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Bio-Electrochemical Fuel Cell: A Review Study on Electricity Generation using Bio Waste

Syed Hasan Khuld[1*], Babar Jamal Naqvi[2], Naeem Samoon[3], Muhammad Kashif[1], Naveed Alam Samdani[1] and Talha Qazi[4]

[1] Institute of Environmental Studies, University of Karachi
[2] Faculty of Engineering, Science & Technology, Indus University
[3] Department of Energy & Environment, Hamdard University
[4] Department of Environmental Sciences, Federal Urdu University of Arts, Science & Technology
Corresponding Authors: hasan118.ykk@hotmail.com

Abstract

This era is all about energy, humans cannot survive without energy. Conventional energy resources are not enough to fulfill the needs of energy that's why it is necessary to find alternate energy resources that will be efficient and environment friendly. Microbial Fuel Cell (MFC) is one of the reasonably low costs and is considered as environment friendly It degrades the harmful substance during production of electricity.

This technology helps out for the producing of electricity by using the microbes. The generation of electricity is the new form of non-renewable energy by treating of the waste water from different types of effluent. The purpose of this technology is to produce the electricity that is environment friendly and sustainable. This review is also the part of research which is also to make a comparison of different MFC feeds which have unique chemical composition and are rich of various biological species and designing. This report also contains the discussion of MFC principle, necessary components, bacteria that are responsible for electricity production. This MFC contain the different batch type of reactor and in each reactor anode and cathode are dipped for time to check the response of flow of electron. Electrodes are used for drawing the comparison data of the MFC and giving new direction for the researchers. Salt bridge or membrane is connected between the reactor for the flow of proton to the cathode side and oxygen is supplied in the cathode compartment.

Keywords: Microbial Fuel Cell, Electricity Generation, Microbial Growth, Industrial Effluent, Sustainable Development

1. INTRODUCTION

Energy is the backbone of modern life and its requirement is increasing day by day around the globe and every country is trying to find alternate ways of production of electricity because the fossil fuels are not enough to fulfill the requirements of electricity. The production of electricity by fossil fuels is very expensive in terms of money and environmental damage. It should also be taken into account that fossil fuels are non-renewable source and one day it will be extinct from the planet if we are not careful today. There are many renewable sources available to produce electricity. Many of them are quite efficient and have great contribution in electricity production of many countries, whereas many of them are still in research process. Once they commercialize, they will have capability to fulfill the future needs of electricity. One of those renewable resources is MFC (Microbial Fuel Cell) (Obileke et al. 2021) because it produces electricity from the wastewater. MFC efficiency of electricity production is too low that's why it is still in research phase and it is limited to laboratory uses. Scientists are working to enhance its efficiency. Its recent modification in components and design can somehow enhance its efficiency significantly.

MFC not only produces electricity but it also works as wastewater treatment (Rahimnejad, et al. 2020) making it efficient in terms of money, which was otherwise used as investment in wastewater treatments plants. MFC have many other applications. Few of them are Bio hydrogen production, wastewater treatment and application of MFC as Biosensor etc. MFC can be obtained in different designs like two chamber MFC and single chamber MFC. Two chamber MFC is a classical design and single chamber MFC is the modern design which occupy less spaceand is cost effective as compared to dual chamber.

In Physics, energy is defined as an ability to do work and can be transferred from one form to another. The energy is neither produced nor can be wiped off. It can be calculated in Joule. (Dhúill, E. N. 2016). There are different types of energy, some are renewable and others are non-renewable e.g. Kinetic, Potential, Electrical, Chemical, Mechanical, Geothermal, Radiant, Nuclear, Sound, Thermal etc. Sources of energy can be divided into Non-Renewable (Fossil Fuel, Nuclear) and Renewable (Solar, Wind, Geothermal, Hydro Power, Waves etc.)

In order to achieve sustainability, it is necessary to find and fulfill the need of energy through other means just like renewable energy. Sustainability does not cover only environment aspect, but it also covers social and economic aspect and find balance in all aspects. (Finkbeiner et al. 2010). The concept "Sustainable Development" was first introduced in 1987 by the world commission on environment and development (Shi, L 2019). It describes

that the use of natural resources should be in that manner that fulfills today's requirement without compromising the future availability (Finkbeiner et al. 2010).

