A Review of Microbial Fuel Cell Technology and its applications

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Abstract:- Energy is the fundamental need of an every living organism to carry out various processes internally (metabolic process) and externally. Hence conventional energy sources like coal, petrol, diesel etc. have been in utilization till today. But, in the perspective of power generation need, focus on renewable energy sources have to be enhanced so as to suffice the future generation energy demand. In the eve of this era, Microbial Fuel Cell technology seems to be the most emerging technology in the renewable field. It includes biological production of electricity in the presence of bacteria, substrates and some chemical solution. This paper fully focuses on microbial fuel cell technology from it's basics to practical implementation.

Keywords:- anode, cathode, membrane, substrate, bacteria, power ,efficiency , mediators, MFC, COD.

I.Introduction

1. Introduction: MFC is the biologically operated device which consists of chambers, substrates (like biomass, cow dung, glucose and wastewater) electrodes and a membrane. MFC may be a single chamber type or double chamber type. Both this chambers are partitioned by a semi permeable member. One part chamber is called as anodic chamber which contains substrates in presence of bacteria. In most of the cases chemical mediators like neutral red or antraquinone 2-6 disalfonate is also use to speed up the intrinsic activity of bacteria. Other part is called as anaerobic chamber which contains chemical solutions like aqueous solution of potassium ferrocyanide which acts like a oxygen provider. Open cathode in presence of air can be applied to its design. Electrodes that are used in MFC are mostly graphite porous rod or foam, because other electrodes like copper is toxic for bacteria and impedes the intrinsic activity of the bacteria. Hence usually graphite foam or porous rod are used for both the chambers, both the electrodes are connected externally by a connecting wire with resistor as a load. Each sub chamber develops its own potential due to which potential difference is generated between the to electrodes. Generated voltage directly depends upon the speed of bacterial activity in the anaerobic chamber overcoming several effecting condition like difference in temperature, Ph, electrode surface area, operation unit.

II.WORKING PRINCIPLE

2. Working Principle: The working principle of MFC is similar to that of hydrogen fuel cell in which oxidations of hydrogen ion give rise to water as a byproduct. fig 1. Shows the single chamber MFC which have been partitioned into two sub chamber using semi permeable membranes. One chamber works in anaerobic condition while other is subjected with aerobic condition. An aerobic chamber consists of organic substrates such as glucose in the above diagram and cathode is exposed to atmospheric oxygen supply. Decomposition of organic substrates takes place in presence of bacteria which feed on glucose and grows over anode. The following reaction takes place in anaerobic chamber.

$C_6H_{12}O_6 + 2H_2O \longrightarrow 6CO_2 + 2C_2H_3CO^- + 10H^+ + 8e^-$

Due to the decomposition of glucose molecule carbon- dioxide, electrons and protons are generated. Protons are transferred into cathodic chamber which have oxygen as a reactant. The electrons flow through the conducting wire and react with oxygen and hydrogen as follow,

$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$

Hence in this way complete reaction in two chamber takes Place giving rise to generation of electricity. The rise of flow depends on many factors like summation of solution, pH, Bacteria, COD, résistance. Due to the presence of resistance, the practical value is less than theoretical values.

III.FUNDAMENTALS OF INORGANIC CHEMISTRY IN MFC TECHNOLOGY

3. Fundamentals of inorganic chemistry in MFC Technology: Enthalpy is the core factor upon which generation of single cell voltage depends. The basis thermo dynamic equation which governs the reaction taking place in each subchember is given as follows,

$\Delta G_R = \Delta G^{\circ} + RT\ ln(\bar{A})$................................(1)

Where ΔGR is the Gibbs free energy for specific condition, =ΔG˚ is the Gibbs free energy under standard condition identified as 98. 15Kmol bar pressure and 1M concentration for all species, R is the universal gas constant (8.3145MK-1T-

1) T is the absolute temperature and pie (unit less) which is the ratio of activity of product divided by reactant. ΔG gives the maximum work that can be derived from a reaction of the variation of energy corresponding to total energy is given by equation 2,

$\Delta N = \Delta G + T\Delta S$......................................(2)

