Fabrication of Electricity from Wastewater by Utilizing Microbial Fuel Cells: A Review

Bhavya R¹, Pavithra V², Aarthi S³, Dharani K⁴, Prabhu N⁵

¹Department of Biotechnology, Vivekanandha College of Engineering for Women, Elayampalayam, Tiruchengode-637 205, Tamilnadu, INDIA
²Department of Biotechnology, Vivekanandha College of Engineering for Women, Elayampalayam, Tiruchengode-637 205, Tamilnadu, INDIA
³Department of Biotechnology, Vivekanandha College of Engineering for Women, Elayampalayam, Tiruchengode-637 205, Tamilnadu, INDIA
⁴Department of Biotechnology, Vivekanandha College of Engineering for Women, Elayampalayam, Tiruchengode-637 205, Tamilnadu, INDIA
⁵Department of Biotechnology, Vivekanandha College of Engineering for Women, Elayampalayam, Tiruchengode-637 205, Tamilnadu, INDIA

⁵Corresponding Author: prabhu.aut.26@gmail.com

ABSTRACT
Bioelectricity is the electric current produced by anaerobic digestion of organic substrate by microorganisms. A microbial fuel cell (MFC) is a device that transforms energy released by natural carbon sources that are not used as substrates by microorganisms to provide voltage and demonstrating to be associate proficient ways that of viable energy production. The electrons released because of the microbial breakdown is seized to keep up ruthless potential density while not an efficient carbon discharge within system. Usage of microorganisms toward bioremediation is similar to the consequence as of the generation of electricity creates the MFC technology a very beneficial plan which could be smeared in varied segment of industries and agricultural wastes. Although the influences of MFCs in generation of electricity was initially low, modern development within the style elements and dealing has increased ability yield to a major step thus permit application of MFCs in varied sectors as well as waste material ministrations and biodepolution. The accompanying review gives a top-level view concerning the parts, operating, alteration and purpose of MFC technology for numerous analysis and industrial application.

Keywords-- Biodepollution, Bioelectricity, Microbial fuel cell, Wastewater

I. INTRODUCTION
Bioelectricity creation is the creation of power by life forms by virtue of creation of electrons coming about because of their digestion. These electrons delivered can be caught in order to keep up a steady fabrication of energy. Bacterial cells when given an appropriate substrate can use the segments creating electrons which can be collected and used by associating them through a circuit. These segments can be stuffed into a gathering called a ‘microbial fuel cell’ (MFC) ending up being a wellspring of vitality. Anaerobic absorption of substrate by the small scale life forms is basic for the production of the electrons happening because of their digestion. The above responses show the metabolic responses did by the microorganisms in the absence of oxygen and then in the presence of oxygen [1].

Microbial fuel cells:
A MFC normally comprises of a few segments fundamentally partitioned into two chambers, that is, anodic and cathodic chamber containing the anode and cathode, separately. These chambers are isolated by a proton exchange membrane (PEM) (Figure 1). The organisms present in the anodic chamber are furnished with an ideal substrate which is anaerobically corrupted to discharge electrons which are moved from the anode to the cathode by means of outer circuit and the protons produced are specifically gone through the exchange membrane. Both these items delivered because of the activity of the organisms in the anodic compartment travel to the cathode and respond with oxygen to create water [2]. MFCs are gadgets that can change over compound vitality into electrical vitality by the procedure of oxidation of different carbon sources or even natural squanders did by electrochemically active bacteria (EAB) [3,4,5,6]. The MFC chambers can be developed by glass, polycarbonate, just as plexiglass [7] Materials, for example, carbon fabric, carbon paper, graphite can be utilized as anode terminal [8,9,10,11]. An air cathode is utilized to keep up the oxygen consuming nature of the terminal and this can be comprised of materials, for example, platinum(Pt) or Pt-black materials. The anode chamber comprises of the natural substrates which are to be used by the microorganisms to deliver electrons which move through the outer circuit to the cathode at last acknowledged by the arrangement present in the cathodic chamber. The protons created go from anode to cathode through the particle trade layer [12].Ferricyanide ([Fe(CN)₆]³⁻) or permanganate([MnO₄]⁻) arrangements
can go about as compelling catholytes however are not manageable [13,14]