Concept of sustainability was initially used for forestry. Which translates that "Don't harvest the forest until the growth of new forest territories" (Wiersum, K. F. 1995), but the term now covers a wide range of topics. This includes Cradle-to-cradle design and waste control practices. For the management of renewable resources there are two principles of sustainable development. First one is harvesting of forest must be equal to re-growth of forest and the second principle is the rate of generation of waste should be equal to the natural assimilative capacities (Page, T. 2013). There were two different opposing concepts between making and nature, one was adaptation of stress and harmony and other concept that consider that nature is something to be over thrown.

Renewable energy comes from natural occurring energy resource that remains in the environment and repetitive energy resource. The best example of this persist and repetitive energy resources are solar energy (sunshine) that exist and repeats daily, wind energy that repeats and exist in atmosphere etc. Renewable energy contains marvelous benefits in the sense of economy. This energy provides security, global availability, and is environmentally friendly. In contrast, nonrenewable is expensive, non-secure, results in environmental damage and exist in few regions (Connolly D. 2014).

In the recent decade scientists are focusing on renewable energy because it mitigates Green House Gas and it is believed that renewable resources are not cause of climate change. Most probably the temperature of the earth increases due to the use of non-renewable resources. And it is believed that the best solution of global warming is by utilizing of renewable resources (Heidari et al. 2016, Macgregor et al. 2015). According to United state of America's Navigant Research renewable energy contributes to worlds energy investment. It is clear from Figure 1 that the Fuel Cell energy production is increasing gradually from 2013 and onwards.

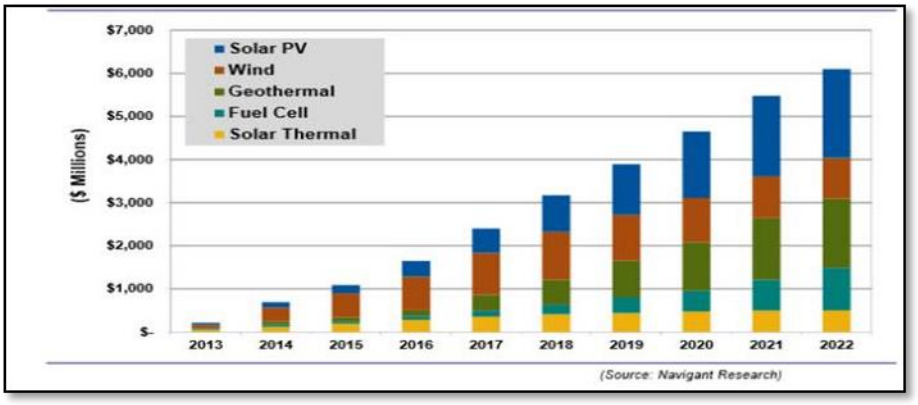

Figure 1: Renewable Energy world market 2013- 2022

In the recent decades, energy requirement is increasing day by day throughout the world. Energy is produced through three different ways: fossil fuels, renewable sources and nuclear sources (Rahimnejad et al. 2011). Large amount of energy is produced by non-renewable source of energy, which includes nuclear and fossil fuels (M. Rahimnejad et al. 2009), Rapid and unsustainable use of non-renewable resources causes continuous rise in the cost of fossil fuel, i.e. coal price, oil price, etc. Ultimately, resulting in a tremendous depletion in the fossil

fuel resource. In addition, burning of fossil fuel in order to produce energy also generates large amounts of harmful gases as byproducts. Which alter the concentration of gases in the atmosphere, these gases mainly include carbon dioxides, methane, NO_x, SO_x, and Carbon Monoxide etc. Carbon dioxide is the major greenhouse gas (GHG) which has negative impact on the environment and is the main reason of climate change, responsible for disturbing the weather pattern (Logan 2004).

1.1 Microbial Fuel Cell for electricity generation

Microbial fuel cell is the conversion of organic substrate into energy in the cell and microorganism is used as the bio catalysis. It was introduced in the twentieth century where we are facing the global warming and other pollution caused by the burning of fossil fuel. This purely environment friendly technology is the miracle of science where energy is produced without depleting the natural resources (Zhang, Halme 1995, Lovley 2006). The merits of this technology are the utilization of waste and its conversion into energy without any separation of gases and process reforming. MFC is the emerging technology that solves the energy crisis. MFC is the simple operation and resolve all the barrier.