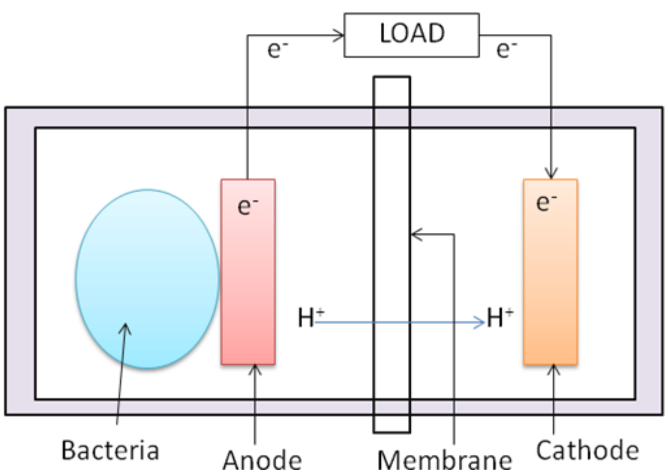

Fig.1

Where T is the temperature during analysis, S is the variation of motor entropy. Under standard condition ΔN˚=-285.8KJmole-1 and =ΔG˚=-237.1Kjmole-1. For MFC calculation it is more desirable to analysis the cell reactions in terms of electro motive force which is nothing but work produce by cell per unit Q.

Emf=+W/Q= - ΔGμ/Q .... (3)
*Where Q=nf, n=total number of electrons exchange in a reaction and f=faraday constant (9.64853*1000C/mole) Hence the overall Emf equation the above three equations is given by*

Emf=Emf°-RT ln(∏)/nf .... (4)

The above expression gives the Emf of each chamber cell of microbial fuel cell that is Eanode and Ecath. Hence the total Emf equation is given by,

$$Emfcell = Eanode - Ecathode \quad (5)$$

Where ∏ is the ratio of product formed to the power of their coefficient and the reactant to the power of their coefficient.

I. IV.ESSENTIAL COMPONENTS OF MFC

1) *Electrodes*:.

The selection of the proper electrode material is crucial for the performance of MFCs in terms of bacterial adhesion, electron transfer and electrochemical efficiency. Although anode and cathode are different, in general both should possess the following properties, i.e. surface area, porosity, electrical conductivity, stability, durability, cost and accessibility.

Anode:- Graphite rods are widely used as anodes in MFCs because of their high electrical conductivity, specific surface area, biocompatibility, chemical stability and low cost.

Cathode:- A robust MFC cathode should have the following properties i.e. high mechanical strength catalytic property,high electronic and ionic conductivity. Graphite rods is the best cathode, however, it has poor catalytic activity so an additional catalyst is used to boost the reduction process.

2) *Substrate*:- Substrate is a surface on which an organism such as plant, fungus or microbial animal lives. The following are the substrates used in the anodic and cathodic chambers:- Anodic Chamber Substrate:-
Glucose and cow dung:- MFC system includes different organic substrates like glucose and cow dung . According to the research, glucose can generate maximum open circuit voltage of 0.45V steady voltage, while cow dung generates 0.69V. But the voltage generated from cow dung is unsteady.

Nickel foam:- Nickel foam has more proper pores for microbes to colonize. Thus, more electricity upto 1.10V can be produced.
Methyl Blue:- It is used as a mediator. It procreates more electrons.

Cathodic Chamber Substrate:-

Lead-oxide+ Sulphide: - Lead oxide has chemical stability in corrosive media and high value of over potential for oxygen evolution process. The output generated by lead oxide is 1.254
V. Sulphide reacts with PbO_2 to form sulfur. Sulfur is eco- friendly.

3) ***Microbes*****:-** The process in MFC begins with the microbial activity on substrate present in anodic chamber. There are various microbes available in microbiology field which can be incorporated in MFC. These are as follows;

1. Eschaeriechia coli (E-Coli)
2. Shewanella putrifaciens
3. Aeromonous Hydrofili
4. Sachrromycescerevisiea
5. Bervibacillus
6. Pseudomonous
7. HalobacteriumSalinarum
8. StaphylothermusMarinus
9. Geobacter Sulfureducens

4) ***Membrane***:- It is one of the most important component of MFC through which complete cell reaction terminates by facilitating the cations transfer from anode to cathode. Hence semipermiable is used for MFC.