Microorganisms

The major contribution of microbial population in MFC technology is accounted by Geobacter [16,17,18] land Shewanella [19,20,21] species also shows that use of MFC for power generation can also we achieved by photosynthetic bacteria .The problem of carbon dioxide removal from atmosphere is eliminated on usage of photosynthetic microbial systems[22] .Researches have been carried out on using cyanobacterial strains as biocatalysts in MFC. Studies shown that synergistics relationship can be achieved between photosynthetic microbial system and heterotrophic system. The symbiotic functioning involves in utilization of organic substrate synthesized during photosynthesis by heterotrophic microbial system. Using of pseudomonas aeruginosa with manipulated NAD co-factor increase the metabolic rate leading to enhance the production. Anaerobic acidogenesis of livestock waste process to be affective in power generation. Anaerobic acidogenesis of dairy cattle compost uncovered Clostridium sp., Pseudomonas luteola and Ochrobactrum pseudogrigonense to be groups present liable for the power production process [23] Algal types of Leptolyngbya sp. Mixed cultures of microorganism population have been utilized in MFCs, for example, natural microbial community, domestic waste material, sediments from marine and lake in addition as distillery wastewater[24,25,26] .The commonly used microorganisms are given in table.1.

Substrates

The natural substrates can be utilised for anaerobic ingestion by the microorganism in biological current production. Wastewater from the household can be used for uninterrupted electric current[27]. The generation of greatest power utilizing wastewater as a substrate using swine wastewater as a substrate in a single chambered MFC was demonstrated by [28]. For bioelectricity production, oil Wastewater can also be used [29, 30]. An effective substrate in bioelectricity production coupled with hydrogen production was also demonstrated by waste sludge [31, 32]. The microbes which are separated from high Andean locale in solitary chambered MFC are employed as substrate by fruit and vegetable wastes [33]. The utilization of nourishment squander leachate acquired from bio-hydrogen aging as potential substrate toward upgraded power fabrication was reported by researchers [34]. The power density measured for various substrates was in the order of propionate < butyrate< acetic acid derivation. This is of explicit significance in light of the fact that acidogenic debasement of natural squanders produces unstable unsaturated fats which relying on their proplicity toward the microorganisms affecting power age [34].

II. MATERIALS AND METHODS

MFC design and components

The MFC generally consists two chamber that is an anodic and a cathodic one separate by a proton exchange membrane as shown in figure: 1. Two chamber MFC

The most simple kind of MFC comprises of two chambers isolated by material that conducts protons between the chambers. The used design has form of ‘H’, containing two bottles joined by a tube which has in built centrifuge that is a ion exchange membrane (CEM) eg: usual salt bridge. The electrodes used can be of any non-corrosive, current conducting with carbon paper cloth.
graphite etc., as anode. There should be a catalyst for water. The anode chamber carry the biodegradable substrate supplements (nitrogen, phosphorous, oxygen and trace materials). The oxygen scatter into the anode chamber and is established the pace of oxygen dispersion into anode without a PEM is 2.7% [35, 36]. A typical two-chambered MFC is shown in Fig.2.

![Diagrammatic outline of a classic dual chamber MFC](image)

**Figure 2:** Diagrammatic outline of a classic dual chamber MFC (Figures with modifications after [37])

**Single chamber MFC**

By avoiding the cathode chamber and PEM with direct contact of cathode a more efficient MFC can be built, because as there is no need in aerating water since the oxygen present in the air is directly transformed to the cathode. Primary design used in labs to give demonstration on electricity or current generation from wastewater consists of cathode in the center of a cylinder and the anode was present around the cathode. Graphite rods fined in the anode chamber is connected to the cathode chamber through outside circuit. Through the middle tube the air is created to bubble so that it reacts with cathode. In some other SCMFC there are two electrodes present on opposite ends of the single tube available in the design. The anode in one of the end is wrapped to avoid the oxygen diffusion into the chamber. The other end is open so that the cathode or electrode faces (outsides) oxygen in the suggested a new air, while the another end is fixed placed in the PEM and face towards the solution chamber. Fig.3 represents the single chamber MFC.

