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

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ABSTRACT

Bioelectricity is the electric current produced by anaerobic ingestion of organic substrate by microorganism. A microbial fuel cell (MFC) is a appliance that transforms energy discharged outcome of oxidation of complicated natural carbon sources that area unit used as substrates by microorganisms to provide voltage thus 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 biodepollution. 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($[MnO]^{4-}$) arrangements

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can go about as compelling catholytes however are not manageable [13,14]

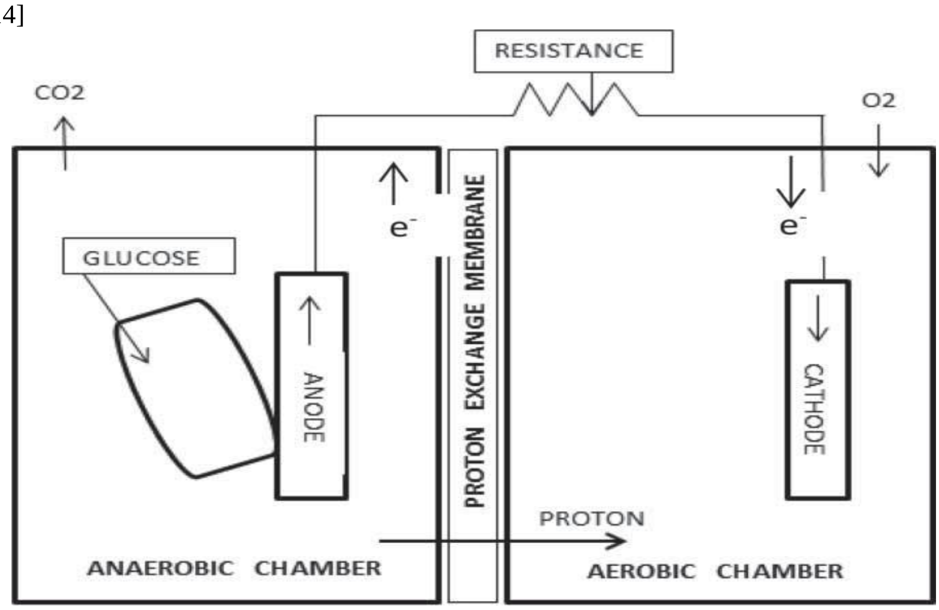

Figure 1: Schematic outline of a typical Microbial Fuel Cell. (Figure drawn with modifications after [15])

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 carbondioxide 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 acidogensis of livestock waste process to be affective in power generation. Anaerobic acidogenesis of dairy cattle compost uncovered Clostridium sp., Pseudomonas luteola and Ochrobactrum pseudogrignonense 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 anaerobiotic 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 proclivity 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.

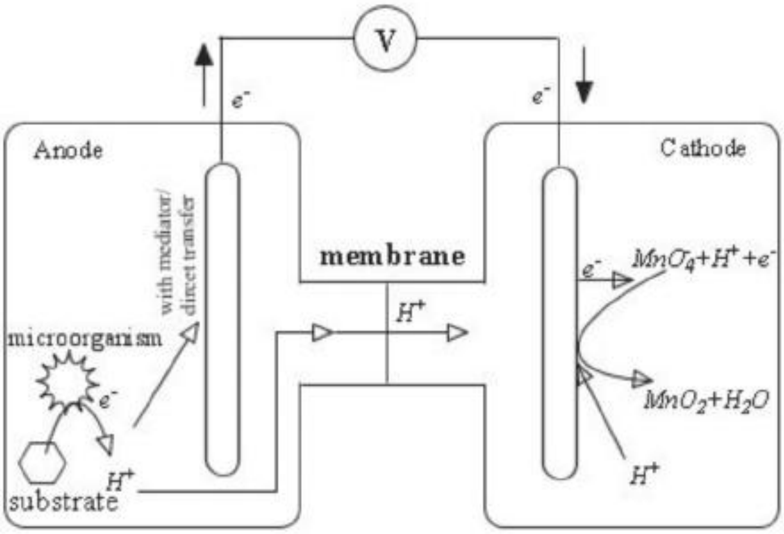

Figure 2: Diagrammatic outline of a classic dual chamber MFC (Figures with modifications after [37])

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.

