International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 10, October-2015

Future of Green Energy: Innovation in Energy from Waste

Engr. Abdul Rehman Rizvi
Lecturer
University College of Engineering & Technology
The Islamia University Bahawalpur.

Engr. Aftab Ahmed Almani
Lecturer
University College of Engineering & Technology
The Islamia University Bahawalpur.

Ali Abdur Rehman, H assan Hameed, Abdul Rehman
Students
University College of Engineering & Technology
The Islamia University Bahawalpur.

***Abstract*—New hope is given by the microbial fuel cell (MFC) for continuous production of energy through the decomposition of the waste materials. Wastewaters contain lactose and convoluted substrates which MFC decompose and generate electrical energy. The proper knowledge of nature of bacteria as electron follower and getting energy from the metabolism reaction is crucial for the production of energy by the MFCs. Distinctly such electron transfer techniques is already applicable. To cope with the viable specifications of the MFC, distinct ways are available for the bacteria. On these basis the definite biotic are selected for operation and performance. Here we are going to discuss about the usage of an anode as electron acceptor and about the quantity of the electric generation. Current flipside for energy generation corresponds to the MFC technique.**

Keywords—Microbial fuel cell, Mediator, Green energy, bacterial power generation, Bacteria, core technology.

I. INTRODUCTION

The technique of generation of energy by the biological fuel cell is not new. Microorganisms based fuel cells was examined first time in 1970s. [1,2] and the fuel cells based on the domestic wastewater were introduced in 1991 [3]. Practical applications run through the large amount of power output by the microbial fuel cells due to their fast growing evolution. A MFC converts energy directly to the electrical energy possible by the substrate. The conversion of energy in the direct way can be carried by the alternation of the microbes from the usual electron follower such as the positive electrode of the microbial fuel cell. Such a transfer is carried out through the membrane or sometime over the electron shuttles. These electrons than flow towards negative electrode via the attached load between the electrodes. When an electron reach at the negative electrode the cathodic reaction occurs and the reduction takes place. MFC yield rate of flow of charges across the electrodes as compared to anaerobic metabolism resolving carbon dioxide gas as shown in figure1.

There are many advantages of microbial fuel cells over the different power generations through biological matter. First, higher efficiency due to the direct conversion of the energy from the substrate to the electricity. Second, no specific temperature range for efficient microbial energy conversion, they can even work at low temperatures. Third, resolved gas remedy is required for the MFC enriched in carbon dioxide because it has not useful energy. Fourth, aerification is not needed because the negative electrode is statically aerated [5]. Fifth, MFCs have potential for the generation of electrical energy at the large framework and also have the ability of generation through different fuels.