1.2 Advancement for Electrode

In the Struggle to improve the cathode designing and the supply of oxygen on continuous basis (He et al. 2007) development for sediments MFC is being done by moving the cathode to increase the presence of oxygen. These amendments in the cell, increases the energy up to 49mW/m² in a Nano rotating system. Sustainable and high-power density can be achieved by using the graphite carbon instead of stainless steel. (Hasvold et al., 1997).

1.2 MFC & Diverse Species

It's seen in the research that groups of species are responsible for the power generation. Mostly several different organisms have the capabilities to produce electricity, have different range of operation ability, system designing anode material (electron donor) & cathode material (electron acceptor).

1.5 Types of MFC According to Physical Difference

There are many different ways through which we characterize the MFC. Four physical different Types of MFC is used working with different potential.

1.6 Poised MFC

The potential of electrochemical fuel cell in the anode side consists of microorganism after calculating the current. In this type of MFC potential is held in the same compartment or either in cathode chamber through the salt bridge or membrane (Dumas et. al., 2008, Niessen et. al., 2004). In this poised type microbial fuel cell current can be controlled through the single chamber or double connected chamber (Haslett, 2012, Bond et al., 2002, (Bond & lovely 2003, Chaudhuri & lovely, 2003 and Cho & Ellington, 2007).

1.7 MFC with Double Chambered

This double chambered MFC hold two compartment one is the anode while other is cathode Electron is transferred to the external circuit on the other side cathode compartment accept the electron then there is flow of electron through the external circuit. Oxidation occurred in the anode side while reduction occurred in the cathode side. Both compartments contribute half of total reaction. The separation of anode and cathode is done through the proton exchange membrane either cation exchange membrane or salt bridge. Double chamber MFC work either in the batch or continuous. The load in the chambered contain microorganism or fermented product microorganism. (Logan *et al*. 2006).

1.8 Single Chambered MFC

This type of MFC consists of two electrodes in one chamber the anode with in the compartment while cathode is either within the compartment or outside the compartment. This single base MFC works with microorganism or by the use of fermented product in the chamber. The single MFC has characteristic to be operated without use of salt bridge/photon exchange membrane. In this cell there is photon exchange membrane outside the chamber. (Logan *et al.* 2006).

2 ENVIRONMENTAL MFC

The environmental MFC have some advantage that consists of two electrode anodes in the anaerobic condition in the aquatic body while cathode in the open water environment (Tender et al. 2002, Lowy et al 2006). The microorganism in the compartment generates electricity. Environmental MFC consists of photosynthesis microorganism (Zou et al. 2009). Anode in the environmental MFC dipped in to the anaerobic environment while cathode is suspended into water that harvest electricity.

2.1 Metal Decomposition

Metal dissimilation is the process by which microorganism transfer electron to metal ions. Reduction of metal is a very important process for the degradation of natural or organic sediments. (Lovley, D. 2006) Iron decomposing bacteria have ability to degrade organic contaminant along with toxic metal waste.

2.2 Metal Reducing Species

The genera name Geobactor sp have ability to oxidize the organic load with the presence of iron (Lovley, D. R., & Phillips, E. J. 1988). These genera are gram negative as well as anaerobic. The area of living of these bacteria is fresh water adding sedimentary environment in which iron is reduced, Geobactor is the major specie in the microbial community and environment in which it is found is the sandy aquifer sediments. Fresh water environment in which geobacter is isolated and oxidized acetate it is used as electron acceptor Bond, (Lovley, D. R. 2003, Bond, & Lovley, et al. 2002 and Kim, et al. 1999).

2.3 Transportation of Electron

In MFC cell electron is directly transfer from the electrode through an anaerobic metabolism of organic matter (Bond & Lovley 2003, Bond et al. 2002) and the reduction of iron metals as a result is energy recovery. Geobacter Sp. and G. sulfur freducen both organisms have same genome along with genetic system and transferred electron through Nano-wire. These organisms are well known for iron reducing bacteria and have direct attraction with insoluble ferric oxide G. sulfurreducens serves as the shuttle of electron and enhance the reduction of insoluble iron (Seeliger, et al. 1998).