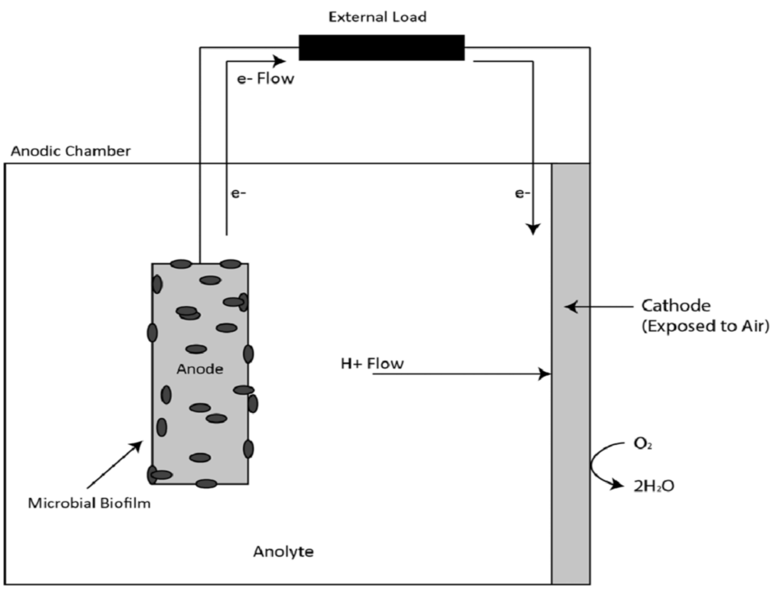

Figure 3: Diagrammatic representation of single chamber MFC (Figure with few modifications after[37,38]

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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) goes 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.

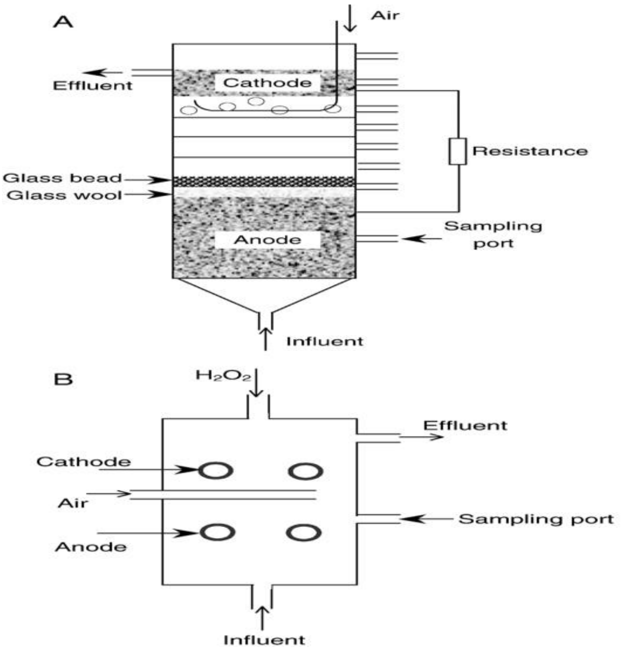

Figure 1: Diagrammatic representation of mediator- and membrane-less MFC with Cylinder (A) and rectangle (B) shape (Figures with few modifications after [40,39] respectively.)