Semi-Permeable membrane:

A semipermeable membrane (or a differentially or partially permeable membrane) is a type of biological or synthetic, polymeric membrane that allows certain molecules or ions to pass through it.The membranes poses some difficulties:
Resistivity of the membrane lowers the power output.

1. Leakage of particles other than protons lowers the energy efficiency.
2. Due to biofouling, membranes need to be cleaned or replaced.
3. Proton transport mechanism

Protons are transported through the exchange membrane via passive diffusion. When the membrane is completely hydrated, protons can be transported via the Grotthuss mechanism. In this mechanism protons can `hop' from one water molecule to another, forcing the excess hydrogen atom at the second water molecule to `hop' to another molecule, thereby restarting the chain of events.

Types of Semi-Permeable membrane:

1. Proton Exchange Membrane
2. Low cost Membrane
3. Proton Exchange Membrane:

These membranes facilitate the flow of the positively charged protons that are the product of the reaction occurring in the MFC. Proton exchange membrane or polymer electrolyte membrane (PEM) is made from ionomer’s and designed to conduct protons while acting as an electronic insulator and reactant barrier.

Function:-Separation of reactants and transport of protons while blocking a direct electronic pathway through membrane. Most common PEM materials are Fluoropolymer (PFSA), Nafion a Dupont product.

1. Proton Conductivity
2. Methanol Permeability
3. Thermal Stability

Disadvantages: Highly Expensive ($200), Low Cost Membrane.

Since the standard material is Nafion, these groups provide gateways for transfer of cations, including H^+ across the membrane. Current densities are much lower in MFCs. Other low cost material is Gore-Tex ($19/yard), Ultrex CMI- 7000(Membranes International Incorp. Glen rock, NJ) ordinary cling film.

V..FACTORS TO BE CONSIDERED FOR MFC ANALYSIS

5. Factors to be considered for MFC analysis:

1) ***Electrode potential***:- From the equation number 4, potential of each half cell of MFC can be found out and from equation number 5 total potential of cell can be determine. Substrate is one of the factor upon which electrode potential depends. Hence having studied many substrates in both the chambers of the cell, table 1 gives the result on the basis of some standard condition.

2) ***Power density***:- If E_{cell} is the total EMF and $R_{external}$ is the resistance of a resistor connected across the terminal of the power generated is given by,

$$P=(E_{cell}*E_{cell})/R_{external} \quad (6)$$

The above expression can not be considered while comparing the result of one MFC with the other. Hence in such case, anode surface area can be taken into account for normalization of power equation and equation becomes ,

$$P_{anode}=(E_{cell}*E_{cell})/(R_{external}*A_{anode}) \quad (7)$$

Where P_{anode} is power density taking anodic surface area (A_{anode}) into consideration. If anode is kind of foam having many pores over it then it becomes quiet difficult to specify the surface area and hence cathode is taken into consideration. To determine the size and cost of reactors and as a useful comparison to chemical fuel cell the power is normalized to the reactor volume power outputs can be determined by the following expression,

$$P_{volumetric}=(E_{cell}*E_{cell})/(V*R_{external}) \quad (8)$$

Where $P_{volumetric}$ is volumetric power and V=total reactor volume
In this way power output calculation is done successfully

3) ***Polarization curve***: - It is the graph between cell terminal voltage and current through resistor connected across the terminal. Complete fuel cell can be analyzed on the basis of this graph to measure the external potential potentiostat is utilized. In order to analyze cell on half cell basis that is (anode or cathode) potential vs. current, the reference electrode live NHE. Silver-Silver fluoride (Ag/AgCl) are use to measure the half cell voltage. When a variable external resistor is used then current and potential values need to be taken only when pseudo steady state conditions have been established.

In this way power output calculation is done successfully.

4) ***Coulombic efficiency***:- It is one of the most important factor in analyzing MFC cell. It is the ratio of actual coulombs transferred to anode from substrate, to maximum possible coulombs if all substrate removal produced current. The total coulomb obtained is determined by integrating the currentover time, to that the coulombic efficiency for an MFC run in fed-batch mode.