3. MFC and Better Designing

In the initial stage the MFC is designed as two chamber cells separated by the protein membrane or salt bridge (Figure 2). Various method is applied to increase the performance of MFC (Liu, H 2004) Liu and logan introduced and tested single chambered reactor without using proton exchange membrane, As similar to the two chambered reactors with cation exchange membrane. It is observed that the efficiency without membrane is high it is tested that the internal resistance reduces or increase the power of output. Recently MFC is used in series or parallel that increase the columbic potential. It can also increase the power density. Ferricyanide is used as cathode that increase the performance of single cell reactor.

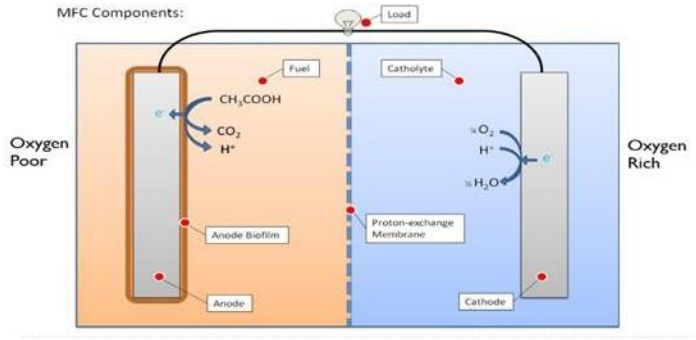

Figure 2: Microbial Fuel Cell

3.1 Anaerobic Sludge

Activated sludge is obtained from wastewater. Iron coated electrode and carbon or graphite electrode during the lag phase in the MFC increases the high voltage. The voltage remains high until the lag phase is maintain in the cell the lag phase until sustain when the organic matter is present in the cell. When the organic matter is completely consumed the lag, phase is decline and the voltage decrease the ferric electrode control voltage for longer period of time (Lovley et al. 1986).

The efficiency of current is increased by the consumption of organic waste. All wastes are converted into the production of current whereas one mole of substrate produce 24 moles of current. The loses of substrate can occur by other means of the process. Utilization of oxygen occurred on the cathodic chamber while anodic side is used for the respiration of bacteria where the electron is produced and substrate is injected in the anode chamber. The loss of substrate can be possible by the other source of electron acceptor.

The efficiency of the current is varying in MFC because of the consumption and loses of the substrate the loss time of substrate is less because of the completion of biological and chemical process in the MFC. The efficiency in the MFC is 75% while using ferricyanide in case of glucose, the efficiency reduced to 49% and 65%. Aeriation in cathode system can increase the density of power due to increase in current efficiency increases. Hydrogen is produced by the electrolysis of water.

3.2 Type of Substrates for MFC

Many types of substrate can be used in the MFC such as sucrose, Glucose, acetate, butyrate and lactate including industrial & domestic waste water. One of the observations for MFC is power by cysteine & protein as nutrient for power generation. Substrate can be utilized in mixed culture in the MFC for the effluent treatment plant.

3.3 MFC and the Microorganism

There is two option in the MFC either we can use pure culture/mixture culture or microbial consortium as shown in figure 3.