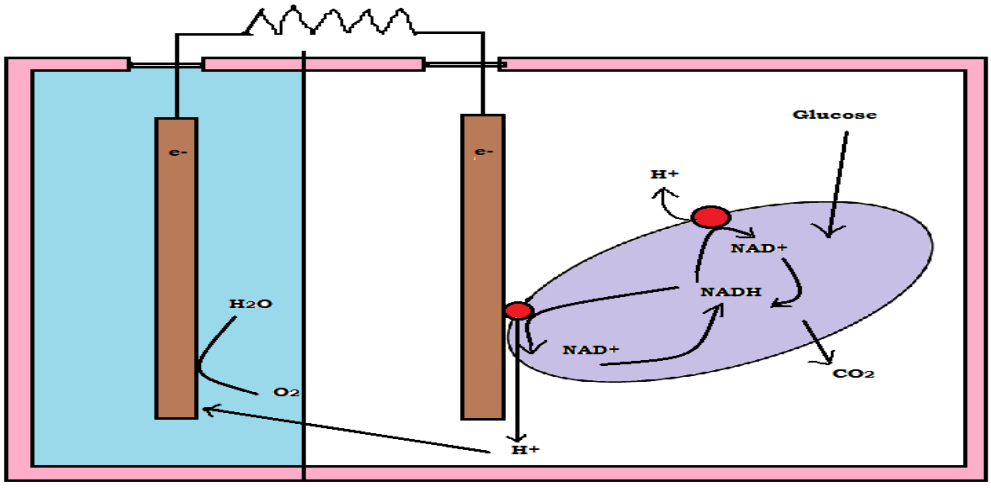

Figure 1 Basic Principle Of MFC

II. METABOLISM OF MICROBIAL FUEL CELLS

Electrical energy generation through the microorganisms is estimated by the movement of microbial electron and proton. The microorganisms digestion process is based on the charge on the positive electrode. If the charge on the positive electrode is decreased than the MFC current will be increased. This will force the electrons to produce at higher rate by the bacterial metabolism to pass through more decreased structure. Metabolism and reduction potential of the bacterial electron shuttle is resolute by the charge on the positive electrode. It is important here to define several metabolism reactions classified according to the charge on the positive electrode: high oxidation reduction metabolism; mean reduction oxidation metabolism and ebullition. Thus the microorganisms noted recently in MFC varies from aerobes towards anaerobes electively.

Bactria can use the respiratory enzymes in the cell respiration due to the large quantity of charge on the positive electrode. NADH dehydrogenase DHO, ubiquinone, co Q,

Cytochrome can be used to transfer electrons and protons generally [6]. A researcher noticed the flow of electric charges from the MFC reserved by the various oxidative and reductive cell respiration. They considered NADH dehydrogenase, iron or sulphur proteins and the Quinone in their MFC as the charge transporter. Higher performance up to 69% is checked by processing the OXPHOS in the MFC [6-7]. Examples are rhodoferax ferrireducens, enterococcus francium[7]. In the existence of the other electron follower such as sulphate the electrons will attract towards such components due to the little quantity of charge on the positive electrode. The production of methane gas is noticed when they are not using positive electrode during the anaerobic sludge formation in the process of inoculation [8]. Otherwise fermentation will be the only process when there is a little quantity of charge on the positive electrode. Probably the fermentation process of glucose can be:

$C_6H_{12}O_6+2H_2O \rightarrow 4H_2+2CO_2+2C_2H_4O_2$
$C_6H_{12}O_6 \rightarrow 2H_2+2CO+C_4H_8O_2$ [1].

From the above reaction we can observe that the third part of the total electrons is available due to the hydrogenase for generation. While the remaining electrons lasts in the by-products of fermentation. The electrons due to the hydrogenase is generally placed on the membrane that is available directly to the electrode. It must be noted here that the metabolic reaction produces the salt contain CH_3COO^- anion and the salt of butyric acid. MFC is detached from the microorganisms that can produce genus Clostridium, alcaligenes fermentation by-products. When the positive electrode has less no of charge on it than the by-products of fermentation such as acetate can be oxidized by the anaerobic bacteria from the Geobecter species. These species are gifted to eliminate the electrons from the acetate in the MFC. Different bacterial species overview is given in the table 1 to eliminate the electrons from the by-products.

Microbial electrodynamics can be detected by the oxidation reduction potential strength produced by the digestion reaction of the microorganisms. Externally connected small resistance firstly show lower charge flow having the high cell potential at the positive electrode and have higher redox potential. The result of experiments in box1 and box 2 is the election between aerobe and anaerobe bacteria for the MFC. With the growth of the microorganisms the rate of metabolic reactions will increase and hence the rate of flow of charge also increases and the positive electrode potential decreases to the moderate level due to the cathodic oxidation reduction reactions. Thus the anode compartment contain obligate anaerobes in the compartment of the positive electrode and the oxygen is passed through the membrane in the compartment [4]. At the small current levels if the high resistance is attached between the positive and negative electrode it causes the potential of the positive electrode to be lower. So that we select the low oxidation reduction and obligate anaerobes causing the probability of the bacterial collection to be limited.