![Diagrammatic representation of single chamber MFC](image)

**Figure 3:** Diagrammatic representation of single chamber MFC (Figure with few modifications after [37,38])
Up-flow model MFC systems

In that MFC a cylinder with plexiglass was divided into two different sections by glass wool as anode and glass bend layers as cathode chamber. The top graphite was disc-shaped was coated over anode and cathode and put at the base and the highest point of the reactor unit[39]. The feed is supplied to the lower part of anode and release of effluent takes places through the cathode chamber and comes out at the top continuously[40,41]. There is no separate electrolyte for anode and cathode. The barriers for diffusion between the two electrodes produces a DO gradient optimum operation of the MFC. The figure 4 represents the up-flow model MFC systems.

Stacked MFC

To investigate the performances of many MFCs joined in series and in parallel a stacked MFC is built [42]. Increased voltage or current is often produced by connecting MFCs in parallel. In adverse affect has not been reported or observed. The efficiency in terms of coulombic % differs greatly in different arrangement of parallel connections. The unit has six individual MFC with granular black lead anode. It is not a mensuration of negatron move rate, while the authors portrayed how much substrate was utilized for power age before the stream streamed out of the MFCs contrasted enormously in the two plans with the equal association giving about a proficiency multiple times. Fig. 5. Stacked MFCs consisting of six individual units with graphite anode.[42]

Wastewater

Wastewater is any water that has been plagued by human use. Wastewater is "utilized water from any combination of local, industrial business or agricultural activities, surface runoff or storm water, and any sewer flow or sewer infiltration.

III. OPERATION

Two aspirating glass bottles are used to maintain the flow rate uniformly when used as head balancing tanks to feeds which the sample into the anaerobic chamber. To maintain the detention time pinch cocks are used. The wastewater is feed sample inside the anode chamber in anaerobic condition. The distilled water was filled in cathodic chamber. The two electrodes are at distance of 5cm.electrodes are attached to the copper wire using clips and the wire is connected to multi-meter outside the unit. Noted down every each of half an hour. The line diagram, pictorial view of overall experimental setup is shown in Fig-6.
Performance of microbial fuel cell

As reported earlier, the efficient working of MFC depends on the reaction between the organic substrate and the electron acceptor (e.g., oxygen). However, this specific voltage could not be found since the electrons transfer chain varies from microbes to microbe and also the growth condition differs. The main anodic reaction between the potential (redox) of the mediator and the anode determines the voltage produced. In some bacteria, these are not capable of releasing electrons to anode and a (redox) mediator is required [43,44]. In this case, the reaction is the gain of electron from the mediator [5,45]. In a MFC without a mediator using anodophiles like G. sulfurreducens R. ferrireducens. Microorganisms produces a bio-film above the surface of the anode and the use the same for anaerobic respiration the anode potential can be measured by the ratio of cytochrome in both oxidized and reduced state. The optimal potential of MFC can be evaluated by the Nernst equation for all the reaction setups. The potential to be found ranges from 100 mV.

\[ \text{Equation (1)} \]