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 creatly 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 black lead anode. (Figure drawn to illustrate a photo in [42]

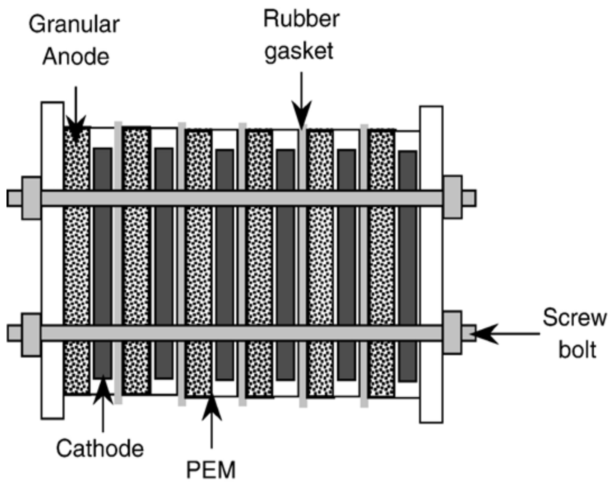

Figure 5: Schematic representation of Stacked MFC consisting of six individual units with graphite anode.[42]

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.

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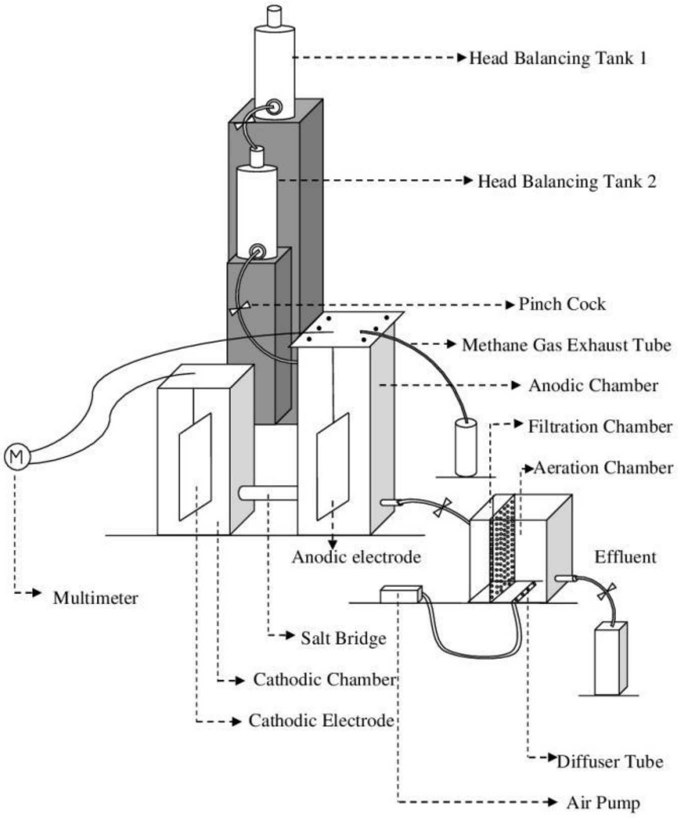
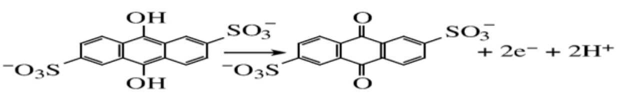


Figure 6: Diagrammatic representation of the experimental Setup[42]

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 (eg: oxygen). However this specific voltage could not be found since the electrons transfer chain varies from microbes to microbe and also the growth condition differ plays a vital role. The main anodic reaction between the potential (redox) of the mediator and the anode determines the voltage produced. In some bacteria those 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 is 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.



(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 oxidization 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 fuelcells. 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 I 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

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probability can be used MFCs that use extraordinary energizes 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_2O. 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.