Table 1 Bacterial Species Observed In MFC

Metabolic reaction	Transfer type	Organism	Electron shuttle	Redox shuttle
Oxidative	Membrane driven	Rhodoferax ferrireducens	Unknown	
	Mediator driven	Geobacter sulfurreducens	c- cytochrome	
		Aeromonas hydrophila	c- cytochrome	
		Escherichia coli	Hydrogenase	Neutral red
		Pseudomonas aeruginosa	Pyocyanin, phenazine	
Fermentative	Membrane driven	Clostridium butyricum	Cytochromes	
	Mediator driven	Enterococcus faecium	Unknown	Pyocyanin

III. ELECTRON TRANSPORT TECHNIQUE IN MFC

For extracellular electron transfer, the electrons which are to be diverted in the direction of electrode requires a physical transport system. This can be done either through membrane bound electron shuttling compounds or through the practice of solvable electron shuttles

The oxidative, membrane bound electron transport is supposed to happen through compounds that belongs to the respiratory chain. Bacteria like Aeromonas hydrophila, Geobacter mettalireducens and Rhodoferax ferrireducens are known to use such pathway. The steric approachability (physical interface between electron acceptor and donor) is the main condition for a component to turn as an electron gateway. Whether the gateway is actually used or not (electron will not move to a more reduced electrode) will be determined by the potential difference of gateway and anode.
Fermentative organisms alike Clostridium butyricum and Enterococcus faecium found in MFCs have hydrogenase. In electron transport in the direction of electrodes, hydrogenses can be directly involved. Lately, Zeikus and McKinlay suggested this possibility of electron transport, though this was in combination with a mobile reduction oxidation shuttle. They exhibited that hydrogenases have a part in reducing neutral red at the bacterial superficial.

Soluble components can be used by bacteria that physically transfer the electron from intracellular (inside the cell) compound which comes to be oxidized to the electrode surface. Redox mediators such as neutral red, methyl viologen and thionin were added in many studies to the reactor. This addition frequently seemed to be vital. Though, redox mediators can be produced by the bacteria themselves, which can happen in two ways: through the generation of oxidizable metabolites (primary metabolites) and through the production of organic (secondary metabolites), reducible compounds.

The secondary metabolites technique was proposed for many bacteria, such as Pseudomonas aeruginosa and Shewanella putrefaciens. It was recently shown that these microorganisms' mediators affect the performance of MFC or general interface in extracellular electron transfer. Current generation in Pseudomonas aeruginosa MFC culture is reduced with a factor of 20% after the genes responsible for mediator production inactivated. The redox mediators can be switched from one bacterium to other bacterial species in order to reach the electrode.
In primary metabolites technique, bacteria can produce mediators by using the mediators such as hydrogen and H_2s. Escherichia coli K12 was used by Schroder and coworkers for the generation of hydrogen gas which was re-oxidized at a poly anilin protected platinum catalyzed electrode immersed in the bioreactor. In this way they get current densities up to 1.51 mA/cm^2, which had not been achieved before. In the same way, Schink and Straub used Sulfurospirillum for the generation of sulphide which was oxidized to more oxidized intermediates with the help of iron.

IV. FACTORS DEFINING THE OPERATION OF MFCS

Both electrochemical and biological processes determines the power generation in a microbial fuel cell.

A. The substrate transformation rate

The substrate (on which microbes act) transformation rate depends on the bacterial kinetics (Ks, bacterial affinity constant for substrate and µmax, the maximum specific rate of bacterial growth), the mass transfer and mixing process in the reactor. The loading rate(g substrate per g biomass available per day), the potential difference over the MFC and the efficiency of proton exchange membrane for transferring protons.

B. Anodic over potentials

Mostly, the open circuit potential (OCP) is found to be 749mV to maximum reported volts of 799 mV. Parameters such as electrode potential, electrode electrochemical features, electrode surface, and the kinetics together with the electron transfer mechanism and the current density of the MFC.

C. *Cathodic over potentials*

Similar to the anodic losses observed, the cathode also displays significant potential losses. To overcome this loss, solutions such as hexacyanoferrate used by several researchers. But hexacyanoferrate should be considered as an electron acceptor rather than a mediator because it is not completely oxidized in air by oxygen. Therefore, MFC cathodes preferably should be open air cathode in order to make it sustainable.