IV. APPLICATIONS

Electricity generation

MFCs area unit is the capability of changing the energy holding on within the chemical compounds during a biomass to electricity with the help of microorganisms. Since chemical vitality from the oxidation of fuel particles are changed over legitimately to electricity instead of heat, the Carnot cycle with a limited thermal efficiency is avoided and theoretically equals the conventional chemical fuel cells. R. ferrireducens produce power with an electron yield as high as 80% that it was reported by researchers [46]. The high Coulombic effectiveness of 97% was accounted by [47] during the oxidation of formate with the catalysis of Pt black. MFC power generation continues to be terribly low rate of electron abstraction. A feasible way to resolve this issue is to store the power in battery-powered gadgets and afterward convey it to end-clients [48]. Capacitors were employed in their biologically impressed robots named EcoBot 1 to store the energy generated. MFCs are particularly appropriate for fueling little telemetry frameworks and remote sensors that have just low force necessities to transmit signal temperature to receivers in remote locations [49,50]. Researchers has viewed the MFC as an ideal energy offer candidate for Gastrobots by self-feeding the biomass collected by themselves [51]. Realistic energetically autonomous robots would in all
probability can be used MFCs that use extraordinary energies like sugar, organic product, dead creepy crawlies, grass and weed. Local consumption of biomass will be accustomed give renewable power for native consumption. Applications of MFCs during a starship are potential since they’ll offer electricity whereas it degrades wastes generated aboard. Some scientists have estimated that within the future a miniature MFC will be planted body to control an implantable clinical gadget with the supplement nutrients equipped by the human body [52]. The MFC technology is especially favored for property long power applications. However, only after potential wellbeing and security issues in the MFC are completely fathomed, would it be able to be applied for various applications.

**Biohydrogen**

MFC being greatly used to produce chemical elements than electricity. Usually protons formed from anode reaction moves towards to cathode to react with oxygen to give water. The protons and the electrons formed through the metabolism in microorganisms generate hydrogen which is not favorable in terms of thermodynamics. The needed potential for MFC is 110mV and is comparably less than 1210mV which is used for direct electrolysis of water at pH 7, through biomass oxidation method. MFC generally produces about 8-9 mol water/mol compared to 4 mol water/mol glucose through conventional fermentation [53]. Other advantages include the accumulation of chemical etc., and it can be used later. Thus, MFC can act as renewable source for hydrogen to overcome the hydrogen demand all over the world economy.[54]

**Wastewater Treatment**

The MFCs can be utilized for treating waste water right off in 1991[55]. Civil waste material contains anorganic compounds which will enable fuel MFCs. The measure of intensity of power produced by MFCs in the wastewater treatment produces power reduces the electricity required for the treatment through the conventional process by 50% and uses more electric power for aeration purpose. Organic atoms, for example, acetic acid derivation, propionate, butyrate can be altogether broken down to CO$_2$ and H$_2$O. A half breed fusing both electrophiles and anodophiles are particularly suitable for wastewater treatment because a variety of organics can be degraded with the help of organics. MFCs required sure microbes have an ability to remove sulfides as needed in waste matter treatment [56]. MFCs can improve the development of bioelectrochemically dynamic organisms during wastewater treatment in this way they have great operational sound qualities. For scaling-up process Consistent stream and single-compartment MFCs and layer less MFCs are recommended [40,41,58]. Up to 80%of the COD can be removed in wastewater treatment [37,28] and a Coulombic efficiency of 80% can be achieved[58].

**Bio Sensors**

Another potential application of the MFC technology is to use it as a sensor for pollutant analysis and in situ process monitoring and control [59,60]. The Coulombic yield of MFCs of wastewater make MFCs can be used as biological oxygen demand (BOD) sensors (Kim et al., 2003). To measure the BOD value of a liquid is to calculate its Coulombic yield [59]. There is a good linear relationship between the Coulombic yield and the strength of the wastewater treatment in BOD concentration. However, a high BOD concentration needs a long reporting time because the Coulombic yield can be calculated only after the BOD has been removed [61]. Since the current values increase with the BOD value linearly, the low BOD value based on the maximum current. During this stage, the anodic reaction is limited by substrate concentration. It is advantageous over other types because they have excellent operational stability and good reproducibility and accuracy. MFC-type BOD sensor constructed for over 5 years without extra maintenance, far longer in service life span than other types of BOD sensors.