Table 1: Commonly used microorganism

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	Self-mediate consortia isolated from MFC with a maximal level of 4.31 W m−2.	Rabaey (2004)

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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)
Desulfovibriodesulfuricans	Sucrose	Sulphate/sulphide as mediator	Ieropoulos et al., 2005a; Park et al., (1997)
Erwinia dissolven	Glucose	Ferric chelate complex as mediators	Vega andFernandez, (1987)
Escherichia coli	Glucose sucrose	Mediators such as methylene blue needed.	Schroder et al.,(2003); Ieropoulos et al.,(2005a); Grzebyk and Pozniak, (2005)
Geobactermetallireducens	Acetate	Mediator-less MFC	Min et al. (2005a)
Geobactersulfurreducens	Acetate	Mediator-less MFC	Bond and Lovley,(2003); Bond et al., (2002)
Gluconobacteroxydans	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)
Rhodoferaxferrireducens	Glucose, xylose sucrose, maltose	Mediator-less MFC	Chaudhuri and Lovley,(2003); Liu et al., (2006)
Shewanellaoneidensis	Lactate	Anthraquinone-2,6-disulfonate (AQDS) as mediator	Ringeisen et al., (2006)
Shewanellaputrefaciens	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.

Microorganism	Type of MFC	Substrate	Electrode materials	Current density/ Power density	Reference
Klebsiella pneumonia	Single-chamber MFC	Glucose	Carbon cloth	199 mA/m^2	Hassan et al., 2012
Desulfovibrio desulfuricans	Double-chamber MFC	Wastewater	Graphite felt	233 mA/ m^2	Min et al., 2005
Escherichia coli	Double-chamber MFC	Glucose	1PAN/ TiO2 composite-anode Carbon cloth–cathode	3390 mA/ m^2	Lu et al., 2009

Saccharomyces cerevisiae	Single-chamber MFC	Synthetic wastewater	Graphite plates	282 mA/ m^2	Rodrigo et al., 2007
Thermincola ferriatica	Double-chamber MFC	Acetate	Graphite carbon fibres	12000 mA/ m^2	Kang et al., 2014
Lysinbacillus	Double-chamber MFC	Glucose	Graphite felt	85 mW/ m^2	Feng et al., 2011
sphaericus Citrobacter sp.	Single-chamber MFC	Acetate	Carbon cloth	205 mA/ m^2	Wen et al., 2009
Ochrobactrum sp	. Double-chamber MFC	Xylose	Carbon fibres brush	2625 mW/ m^3	Feng et al., 2008
Shewanella putrefaciens	Single-chamber MFC	Lactate	Carbon cloth	4920 mW/ m^3	Durruty et al., 2012
Scenedesmum	Double-chamber MFC	Acetate	Carbon fiber brush-anode Carbon cloth-cathode	1926 mW/ m^2	Cheng et al., 2010
Shewanella oneidensis	Mini-MFC	Lactate	Graphite-felt	3000 mW/ m^2	Fang et al., 2013
Cyanobacteria	Single-chamber MFC	Domestic wastewater	Graphite felt-anode, Carbon cloth-cathode	114 mW/ m^2	Prathap et al., 2013
Chlorella vulgaris	Double-chamber MFC	Wastewater	Carbon felt-anode Carbon cloth-cathode	2485 mW/ m^3	Kracke et al., 2015.
Rhodopseudomonas palustris	Single-chamber MFC	Wastewater	Carbon paper-anode Carbon cloth-cathode	2720 mW/ m^2	Pirbadian et al., 2014
Coriolus versicolor	Double-chamber MFC	2ABTS	Carbon fibres	320 mW/ m^3	Okamoto et al., 2014
Geobacter metallireducens	Double-chamber MFC	Domestic wastewater	Carbon paper	40 mW/ m^2	Nevin et al., 2008
Geobacter sulfurreducens	Double-chamber MFC	Acetate	Carbon fibres	1.9 mW/ m^2	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/ m^2	Richter et al., 2008
Potato wastewater	Single-chamber MFC	Potato wastewater	Graphite fiber brush	217 mW/m	Richter et al., 2008