V. MICROBIAL POTENTIAL FOR GENERATION OF ELECTRICITY

By transferring electrons from electron donor such as glucose at low potential to electron acceptor such as oxygen at high potential, bacteria attains energy. An over view of reactions is given in Table I. The gained energy can be calculated as $\Delta G = -n \times F \times \Delta E$ (where n= number of electrons exchanged, F= Faraday's constant and ΔV= Potential difference between electron acceptor and donor). Bacteria from reducing equivalents from NADH to oxygen glucose NADH as an electron, then the shuttle (NADH electron shuttle and then falls between the conclusions of bacteria account without considering potential), the potential difference is ~ 1.202 V [ΔE= (+0.841V)-(-0.361V)], and the gained energy(2 electrons per NADH) $\Delta G = -2.1\times10^2$ KJ/mol. If sulphate is electron acceptor then potential difference drops to ~ 98 mV giving $\Delta G = \sim 2.1\times10^1$ KJ/mol. For more information see [10].

Table 2 Redox Reaction Of MFC

Redox reactions	E'_0(mV)
$2H^+ + 2e^- \rightarrow H$	-418
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	-420
$NAD^+ + H^+ + 2e^- \rightarrow NADH$	-322
$S + 2H^+ + 2e^- \rightarrow H_2S$	-272
$SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$	-218
$Pyruvate^{2-} + 2H^+ + 2e^- \rightarrow Lactate$	-183
$FAD + 2H^+ + 2e^- \rightarrow FADH_2$	-178
$Fumerate^{2-} + 2H^+ + 2e \rightarrow Succinate^{2-}$	+33
$b(Fe^{3+}) + e^- \rightarrow b(Fe^{2+})$	+77
$Ubiquinone + 2H^+ + 2e^- \rightarrow Ubiquinone\ H_2$	+102
$c(Fe^{3+}) + e^- \rightarrow c(Fe^{2+})$	+255
$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O$	+421
$NO_2^- + 8H^+ + 6e^- \rightarrow NH_4^+ + 2H_2O$	+442
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	+773
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	+842

For the bacteria to grow in that case the energy obtainable is very low. In MFC the environment is anaerobic. If anode is at higher potential like sulphate present in the feeding stream, then gained energy for bacteria will be much larger which can be delivered to the anode. Therefore, the anode will be preferred electron acceptor.

VI. AVAILABLE ENERGY FOR POWER GENERATION

The amount of Joules produced in an electrochemical reaction can be calculated by the product of output power and the time duration for such power: $E=P\times t$ (where E= Energy in joules, P= Output power in watts and t= time duration in seconds). The power is current I and voltage V dependent: $P=V\times I$. The voltage V can be calculated by using Ohm's Law which gives $V=I\times R$ in which R is the resistance measured in Ohm. The net voltage can be calculated by the relation $V= E^0 - \eta_a - \eta_c - I\times R$ (whereas E^0= maximum cell voltage, η_a, $\eta_{c=}$ electrode losses and $I\times R$ are losses due to the resistance of electrolyte). Hence, the measured voltages will be less than the attainable voltages. Practically, the maximum open circuit potentials(the potential in the absence of load) observed are found to be in the order of 750.12-801.22 mV. In closed circuit, the voltage drop increases due to internal resistance in the flow of electrons and so called over potential. There are three types of over potentials: Ohmic losses, concentrated polarization and activation over potential. Activation over potential is the main limiting factor in MFCs. This potential is dependent on the following factors: the electrical and chemical properties of electrodes, current I density at the anode, temperature and the availability of mediator.