**V. CONCLUSION**

Electricity production through bio-based technology can help to achieve various goals like vitality creation to biofuel creation just as bioremediation. Electricity production from MFC can be used as economical wellspring of vitality limiting the use of non-renewable energy sources. By using microorganism effective way of removing the pollutants which could spoil the environment and make way for renewable energy.

| Microbes                        | Substrate | Applications                  | Reference                        |
|---------------------------------|-----------|-------------------------------|----------------------------------|
| Actinobacillus succinogenes     | Glucose   | Neutral red or thionin as electron mediator | Park and Zeikus, (2000); Park and Zeikus,(1999); Park et al., (1999) |
| Aeromonas hydrophila           | Acetate   | Mediator-less MFC             | Pham et al. (2003)               |
| Alcaligenes faecalis, Enterococcus gallinarum, Pseudomonas aeruginosa | Glucose | Selfmediate consortia isolated from MFC with a maximal level of 4.31 W m$^{-2}$ | Rabaey (2004) |
| Microorganism                          | Type of MFC          | Substrate                  | Electrode materials       | Current density/Power density | Reference                                      |
|---------------------------------------|----------------------|----------------------------|----------------------------|--------------------------------|------------------------------------------------|
| Clostridium beijerinckii              | Starch, glucose, lactate, molasses | Fermentative bacterium     | Niessen et al. (2004b)     |                                 |                                                |
| Clostridium butyricum                 | Starch, glucose, lactate, molasses | Fermentative bacterium     | Niessen et al., 2004b; Park et al., (2001) |                                 |                                                |
| Desulfovibrio desulfuricans           | Sucrose              | Sulphate/sulphide as mediator | Ieropoulos et al., 2005a; Park et al., (1997) |                                 |                                                |
| Erwinia dissolven                     | Glucose              | Ferric chelate complex as mediators | Vega and Fernandez, (1987) |                                 |                                                |
| Escherichia coli                      | Glucose sucrose      | Mediators such as methylene blue needed. | Schroder et al., (2003); Ieropoulos et al., (2005a); Grzebyk and Pozniak, (2005) |                                 |                                                |
| Geobacter metallireducens            | Acetate              | Mediator-less MFC          | Min et al. (2005a)         |                                 |                                                |
| Geobacter sulfurreducens              | Acetate              | Mediator-less MFC          | Bond and Lovley, (2003); Bond et al., (2002) |                                 |                                                |
| Gluconobacter oxydans                 | Glucose              | Mediator (HNQ, resazurin or thionine) needed. | Lee et al. (2002) |                                 |                                                |
| Klebsiella pneumonia                  | Glucose              | HNQ as mediator biomineralized manganese as electron acceptor | Rhoads et al., (2005); Menicucci et al., (2006) |                                 |                                                |
| Lactobacillus plantarum               | Glucose              | Ferric chelate complex as mediators | Vega and Fernandez, (1987) |                                 |                                                |
| Proteus mirabilis                     | Glucose              | Thionin as mediator        | Choi et al., 2003; Thurston et al.,(1985) |                                 |                                                |
| Pseudomonas aeruginosa                | Glucose              | Pyocyanin and phenazine-1-carboxamide as mediator | Rabaey et al., (2004), (2005a) |                                 |                                                |
| Rhodoferax ferrireducens              | Glucose, xylose, sucrose, maltose | Mediator-less MFC          | Chaudhuri and Lovley, (2003); Liu et al., (2006) |                                 |                                                |
| Shewanella oneidensis                 | Lactate              | Anthraquinone-2,6-disulfonate (AQDS) as mediator | Ringeisen et al., (2006) |                                 |                                                |
| Shewanella putrefaciens               | Lactate, pyruvate, acetate, glucose | Mediator-less MFC but incorporating an electron mediator like Mn(IV) or NR into the anode enhanced the electricity production | Kim et al., (1999a,b); Park and Zeikus, (2002) |                                 |                                                |
| Streptococcus lactis                  | Glucose              | Ferric chelate complex as mediators | Vega and Fernandez, (1987) |                                 |                                                |