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Activated sludge	Double-chamber MFC	Acetate, glucose	Carbon paper	410 mV	Clarke et al., 2011
Primary wastewater	Double-chamber MFC	Acetate	Graphite rods	152 mA/ m^2	Coursolle et al., 2010
Activated sludge	Single-chamber MFC	Acetate, glucose	Carbon cloth	1084 mW/ m^2	Inoue et al., 2010
Activated sludge	Double-chamber MFC	1POME	Polyacrylonitrile carbon felt	107 mW/ m^2	Malvankar et al., 2012
Activated sludge	Single-chamber MFC	Glucose	Carbon cloth	68 mW/ m^2	Okamoto et al., 2014
Activated sludge	Single-chamber MFC	Acetate	Graphite coated with graphene -anode, carbon cloth-cathode	670 mW/ m^2	Lebedev et al., 2014
Primary wastewater	Single-chamber MFC	Acetic acid	Graphite fiber brushes-anode Carbon cloth-cathode	835 mW/ m^2	Baranitharan et al., 2015
Primary wastewater	Single-chamber MFC	Ethanol	Graphite fiber brushes-anode Carbon cloth-cathode	820 mW/ m^2	Baranitharan et al., 2015
Primary wastewater	Single-chamber MFC	Lactic acid	Graphite fiber brushes-anode Carbon cloth-cathode	739 mW/ m^2	Baranitharan et al., 2015
Primary wastewater	Single-chamber MFC	Succinic acid	Graphite fiber brushes-anode Carbon cloth-cathode	444 mW/ m^2	Baranitharan et al., 2015
Anaerobic sludge	Double-chamber MFC	Slaughterhouse wastewater	Carbon cloth-anode Titanium mesh-cathode	578 mW/ m^2	Ci et al., 2012
Anaerobic reactor effluent	Double-chamber MFC	Acetate	Carbon cloth-anode Granular active carbon-cathode	1200 mW/ m^3	Liang et al., 2011
Soil	Double-chamber MFC	Cellulose	Carbon paper	188 mW/ m^2	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

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 Graphite felt as cathode	91	Zhang et al., 2012;
Palm oil mill effluent	1UML-MFCs	Graphite granules, Carbon fiber felt	90	Wang et al., 2011
Animal carcass wastewater	Up-flow tubular MFC	Graphite felt as anode Carbon cloth as cathode	51	Kong et al., 2014
Food waste leachate	Double-chamber MFC	Carbon felt	85	Strycharz et al., 2008;
Chemical wastewater	Double-chamber MFC	Graphite plates	63	Orellana et al., 2013;

REFERENCE

[1] Moqsud, M. A., Omine, K., Yasufuku, N., Hyodo, M., & Nakata, Y. (2013). Microbial fuel cell (MFC) for bioelectricity generation from organic wastes. *Waste Management*, *33*(11), 2465-2469. https://doi.org/10.1016/j.wasman.2013.07.026

[2] Sharma Y, Li B. (2010). The variation of power generation with organic substrates in single-chamber microbial fuel cells (SCMFCs). *Bioresour Technol. 101*(6), 1844-50. https://doi.org/10.1016/j.biortech.2009.10.040

[3] Angenent LT, Karim K, Al-Dahhan MH, Wrenn BA,Dominguez-Espinosa R.. (2004). Production of bioenergy andbiochemicals from industrial and agricultural wastewater. *Trends Biotechno 22*(9), 477–485.

[4] Aelterman P, Freguia S, Keller J, VerstraeteW, Rabaey K., (2008).The anode potential regulates bacterial activity in microbial fuel cells. *Appl. Microbiol Biotechnol, 78*(3), 409–418.

[5] Lovley DR, GiovannoniSJ,White DC, Champine JE, PhillipsEJ, Gorby YA, Goodwin S. (2008). Geobactermetallireducensgen. nov. sp. nov., a microorganism capable of coupling thecomplete oxidation of organic compounds to the reductionof iron and other metals. *Arch Microbiol., 159*(4), 336–344.