VI .Applications

6. Applications:

1) ***Gastrobots*** – It is one of the applications of MFCs. Gastrobots, a class of intelligent machines that derive their operational power by exploiting the digestion of real food. Robots of this type could potentially be made self sufficient with just an input of natural food, water and air, and as such would be ideal for a host of applications that demand “living off the land” during fully autonomous “start and forget” missions. One possible method of powering such machines is through the use of a Microbial Fuel Cell (MFC), which can directly convert various food substrates into electricity. MFCs offer specific advantages over other renewable energy conversion methods, such as photovoltaic panels, principally in terms of compact configuration and 24 hour operation. Incorporating such a MFC into a robot is not a trivial matter, and many challenges have to be addressed and overcome.

2) ***Biosensors*** - Microbial biosensors have been investigated mainly as water quality monitoring devices and currently, few prototypes used as water toxicity sensors have been commercialised . The use of microbes that survive under highly alkaline, acidic, high temperature, and saline conditions opens up attractive perspectives on water monitoring for industrial process waste monitoring . The full deployment of microbial biosensors is however faced with various challenges. These include low selectivity, low detection limits, risk of contamination with other microorganisms, and mass transfer limitations caused by the necessary permeation of substrates and products through the cells .

3) ***Waste Water Treatment*** - MFC technology can be applied as a renewable energy source with applications in power generation, wastewater treatment and water quality monitoring. MFCs can provide clean, safe, and quiet performance. MFCs are used in water treatment to harvest energy utilizing anaerobic digestion. The process can also reduce pathogens. However, it requires temperatures upwards of 30 degrees C .

4) **Biohydrogen -** Microbial fuel cell can be readily modified to produce hydrogen instead of electricity. Under normal operating conditions, protons released by the anodic reaction migrate to the cathode to combine with oxygen to form water. Hydrogen generation from the protons and the electrons produced by the metabolism of microbes in an MFC is thermodynamically unfavourable. Applied an external potential to increase the cathode potential in a MFC circuit and thus overcame the thermodynamic barrier. In this mode, protons and electrons produced by the anodic reaction are combined at the cathode to form hydrogen. MFCs can potentially produce about 8–9 mol H2/mol glucose compared to the typical 4 mol H2/mol glucose achieved in conventional fermentation (Liu *et al.*, 2005c). In biohydrogen production using MFCs, oxygen is no longer needed in the cathodic chamber. Thus, MFC efficiencies improve because oxygen leak to the anodic chamber is no longer an issue.

5) Another advantage is that hydrogen can be accumulated and stored for later usage to overcome the inherent low power feature of the MFCs. Therefore, MFCs provide a renewable hydrogen source that can contribute to the overall hydrogen demand in a hydrogen economy (Liu *et al*., 2005c).

5) **Implanted medical devices -** A strange application for MFC technology is to power implanted medical devices using glucose and oxygen from blood. An implanted MFC could provide power indefinitely and negate the need for surgery to replace batteries (Kerzenmacher et al., 2008). Interest has also been expressed in using human white blood cells as a source of electrons for an anode. Experiments using white blood cells in phosphate-buffered saline solution with a ferric-cyanide cathode produced a low current level of 1–3 μAcm2 but it could not determine if electron transport to the anode was through a direct or indirect process (Justin et al., 2005). Some scientists predict that in the future a miniature MFC can be implanted in a human body to power an implantable medical device with the nutrients supplied by the human body.

CONCLUSION

Conclusion -The study of microbial fuel cell has proven that it could be the most preferred alternative source for the energy need of forthcoming generation. But much research is yet to be done over this technology which has the capacity to serve energy need of future generation.. But, gradually, researchers are seeking higher output from it which can be utilized at large scale level applications. Hence, microbial fuel cell technology has been emerging gradually and attaining solidarity in its stand in renewable world.

REFERENCES

References

1) Anand Prakash, Shaheen Aziz and Suhail A. Soomro , "Utilization of sewage sludge for production of electricity using mediated salt bridge based dual chamber microbial fuel cell", Journal of Bioprocessing and Biotechniques 2015, Volume 5.(Open access journal).