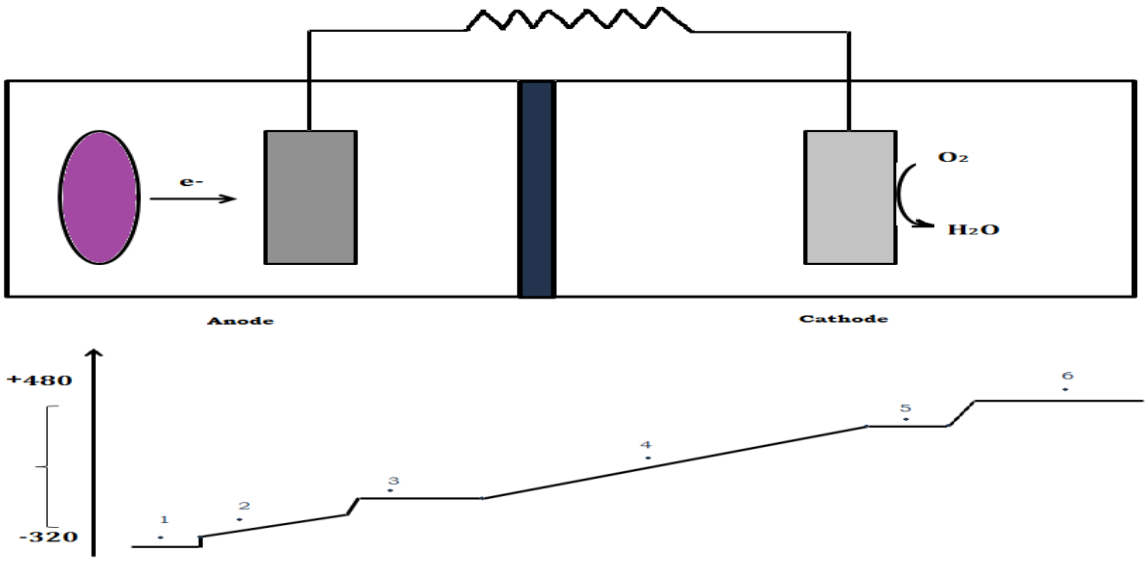

Figure 2 Losses In MFC At Different Steps

Table 3 Efficiency Of MFC IN Different Cultures Medium

Culture	Electrode	Substrate	I(current, mA)	P (mW/m^2)	P(mW/m^3)
Mixed Culture					
Activated sludge	Woven graphite	Wastewater	0.21	8.1	1.61
	Woven graphite	Lactate	11.2	5.4	35
	Plain graphite		2.61	789	33
	Woven graphite	Glucose	0.91	495	12
Mixed consortium	Carbon paper	Acetate	1.26	505	14
	Granular graphite	Glucose	5.5	19	38
Mixed Saltwater	Plain graphite	S2/acetate	61	33.1	n.a*
	Plain graphite	Acetate	0.24	10.3	n.a*
Axenic Culture					
Geobacter sulfurreducens					
Rhodoferax ferrireducens	Plain graphite	Glucose	0.21	8.2	0.253
	Graphite foam		0.4515	34	0.962
	Woven graphite		0.56	17.2	1.73
Pseudomonas aeruginosa	Plain graphite	Glucose	0.12	88.1	8.9
Escherichia coli	Woven graphite	Lactate	3.31	1.22	7.64
	Plain graphite		2.61	92	3.61
Proteus vulgaris	Glassy carbon	Glucose	0.81	4.52	18.3
Erwinia dissolvens	Woven graphite	Glucose	0.73	0.271	n.a
Shewanella putrefaciens	Woven graphite	Lactate	0.041	0.00033	0.081

*n.a= Insufficient Available Data

VII. THE PROTON EXCHANGE MEMBRANE FUNCTIONING

Nafion is applied in the studies of MFC so far as proton exchange membranes. However, e.g., these are sensitive to Bio-fouling to ammonium . Ultrix cation exchange membrane was used for paramount result. Liu *et al.* in 2004 used separator in the form of pressed carbon paper excluding the membrane. However , although the internal resistance of MFC is considerably decreased by this exclusion. but poisoning of cathode catalyst and provoked growth at the cathode based on anolyte constituents are caused by this separation. Data regarding these carbon paper system for duration of more than few days are not yet available.

D. Internal Resistance

The internal resistance of the microbial fuel cell depends upon resistance between electrode ,resistance of electrolyte

and by the membrane resistance 'nefion has the lowest resistance'. Optimization of operation depend upon the distance between cathode and anode . lesser the distance between them more the operation in optimal. Resistance related losses are significantly influenced by the proton migration. To reduce these losses adequate mixing could be used.