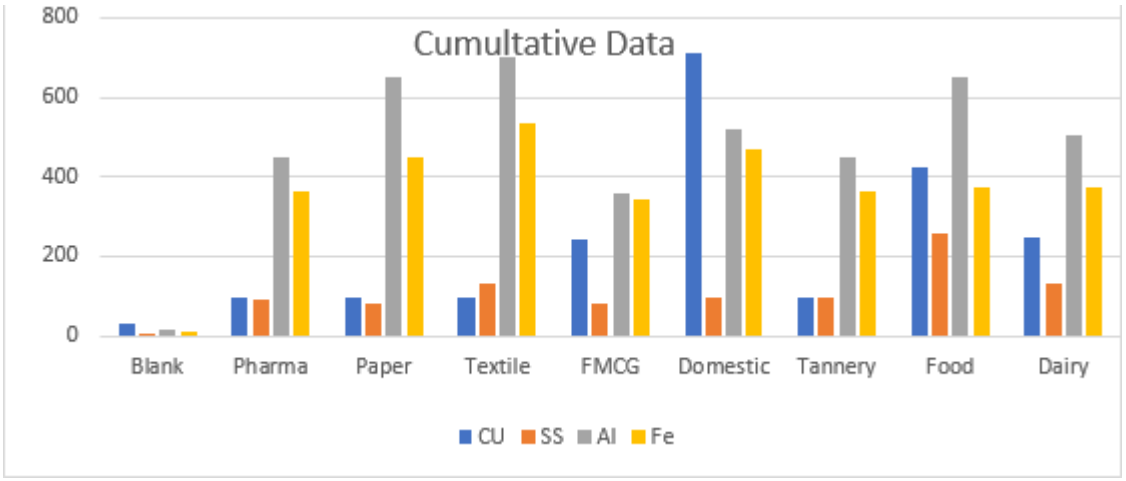

Figure 3: Generation of electricity by different cathodes & with same anode but different Industries

4.0 CONCLUSION

MFC is the new area of research and that has gained interest in the last decade. It is the latest technology by which the waste water is treated and is considered as the renewable technology. The electro chemicals potential is generated by oxidation or reduction of substrate leading to electric current production. Oxidation occurred at the anode compartment by adding the substrate such as sucrose, acetate or compound that have organics material. If oxygen is not present oxidation is carried to oxygen instead of substrate having electron. It is transformed to an electrode.

The readings & analysis graphs clearly reveal that the effluent from different industries shows the different result in addition with this material of electrode gave different response because of nature of the material. Two of the variables directly related to energy one is the effluent of high BOD & COD second is the nature of electrode. Effluent that having an active microbial activity give the Constant result instead of inactive effluent make an effluent active used substrate to enhance the microbial activity. Energy declined after certain intervals because of the inactive microbial activities.

Different waste water from low concentration to high concentration have been used in the MFC and gain the different range of voltage, several types of designing and different types of inoculums are utilized in the reactors. Few challenges are faced that the latest engineering design that have low resistance economical feasible PEM material used in the MFC, less spacing between the electrode some materials are not cost effective such as graphite or carbon paper or carbon clothing. continuous supply of the effluent to the reactor as a result of continuous flow of current other challenge for MFC is the constant flow of electron in the reactor.

More research is required in the field of MFC to make the reactor more efficient it should be in series along with continuous supply of effluent and select the particular species that decompose the organic matter along with high rate of energy.

5. FUTURE RECOMMENDATIONS

Morphology and the growth of microbe could give the great impact on the generation of electricity mainly with the restrained mediator electrode that should be studied when the biomass concentration is high. Since the mixed mediator reveal better result as compared to the soluble mediator specially in the presence of photosynthesis hence bio electrode result will be examined in the bio anode by the utilization of others bacteria with the proteins of other cell membrane as well as the consequence on population of MFC. Effectiveness and the economical aspect of MFC would be highly expanded using huge surface area electrode and improved membrane or Salt Bridge. Electrode with the flat plate and the graphite & aluminum has effective electrode geometry. Very soon in the future that MFC will cover the electricity requirement alone rather than other resources using.

Table 1: Generation of electricity by different cathodes & with same anode but different Industries

Industries	Types of Different Electrodes mW/m²				
	Copper	Stainless Steel	Aluminum	Iron	References
Blank	28.8	7.2	17.4	8.75	(Duteanu et al. 2010)
Pharmaceutical	93.7	92.8	447.2	362.1	(Barua et. al 2010)
Paper	97.76	81.53	650.1	449.7	(Estabrooks et. al. 2006)
Textile	96.4	132.73	698.6	536.5	(Finkbeiner et al. 2010)
FMCG	239.91	78.7	356	342.4	(Finkbeiner et al. 2010)
Domestic Waste	712.3	97.51	519	470.4	(Gaspard et al. 1998)
Tannery	95.7	94.3	447	362.1	(Chinnasamy et al. 2010)
Food	423.1	257.5	650.8	373.5	(Dan Eddy 1991)
Dairy	245.5	130.2	502.3	374.5	(Davis et al. 1962)

Table 2 Analysis Report of Waste water from different Industries.