2) Mustakeem Review Paper**:** "Electrode materials for microbial fuel cells: nanomaterial approach."**,** Mater Renew Sustain Energy(2015)4:22.(Page no. 1-22)This article is published with open access at Springerlink.com.

3) Helinando P. de Oliveira, Mateus M. da Costa Universidade Federal do Vale do Sao Francisco Univasf,Juazeiro, BA, Brazil, "Development of low cost microbial fuel cell based on *Escherichia coli."* IEEE Paper 2015 (Page no. : 940-942)

4) Andrew Meehan, Hongwei Gao*, Senior Member, IEEE, and Zbigniew Lewandowski, "*Energy Harvesting With Microbial Fuel Cell and Power Management System*",* IEEE Transactions on Power Electronics, Volume 26, (Page no.:176-181), January 2011.

5) Yun-Hai Wang, Huan Xi, Feng-Jiao Lin, Bai-Shi Wang,Qing-Yun Chen,State Key Laboratory of Multi phase Flow, Department of Environmental Science and Engineering Xi'an Jiaotong University Xi' an, China, "The Effect of
Substrates and Anodes on Microbial Fuel Cell Performance." IEEE Paper 2011,(Page no. : 1841-1843).

6) Yujie Feng, He Lee, Xin Wang,Yaolan Liu, Department of Environmental Science & Engineering,Harbin Institute of Technology,Harbin, China , "Electricity Generation in Microbial Fuel Cells at different temperature and Isolation of Electrogenic Bacteria."IEEE 2009.

7) J-M. Monier, L. Niard, N. Haddour, B. Allard and F. Buret, *Member, IEEE, "*Microbial Fuel Cells: from biomass (waste) to Electricity"**,** 2008 IEEE paper (Page no.: 663-668).

8) Yinfang Zhi, Hong Liu, Bio-engineering Department, Beijing University of Aeronautics and Astronautics & Lu Yao
,Department of Environmental Engineering, Beijing University of Aeronautics and Astronautics Beijing, China , "The Effect of Suspended Sludge on Electricity Generation in Microbial Fuel Cells ",2008 IEEE paper (Page no. :2923- 2927).

9) Brucee Logan , Berthamelers, Hydrogen Energy Center, 212 Sackett Building, Penn State University , University Park, Pennsylvania, 16802, Sub-Department of Environmental Technology, Wageningen University, *"*Microbial Fuel Cells: Methodology and Technology*",* ENVIRONMENTAL SCIENCE & TECHNOLOGY, Volume 40, (Page no.: 5181- 5192), 2006.

10)Anand Prakash, Shaheen Aziz and Suhail A. Soomro , "Utilization of sewage sludge for production of electricity using mediated salt bridge based dual chamber microbial fuel cell", Journal of Bioprocessing and Biotechniques 2015, Volume 5.(Open access journal).

11) Mustakeem Review Paper**:** "Electrode materials for microbial fuel cells: nanomaterial approach."**,** Mater Renew Sustain Energy(2015)4:22.(Page no. 1-22)This article is published with open access at Springerlink.com.

12) Helinando P. de Oliveira, Mateus M. da Costa Universidade Federal do Vale do Sao Francisco Univasf,Juazeiro, BA, Brazil, "Development of low cost microbial fuel cell based on *Escherichia coli."* IEEE Paper 2015 (Page no. : 940-942)

13)Andrew Meehan, Hongwei Gao*, Senior Member, IEEE, and Zbigniew Lewandowski, "*Energy Harvesting With Microbial Fuel Cell and Power Management System*",* IEEE Transactions on Power Electronics, Volume 26, (Page no.:176-181), January 2011.

14) Yun-Hai Wang, Huan Xi, Feng-Jiao Lin, Bai-Shi Wang,Qing-Yun Chen,State Key Laboratory of Multi phase Flow, Department of Environmental Science and Engineering Xi'an Jiaotong University Xi' an, China, "The Effect of
Substrates and Anodes on Microbial Fuel Cell Performance." IEEE Paper 2011,(Page no. : 1841-1843).