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[6] Logan BE. (2009). Exoelectrogenic bacteria that powermicrobialfuel cells. *Nature Reviews Microbiology, 7*(5), 375-381.
[7] Rhoads A, Beyenal H, Lewandowski Z. (2005). Microbial fuelcell using anaerobic respiration as an anodic reaction and biomineralized manganese as a cathodic reactant. *Environ Sci Technol. 39*(12), 4666–4671.
[8] Zhang Y, Mo G, Li X, Zhang W, Zhang J, Yea J, HuangX, Yu C. (2011). A graphene modified anode to improvethe performance of microbial fuel cells. *J Power Sources,196*(13), 5402–5407.
[9] Zhou M, Chi M, Luo J, He H, Jin T. (2011). An overview ofelectrode materials in microbial fuel cells. *J. Power Sources, 196*(10), 4427–4435.
[10] Wei J, Liang P, Cao X, Huang X. (2011). Use of inexpensive semicoke and activated carbon as biocathode in microbial fuelcells. *Bioresour Technol, 102*(22), 10431–10435.
[11] Sangeetha T, Muthukumar M. (2013). Influence of electrodematerial and electrode distance on bioelectricity productionfrom sago-processing wastewater using microbial fuel cell. *Environ Prog Sustain Energy, 32*(2), 390–395.
[12] Wang H, Ren ZJ. (2013). A comprehensive review of microbial electrochemical systems as a platform technology. *Biotechnol Adv, 31*(8), 1796–1807.
[13] Pham TH, Jang JK, Chang IS, Kim BH. (2004). Improvement of cathode reaction of a mediatorless microbial fuel cell. *J. Microbiol Biotechnol, 14*(2), 324–329.
[14] Wei L, Han H, Shen J. (2012).Effectsof cathodic electron acceptorsand potassium ferricyanide concentrations on the performance of microbial fuel cell. *Int. J. Hydrogen Energy, 37*(17), 12980–12986.
[15] Lovley DR, Holmes DE, Nevin KP. (2004). Dissimilatory Fe(III) and Mn(IV) reduction. *Adv Microb Physiol*, 49, 219–286.
[16] Lovley DR, Giovannoni SJ, White DC, Champine JE, Phillips EJ, Gorby YA, Goodwin S. (1993). Geobacter metallireducens gen. nov. sp. nov., a microorganism capable of coupling the complete oxidation of organic compounds to the reduction of iron and other metals. *Arch Microbiol.. 159*(4), 336–344.
[17] Rotaru A-E Holmes DE, Franks AE, Orellana R, Risso C, Nevin KP. (2011). Geobacter: the microbe electric's physiology, ecology, and practical applications. *Adv Microb Physiol*, 59, 1–100.
[18] Nevin KP, Richter H, Covalla SF., Johnson JP, Woodard TL, Orloff AL, Jia H, Zhang M. Lovley DR. (2008). Power output and columbic efficiencies from biofilms of Geobactersulfurreducens comparable to mixed community microbial fuel cells. *Environ Microbiol* 10, 2505–2514.
[19] Gorby YA, Yanina S, McLean JS, Rosso KM, Moyles D, Dohnalkova A, Beveridge TJ, Chang IS, Kim BH, KimKS, et al. (2006). Electrically conductive bacterial nanowiresproduced by Shewanellaoneidensis strain MR-1 and othermicroorganisms. *PNAS, 103*(30), 11358–11363.