Table 2: Performance of microbial fuel cells for bioelectricity generation using pure cultures.
Saccharomyces cerevisiae | Single-chamber MFC | Synthetic wastewater | Graphite plates | 282 mA/ m² | Rodrigo et al., 2007

Thermomincola ferriatica | Double-chamber MFC | Acetate | Graphite carbon fibres | 12000 mA/ m² | Kang et al., 2014

Lysinibacillus | Double-chamber MFC | Glucose | Graphite felt | 85 mW/ m² | Feng et al., 2011

sphaericus | Single-chamber MFC | Acetate | Carbon cloth | 205 mA/ m² | Wen et al., 2009

Citrobacter sp. | Single-chamber MFC | Xylose | Carbon fibres brush | 2625 mW/ m³ | Feng et al., 2008

Ochrobactrum sp. | Double-chamber MFC | Lactate | Carbon cloth | 4920 mW/ m³ | Durruty et al., 2012

Scenedesmus | Double-chamber MFC | Acetate | Carbon fiber brush-anode, Carbon cloth-cathode | 1926 mW/ m² | Cheng et al., 2010

Shewanella putrefaciens | Single-chamber MFC | Lactate | Graphite-felt | 3000 mW/ m² | Fang et al., 2013

Cyanobacteria | Single-chamber MFC | Domestic wastewater | Graphite-felt-anode, Carbon cloth-cathode | 114 mW/ m² | Prathap et al., 2013

Chlorella vulgaris | Double-chamber MFC | Wastewater | Carbon felt-anode, Carbon cloth-cathode | 2485 mW/ m³ | Kracke et al., 2015.

Rhodopseudomonas palustris | Single-chamber MFC | Wastewater | Carbon paper-anode, Carbon cloth-cathode | 2720 mW/ m² | Pirbadian et al., 2014

Coriolus versicolor | Double-chamber MFC | 2ABTS | Carbon fibres | 320 mW/ m³ | Okamoto et al., 2014

Geobacter metallireducens | Double-chamber MFC | Domestic wastewater | Carbon paper | 40 mW/ m² | Nevin et al., 2008

Geobacter sulfurreducens | Double-chamber MFC | Acetate | Carbon fibres | 1.9 mW/ m² | Wetser et al., 2015

Table 3: Performance of microbial fuel cells for bioelectricity generation using mixed cultures

| Source of inoculum         | Type of MFC | Substrate               | Electrode material | Current density/Power density/Voltage | Reference       |
|----------------------------|-------------|-------------------------|--------------------|---------------------------------------|-----------------|
| Dairy manure wastewater    | Single-chamber MFC | Dairy manure wastewater | Graphite fiber brush | 190 mW/ m²                             | Richter et al., 2008 |
| Potato wastewater          | Single-chamber MFC | Potato wastewater       | Graphite fiber brush | 217 mW/m                               | Richter et al., 2008 |
| Activated sludge | Primary wastewater | Activated sludge | Activated sludge | Activated sludge | Activated sludge | Activated sludge | Primary wastewater | Primary wastewater | Primary wastewater | Primary wastewater | Anaerobic sludge | Anaerobic reactor effluent | Soil |
|-----------------|--------------------|------------------|------------------|------------------|------------------|------------------|--------------------|--------------------|--------------------|--------------------|------------------|--------------------------|------|
| Double-chamber MFC | Double-chamber MFC | Single-chamber MFC | Double-chamber MFC | Single-chamber MFC | Single-chamber MFC | Single-chamber MFC | Single-chamber MFC | Single-chamber MFC | Single-chamber MFC | Single-chamber MFC | Double-chamber MFC | Double-chamber MFC | Double-chamber MFC |
| Acetate, glucose | Acetate | Acetate, glucose | IPOME | Glucose | Acetate | Acetate | Acetic acid | Ethanol | Lactic acid | Succinic acid | Slaughterhouse wastewater | Acetate |
| Carbon paper | Graphite rods | Carbon cloth | Polyacrylonitrile carbon felt | Carbon cloth | Graphite coated with graphene -anode, carbon cloth-cathode | Graphite coated with graphene -anode, carbon cloth-cathode | Graphite fiber brushes-anode Carbon cloth-cathode | Graphite fiber brushes-anode Carbon cloth-cathode | Graphite fiber brushes-anode Carbon cloth-cathode | Graphite fiber brushes-anode Carbon cloth-cathode | Carbon cloth | Carbon cloth | Cellulose |
| 410 mV | 152 mA/ m² | 1084 mW/ m² | 107 mW/ m² | 68 mW/ m² | 670 mW/ m² | 835 mW/ m² | 820 mW/ m² | 739 mW/ m² | 444 mW/ m² | 578 mW/ m² | 1200 mW/ m³ | 188 mW/ m² |
| Clarke et al., 2011 | Coursolle et al., 2010 | Inoue et al., 2010 | Malvankar et al., 2012 | Okamoto et al., 2014 | Lebedev et al., 2014 | Baranitharan et al., 2015 | Baranitharan et al., 2015 | Baranitharan et al., 2015 | Baranitharan et al., 2015 | Ci et al., 2012 | Liang et al., 2011 | Wu et al., 2013 |