15)Yujie Feng, He Lee, Xin Wang,Yaolan Liu, Department of Environmental Science & Engineering,Harbin Institute of Technology,Harbin, China , "Electricity Generation in Microbial Fuel Cells at different temperature and Isolation of Electrogenic Bacteria."IEEE 2009.

16) J-M. Monier, L. Niard, N. Haddour, B. Allard and F. Buret, *Member, IEEE, "*Microbial Fuel Cells: from biomass (waste) to Electricity"**,** 2008 IEEE paper (Page no.: 663-668).

17) Yinfang Zhi, Hong Liu, Bio-engineering Department, Beijing University of Aeronautics and Astronautics & Lu Yao
,Department of Environmental Engineering, Beijing University of Aeronautics and Astronautics Beijing, China , "The Effect of Suspended Sludge on Electricity Generation in Microbial Fuel Cells ",2008 IEEE paper (Page no. :2923- 2927).

18) Brucee Logan , Berthamelers, Hydrogen Energy Center, 212 Sackett Building, Penn State University , University Park, Pennsylvania, 16802, Sub-Department of Environmental Technology, Wageningen University, *"*Microbial Fuel Cells: Methodology and Technology*",* ENVIRONMENTAL SCIENCE & TECHNOLOGY, Volume 40, (Page no.: 5181- 5192), 2006.

19)Anand Prakash, Shaheen Aziz and Suhail A. Soomro , "Utilization of sewage sludge for production of electricity using mediated salt bridge based dual chamber microbial fuel cell", Journal of Bioprocessing and Biotechniques 2015, Volume 5.(Open access journal).

20) Mustakeem Review Paper**:** "Electrode materials for microbial fuel cells: nanomaterial approach."**,** Mater Renew Sustain Energy(2015)4:22.(Page no. 1-22)This article is published with open access at Springerlink.com.

21) Helinando P. de Oliveira, Mateus M. da Costa Universidade Federal do Vale do Sao Francisco Univasf,Juazeiro, BA, Brazil, "Development of low cost microbial fuel cell based on *Escherichia coli."* IEEE Paper 2015 (Page no. : 940-942)

22)Andrew Meehan, Hongwei Gao*, Senior Member, IEEE, and Zbigniew Lewandowski, "*Energy Harvesting With Microbial Fuel Cell and Power Management System*",* IEEE Transactions on Power Electronics, Volume 26, (Page no.:176-181), January 2011.

23) Yun-Hai Wang, Huan Xi, Feng-Jiao Lin, Bai-Shi Wang,Qing-Yun Chen,State Key Laboratory of Multi phase Flow, Department of Environmental Science and Engineering Xi'an Jiaotong University Xi' an, China, "The Effect of Substrates and Anodes on Microbial Fuel Cell Performance." IEEE Paper 2011,(Page no. : 1841-1843).

24)Yujie Feng, He Lee, Xin Wang,Yaolan Liu, Department of Environmental Science & Engineering,Harbin Institute of Technology,Harbin, China , "Electricity Generation in Microbial Fuel Cells at different temperature and Isolation of Electrogenic Bacteria."IEEE 2009.

25) J-M. Monier, L. Niard, N. Haddour, B. Allard and F. Buret, *Member, IEEE, "*Microbial Fuel Cells: from biomass (waste) to Electricity"**,** 2008 IEEE paper (Page no.: 663-668).

26) Yinfang Zhi, Hong Liu, Bio-engineering Department, Beijing University of Aeronautics and Astronautics & Lu Yao ,Department of Environmental Engineering, Beijing University of Aeronautics and Astronautics Beijing, China , "The Effect of Suspended Sludge on Electricity Generation in Microbial Fuel Cells ",2008 IEEE paper (Page no. :2923- 2927).

27) Brucee Logan , Berthamelers, Hydrogen Energy Center, 212 Sackett Building, Penn State University , University Park, Pennsylvania, 16802, Sub-Department of Environmental Technology, Wageningen University, *"*Microbial Fuel Cells: Methodology and Technology*",* ENVIRONMENTAL SCIENCE & TECHNOLOGY, Volume 40, (Page no.: 5181- 5192), 2006.