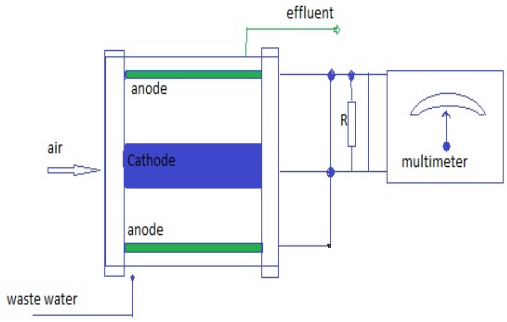

Figure 3 Tabular MFC with Inner Cathode Compartment

VIII. PERFORMANCE DATA

Power result expressed as per anode surface and as per unit MFC reactor volume has some obvious difference . power output can be expressed as mA/m^2 and mW/m^2 of surface electrode, as derived from catalytic fuel cell (conventional) description. mW/m^2 might be good for fuel cell but due to the specific requirement and decrease in pore size and free space in reactor due to occupation of certain volume ,the same unit cannot be used for MFC. All studies refer to the definite grouping for , volume of reactor, PEMs, organic loading rate , catholyte and anode surface. It is difficult at this time to compare/ group this data. It is beneficiary to use watts/m^3 of anode volume for performance of reactor from technical point of view. This unit has wide use not only for present but also for previous bioconversion technologies. There is a noteworthy difference between efficiency calculated based on amount of electron transferred in relation to the theoretically delivered electron by the substrate and energetic efficiency. Energetic efficiency also entails the energy of the electron transferred, including both current and voltage. Unequal relation is always found between MFC current and power as per table 2. importance needs to be put on the electron transfer rate at a certain potential, and the progress of the operational parameters such as resistance. Ultimate goal must be determined by taking resistive parameter into account whether columbic (for large scale like waste water treatment plant) or energetic efficiency(for small scale). The output varies from mili to several W/m^2 electrode surface.

For the optimization it is advised that suitable bacterial group and bacterial adaptation to the efficient reactor condition. Rate of enrichment will only be determined by the selection bacterial type or group it does not have any effect on structural outcome for this process. eight time increase in bacterial substrate to electricity conversion rates were seen after three and half month of selection and adaption based on mixed aerobic and anaerobic and using glucose as a feed. Larger anode surface results in faster increase of conversion rate.

Microbes that can produce soluble redox mediators are categorized into batches. This batch system will allow us to choose which batch is more efficient and help in selecting a species biofilm forming species that can either grown on the electrode or transfer electron using mobile shutting molecules.

By the addition of soluble redox mediator to the anode batch, optimization can be achieved because addition of soluble redox mediator ,improves the electron transfer consistency. The mediator so far, pragmatically selected in range of 300mv or more less than this and is considered as best. Redox mediator should be selected, which allows the bacteria to have sufficiently high turnover rate in relation to electrode and taking into consideration, which efficiency is the objective.

For improving the anode material researchers used to mix different substance with catalytic properties. It is shown by some researcher that by using kaolin modified electrode we can yield power up to $789W/m^2$. Allowing a lower current density by increasing the surface of anode and higher biofilm surface will decrease the activation over potential. Small pore in the film can be clogged by the bacteria limiting the power. Bacteria can die due to the un availability of food and thus decreasing the active electrode surface before lysis. Power output will be effected greatly by the decrease of internal resistance and over potential.

IX. FEASIBLE CORE TECHNOLOGY

Removal of the waste substrate id required by the waste driven applications. For oxidation per kg of carbohydrates requires almost 1.01 kWh of energy . aeration cost of 0.5 kWh per m^3 is held on treatment of domestic waste water, which amount in 30 kWh per capita per year (about 3 euros is the cost per capita per year). For high strength wastewater several technologies were developed to resolve this issue. One of the technology include the production of ethane during treatment especially during treatment of industrial waste. Some reactor like UASB typically handle waste water at the rate of 10-20 kg COD per m^3 per day and have efficiency of 35 % having a power output of 0.5-1kW/m^3. Efficiency is greatly affected by the losses during the process of treatment , in the future this efficiency will be increased owing to development of fuel cell that utilize methane more effectively .