Parameter	Waste Water Analysis of different Industries								
	Pharma	Paper	Textile	FMCG	Domestic	Tannery	Food	Dairy	References
BOD mg/ltr.	1004	2761	3852	2850	950	4203	4200	2600	(Rahimnejad et al. 2009)
COD mg /ltr.	2280	6100	4762	4901	1051	4800	5500	3560	(Rahimnejad et al. 2015)
TSS mg/ ltr.	492	580	770	650	500	480	748	800	(Potter 1911)
TDS mg/ ltr.	235	1260	1340	996	420	452	1080	721	(Schnurer et al. 2010)
Sulphide mg/ltr.	1805	6.35	1	4.3	1201	0.408	0.194	1.502	(Roundy et al. 2003)
pH	6.1	6.96	6.57	6.3	7.5	5.5	5.2	6.3	(Schnurer et al. 2010)
Temperature ºC	25	31	30	28	24	26	28	31	(Cheng et al. 2008)

Table 3 Using Pure Culture and Performance of MFC

Inoculum	Types of MFC	Substrate	Electrode Material	Current density mW/m²	References
Klebsiella Pneumonia	Single-chamber MFC	Glucose	Carbon cloth	199	(Barua et al. 2010)
Desulfovbrio desulfuicans	Double-chamber MFC	Wastewater	Graphite felt	233	(Barua et al. 2010)
Escherichia coli	Double-chamber MFC	Glucose	PAN/TiO2 composite anode	3390	(Gaspard et al. 1998)
Saccharomyces cerevisiae	Single-chamber MFC	Synthetic wastewater	Graphite plates	282	(Gil et al. 2003)
Thermincola ferriacetica	Double-chamber MFC	Acetate Graphite	carbon fibers	12,00	(Heidari et al. 2016)
Lysinibacillus sphaericus	Double-chamber MFC	Glucose	Graphite felt	85	(Huang et al. 2011)
Geobacter metallireducens	Double-chamber MFC	Domestic wastewater	Carbon paper	40	(Dhúill 2016)
Geobacter sulfurreducens	Double-chamber MFC	Acetate	Carbon fibers	1.9	(Dumas et al. 2008)

Table 4 Using Mixed Culture and Performance of MFC

Inoculum	Types of MFC	Substrate	Electrode Material	Current density mW/m2	References
Dairy manure wastewater	Single-chamber MFC	Dairy manure wastewater	Graphite fiber brush	190	(Bosch et al.2006)
Activated sludge	Double-chamber MFC	Acetate, glucose	Carbon paper	410	(Wei et al. 2011)
Activated sludge	Double-chamber MFC	POME Polyacrylonitrile	carbon felt	107	(Sze 2008)
Activated sludge	Single-chamber MFC	Glucose	Carbon cloth	68	(Tender et al. 2002)
Activated sludge	Single-chamber MFC	Acetate	Graphite coated with graphene anode	670	(Cheng et al. 2008)

Table 5 Alternate material to PEM

PEM	Voltage mV	Current mA	Current Density mW/m^2	COD %	References
Neflon	329	1.28	183	66	(Chaturvedi 2016)
Glass Wool	308	0.93	111	43	(Chinnasamy et al. 2010)
Cellulose membrane	334	1.37	196	52	(Chang et al. 2004)

Table 6 Heavy metal & Performance of Microbial Fuel Cell

Heavy Metals	Types of MFC	Electrode Material	% Removal	Current Density	References
Chromium (VI)	Double-chamber MFC	Graphite granules cathode	94	6.4 mW/m2	(Lovley et al. 1992)
Chromium (VI)	Double-chamber MFC	Carbon fibre felt	76	970 mW/m2	(Lovley et al. 1998)
Cadmium	Single-chamber MFC	Carbon cloth	90	3600 mW/m2	(Logan 2004)
Mercury (Hg^{2+})	Double-chamber MFC	Graphite felt anode	99.5	433 mW/m2	Mahadevan et al. 2006)
Cyanide	Double-chamber MFC	Carbon cloth	88.3	-	(Lovley et al. 1986)
Copper (Cu^{2+})	Double-chamber MFC	Graphite felt electrodes	99.5	319 mW/m2	(Lovley et al. 1992)

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