### Table 4: Performance of microbial fuel cells for wastewater treatment

| Wastewater          | Type of MFC | Electrode material                                      | % COD reduction | Reference        |
|---------------------|-------------|--------------------------------------------------------|-----------------|------------------|
| Swine wastewater    | Single-chamber MFC | Toray carbon paper as anode carbon cloth as cathode | 92              | Kumar et al., 2015 |
| Process Type                        | System Type     | Electrodes                  | Efficiency | Reference          |
|------------------------------------|-----------------|-----------------------------|------------|--------------------|
| Starch processing wastewater       | Single-chamber MFC | Carbon paper                | 98         | Yu et al., 2015    |
| Real urban wastewater              | Double-chamber MFC | Graphite electrodes         | 70         | Zhang et al., 2014 |
| Olive mill wastewaters             | Single-chamber MFC | Carbon cloth as electrodes  | 65         | Ahmed et al., 2012 |
| Protein-rich wastewater            | Double-chamber MFC | Graphite rods as electrodes | 80         | Xu et al., 2015    |
| Paper recycling wastewater         | Single-chamber MFC | Graphite fibers-brush       | 76         | Huang et al., 2008 |
| Cassava mill wastewater            | Double-chamber MFC | Graphite plates electrode   | 86         | Li et al., 2010    |
| Food processing wastewater         | Double-chamber MFC | Carbon paper electrodes     | 95         | Li et al., 2013    |
| Domestic wastewater                | Double-chamber MFC | Plain graphite electrodes   | 88         | Oh et al., 2005    |
| Chocolate industry wastewater      | Double-chamber MFC | Graphite rods as electrodes | 75         | Ahn et al., 2010   |
| Biodiesel wastes                   | Single-chamber MFC | Carbon brush electrodes     | 90         | Kaewkannetra et al., 2011 |
| Beer brewery wastewater            | Single-chamber MFC | Carbon fibers               | 43         | Abourached et al., 2014 |
| Potato Processing wastewater       | Tubular MFC      | Graphite particles as anode Carbon felt as cathode | 91         | Zhang et al., 2012; Wang et al., 2011 |
| Palm oil mill effluent             | 1UML-MFCs        | Graphite granules, Carbon fiber felt | 90         | Kong et al., 2014 |
| Animal carcass wastewater          | Up-flow tubular MFC | Graphite felt as anode Carbon cloth as cathode | 51         | Strycharz et al., 2008; Orellana et al., 2013; |
| Food waste leachate                | Double-chamber MFC | Carbon felt                 | 85         |                   |
| Chemical wastewater                | Double-chamber MFC | Graphite plates             | 63         |                   |

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