[20] Watson VJ, Logan BE. (2010). Power production in MFCs inoculated with Shewanella oneidensis MR-1 or mixed cultures. *Biotechnol Bioeng, 105*(3), 489–498.
[21] Wang H, Ren ZJ. (2013). A comprehensive review of microbialelectrochemical systems as a platform technology. *Biotechnol Adv, 31*(8), 1796–1807.
[22] Rosenbaum M, He Z, Angenent LT. (2010). Light energy to bioelectricity:photosynthetic microbial fuel cells. *Curr Opin Biotechnol*, 21,259–264.
[23] Zhao G, Maa F, Wei L, Chua H, Chang CC, Zhang XJ. (2012). Electricity generation from cattle dung using microbialfuel cell technology during anaerobic acidogenesis andthe development of microbial populations. *Waste Manage*, 32, 1651–1658.
[24] Logan BE, Murano C, Scott K, Gray ND, Head IM. (2005).Electricity generation from cysteine in a microbial fuel cell. *Water Res*, 39, 942–52.
[25] Rabaey K, Verstraete W. (2005). Microbial fuel cells: novel biotechnology for energy generation. *Trends Biotechnol*, 23, 291–298.
[26] Feng Y, Wang X, Logan BE, Lee H. (2008). Brewery wastewater treatment using air-cathode microbial fuel cells. *Appl Microbiol and Biotechnol*, 78, 873-880.
[27] Choi J, Ahn Y. (2013). Continuous electricity generation instacked air cathode microbial fuel cell treating domesticwastewater. *J Environ Manage*, 130, 146–152.
[28] Min B, Kim JR, Oh SE, Regan JM, Logan BE. (2005). Electricity generation from swine wastewater using microbial fuel cells. *Water Res*, 39, 4961–4968.
[29] Jiang Y, Ulrich AC, Liu Y. (2013). Coupling bioelectricity generation and oil sands tailings treatment using microbial fuel cells. *Bioresour Technol*, 139, 349–354.
[30] Choi J, Liu Y. (2014). Power generation and oil sands processaffectedwater treatment in microbial fuel cells. *Bioresour Technol*,169, 581–587.
[31] Ge Z, Zhang F, Grimaud J, Hurst J, He Z. (2013). Long-terminvestigation of microbial fuel cells treating primary sludgeor digested sludge. *Bioresour Technol*, 136, 509–514.
[32] Choi J, Ahn Y. (2014). Increased power generation fromprimarysludge in microbial fuel cells coupled with prefermentation. *Bioprocess Biosyst Eng., 37*(12), 2549–2557.
[33] Logroño W, Ramírez G, Recalde C, Echeverría M, Cunachi A. (2015). Bioelectricity generation from vegetables and fruitswastes by using single chamber microbial fuel cells with high and eansoils. *Energy Procedia*, 75, 2009–2014.
[34] Choi J, Ahn Y. (2015). Enhanced bioelectricity harvestingin microbial fuel cells treating food waste leachate produced from bio hydrogen fermentation. *Bioresour Technol*, 183, 53–60.