Power density of the methane driven MFC is lower than that of battery using glucose, and latter have high energy efficiency. Bio mass in any form have some energetic value whether it is crop , food in any form or even waste. In case of waste the value is generally negative. 1 kg of sugar contain 4.411 kWh of energy. This amount of sugar equal to 1.05 kg of COD. Out of one kg of sugar 1.21m^3H_2gas , 0.49 L of etanol,0.361 m^3 CH_4 gas , or 0.55 m^3 of biogas in differing this 1.101 KWh of energy is worth about 0.16 Euros or 24 Pakistani rupees. Because of

market value of sugar and cost of energy produce by it is more than this so it not useful to use sugar driven batteries on large scale. However waste form carbohydrates can used for this purpose.

Energy from biomass by means of anaerobic digestion is in competition with energy produced from other resources even from the fossil fuel. But the microbial fuel cell is far below than this completion. Power output, from loading rates of 0.11 to 10 kg COD /m^3, is 0.01 to 1.256 kW/m^3. Even if the cost of MFC Fuel is decreased as the same rate as chemical fuel cell does still it need more breakthrough to compete these. However the operation of MFC and its property to do work in ambient temperature gives us opportunity that other resources doesn't. moreover its fuel is more than that of other resources and have minimum or negative cost. Treatment cost of the waste water is great the use of MFC has great impact on economic balance of the process.

Suitable design and operation can create a chance to apply this technique for greater use. Apart from economical point of view this technology has its own great importance and in future it can be used as core technology ("basic technology adaptable to wide variety of applications"). Its property of conversion of energy at medium temperatures and movement of electron even if low electron donor is provided is so great that no existing technology meet this criteria.

X. CONCLUSION

Microbial fuel cell is the technology that is now in evolving to become the main part of energy production without producing any waste. Moreover its property to use wastewater has great impact on energy market and even on the country economy which using their resources on wastewater treatment plants. However to increase its production to useful value of stable 1kWh/m^3 more modification are needed. This technology gives us hope to create more clean and efficient energy and become a technology which converts carbohydrates to electricity in the near future.

REFERENCES

[1] Suzuki, S. (1976) Fuel cells with hydrogen forming bacteria. Hospital hygiene Gesundheitswesen und disinfection.
[2] Roller S.D. at el. (1984) electron transfer coupling in MFC. Comparison of redox mediator reduction rates and respiratory rates of bacteria. J. chem. Technol. Biotechnol. B Biotechnol.
[3] Habermann, W. Pommer, E-H (1991) Biological fuel cell with sulphide storage capacity. Appl. Microbial. Biotechnol.
[4] Liu, H.et al. 2004 electricity generation using an air cathode single chamber microbial fuel cell in the presence and absence of proton exchange membrane. Environ. Sci. Technol.
[5] Liu, H.et.al 2004 production of electricity during waste water treatment using a single chamber microbial fuel cell Environ. Sci. Technol.
[6] Rabaey, K. et.al 2003 microbial fuel cell capable of converting glucose to electricity high rate and efficiency. Biotechnol. Lett. 25, 1531-1535.
[7] Rabaey, K. et.al 2004 biofuel cell select for microbial consortia that self-mediate electron transfer. Appl. Environ. Microbial 70, 5373-5382.
[8] Schorder, U.et.al.2003 A generation of microbial fuel cell with boosted current output. Angew. Chem. Int. Ed. Engl. 42,2880-2883.
[9] Lee, J.Y.et.al. 2003 Use of acetate for enrichment electro chemically active microorganisms and their 16S rDNA analysis. FEMS. Microbial. Lett. 223, 185-191.
[10] Thauer, R.K. et. al. (1977) Energy conservation in chemotropic anaerobic bacteria. Bacterol. Rev. 41, 100-180.