Batang Sagu. *Jurnal Teknosains*, 172-175.

Retnosari, A. A., &; Shovitri, M. (2013). *Isolate Ability* of *Bacillus sp. in Degrading Septic Tank Sewage.*

Riscahya, R., Syamsuri, P., Dewi, T., Pribadi, K., &; Rosada, K. K. (2021). Utilization

DOI : 10.22373/ijes.v1i2.4148
ISSN 3046-885X

of Microbial Fuel Cells to Overcome Environmental Pollution and Produce Microenergy. In *Sainteknol* (Vol. 19, Issue 1).

Roy, H., Rahman, T. U., Tasnim, N., Arju, J., Rafid, Md. M., Islam, Md. R., Pervez, Md. N., Cai, Y., Naddeo, V., &; Islam, Md. S. (2023). Microbial Fuel Cell Construction Features and Application for Sustainable Wastewater Treatment. *Membranes*, *13*(5), 490.

Santoro, C., Arbizzani, C., Erable, B., &; Ieropoulos, I. (2017). Microbial fuel cells: From fundamentals to applications. A review. *Journal of Power Sources*, *356*, 225–244.

Sih Setyono, J., Hari Mardiansjah, F., Febrina Kusumo Astuti, M., ProfHSoedarto, J. S., Tembalang, K., &; Semarang Jurnal Riptek, K. (2019). Development of new energy and energy potential. In *Journal of Riptek* (Vol. 13, Issue 2).

Sofyan, A., Pakiding, M., &; Rumbayan, E. M. (2015). Study of Planning Needs and Fulfillment of Electrical Energy in Manado City. *Journal of Electrical and Computer Engineering*, 1–12.

Sugiyono, A., Dharma, A., Badan, P., Dan, P., Technology, P., Sidik Boedoyo, M., &; Studies, B. (2013). *Indonesia Energy Outlook 2013: Energy Development in Support of Transportation Sector and Mineral Processing Industry*.

Utami, L., & Fatisa, Y. (2019). Electricity Production from Peat Water Uses Microbial Fuel Cells Technology. *Indonesian Journal of Chemical Science and Technology*, *02*(1), 55-60.

Vidales, A. G., Sasha Omanovic, & Boris Tartakovsky. (2019). Combined energy storage and methane bioelectrosynthesis from carbon dioxide in a microbial electrosynthesis system. *Bioresource Technology Reports*, *8*.

Wahyuni, I., Heriyono, H., Baharuddin, M., Ibrahim Patunrengi, I., & Artikel, S. (n.d.). Electrical Energy Potential of Microbial Fuel Cell (MFC) Using Molasses Substrate and Pseudomonas sp. *ALCHEMY: Journal of Chemistry*.

Wang, Y.-Z., Shen, Y., Gao, L., Liao, Z.-H., Sun, J.-Z., & Yong, Y.-C. (2017).

Improving the extracellular electron transfer of Shewanella oneidensis MR-1 for enhanced bioelectricity production from biomass hydrolysate. *RSC Advances*, *7*(48), 30488–30494.

Zhao, Y.-G., Zhang, Y., She, Z., Shi, Y., Wang, M., Gao, M., & Guo, L. (2017). Effect of Substrate Conversion on Performance of Microbial Fuel Cells and Anodic Microbial Communities. *Environmental Engineering Science*, *34*(9), 666–674.

Zheng, X., & Nirmalakhandan, N. (2010). Cattle wastes as substrates for bioelectricity production via microbial fuel cells. *Biotechnology Letters*, *32*(12), 1809–1814.