[35] Logan B.E, Rabaey K, (2006). *Microbial fuel cells methodology and technology* pp. 11-17.
[36] Kim J.R., Premier, Lee G.C. (2010). Sustainable wastewater treatment: how might microbial fuel cells contribute. *Biotechnoladvances*, 286, 871-881.
[37] Liu H, Ramnarayanan R, Logan BE. (2004). Production of electricity duringwastewater treatment using a single chamber microbial fuel cell. *Environ Sci Technol*, 28, 2281–2285.
[38] Rabaey K, Clauwaert P, Aelterman P, VerstraeteW. (2005). Tubularmicrobial fuel cells for efficient electricity generation. *Environ Sci Technol, 39*(20), 8077–8082.
[39] Tartakovsky B Guiot SR. (2006).A comparison of air and hydrogen peroxideoxygenated microbial fuel cell reactors. *Biotechnol Prog*, 22, 2416.
[40] Jang JK, Pham TH, Chang IS, Kang KH, Moon H, Cho KS, et al. (2004). Construction and operation of a novel mediator-and membranelessmicrobial fuel cell. *Process Biochem*, 39, 1007–1012.
[41] Moon H, Chang IS, Jang JK, Kim BH. (2005). Residence time distribution inmicrobial fuel cell and its influence on COD removal withelectricity generation. *Biochem Eng J*, 27, 59–65.
[42] Aelterman P, Rabaey K, Pham HT, Boon N, VerstraeteW. (2006). Continuouselectricity generation at high voltages and currents using stacked microbial fuel cells. *Environ Sci Technol*, 40, 3388–3394.
[43] Stirling JL, Bennetto HP, Delaney GM, Mason JR, Roller SD, TanakaK, et al. (1983). Microbial fuel cells. *Biochem Soc Trans*, 11, 4513.
[44] Bennetto HP. (1984). Microbial fuel cells. *Life Chem Rep*, 2, 363–453.
[45] Nevin KP, Lovley DR. (2000). Lack of production of electron-shuttling compounds or solubilization of Fe(III) during reduction ofinsoluble Fe(III) oxide by Geobactermetallireducens. *Appl Environ Microbiol*, 66, 2248–2251.
[46] Chaudhuri SK, Lovley DR. (2003). Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells. *Nat Biotechnol*, 21, 1229–1232.
[47] RosenbaumM, Schroder U, Scholz F. (2006). Investigation of the electrocatalyticoxidation of formate and ethanol at platinum black under microbialfuel cell conditions. J *Solid State Electroche*,.10, 872–878.
[48] Ieropoulos I, Greenman J, Melhuish C. (2003). Imitation metabolism: energyautonomy in biologically inspired robots. *Proceedings of the 2nd international symposium on imitation of animals and artifacts .a. p*. 191–194.
[49] Ieropoulos I, Melhuish C, Greenman J. EcoBot-II. (2005). An artificial agentwith a natural metabolism. *Adv Robot Syst c*., 2, 295–300.
[50] Shantaram A, Beyenal H, Veluchamy RRA, Lewandowski Z. (2005). Wireless sensors powered by microbial fuel cells. *Environ Sci Technol*, 39, 5037–5042.
[51] Wilkinson S. (2000). “Gastrobots” — benefits and challenges of microbial fuel cells in food powered robot applications. *Auton Robot.*, 9, 99−111.
[52] Chia M. (2002). Aminiaturizedmicrobial fuel cell. Technical digest of solid state sensors and actuatorsworkshop, *Hilton Head Island*, 59–60
[53] LiuH,Grot S, Logan BE. (2005). Electrochemically assistedmicrobial production of hydrogen from acetate. *Environ Sci Tchnol .c*. 317–20.
[54] Holzman DC. (2005). Microbe power. *Environ Health Persp*, 113, A7547.
[55]Habermann W, Pommer EH. (1991). Biological fuelcells with sulphide storage capacity. *Appl Microbiol Biotechnol*, 35, 128–33.
[56] Rabaey K, Van De Sompel K, Maignien L, Boon N, AeltermanP, Clauwaert P, et al. (2006). Microbial fuel cells for sulfide removal. *Environ Sci Technol*, 40, 521824.
[57] He Z, Minteer SD, Angenent L. (2005). Electricity generation from artificialwastewater using an up flow microbial fuel cell. *Environ Sci Technol*, 39,5262–5267.
[58] Kim JR, Min B, Logan BE. (2005). Evaluation of procedures to acclimate a microbial fuel cell for electricity production. *Appl Microbiol Biotechnol*. 68, 23–30.
[59] Chang IS, Jang JK, Gil GC, Kim M, Kim HJ, Cho BW, et al. (2004). Continuous determination of biochemical oxygen demand using microbial fuelcell type biosensor. *Biosens Bioelectron*, 19, 607–613.
[60] Chang IS, Moon H, Jang JK, Kim BH. (2005). Improvement of a microbial fuel cell performance as a BOD sensor using respiratory inhibitors. *Biosens Bioelectron*, 20, 1856–1859.
[61] Moon H, Chang IS, Kang KH, Jang JK, Kim BH. (2004). Improving the dynamic response of a mediator-less microbial fuel cell as a bio chemical oxygen demand (BOD) sensor. *Biotechnol Lett*, 26, 1717–1721.