Comparative Study on Sustainable Bioelectricity Generation from Microbial Fuel Cell Using Bio-waste as Fuel

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Abstract- Electricity generation from microbial fuel cell (MFC) using cow dung and cow urine as fuel was investigated in this study. The electrodes used in MFC were combinations of copper, brass and magnesium sheets of 0.2 mm thickness and having 6"X 6" dimension. Comparative studies resulted from using cow dung as fuel in two chamber design of MFC under aerobic and anaerobic conditions. Studies were carried out using cow urine as fuel in six chamber design of MFC under anaerobic condition. Dual chamber design and six chamber design gave an average output of 1.1 volt and 4.2 volt respectively.

Index Terms- Bioelectricity, MFC, electrode, design

I. INTRODUCTION

A Technology using microbial fuel cell (MFC) that convert the energy stored in chemical bonds in organic compounds to electrical energy achieved through the catalytic reactions by microorganisms has generated considerable interests among academic researchers in recent years[1,6,16]. Microbial fuel cells (MFCs) are a promising technology for electricity production from a variety of materials.

India is blessed with plenty of energy sources such as solar, wind, hydro and biomass. Biomass alone has got energy potential of about 66000 MW, out of which, about 900 MW energy had been achieved till 2006.So there is a lot of biomass which can be used efficiently and sustainably. Recent studies have shown that oil and other fossil fuels will not be available in next 100 years and it is expected that the demand for oil will exceed the production [1]. One estimate of population growth, coupled economy growth at current levels puts a global demand of 41TW in 2050 at current energy growth rates. However, considering anticipated energy trends, a more reasonable projection is 27 TW by 2050 and 43TW by 2100 [11]. Major concern is the fact that release of stored carbon in fossil fuels is increasing the concentration of carbon dioxide in the atmosphere, with increases from 316ppmv in 1959 to 377 ppm in 2004[11]. By 2100 it is estimated that CO_2 concentration will reach anywhere from 560 ppm to 970 ppm [1]. Today greatest environmental challenge is to simultaneously solve energy production and CO_2 release. There is strong need to develop a whole new energy platform that produces sufficient energy while at the same time reduces CO_2 emissions. The use of fossil fuels, especially oil and gas, in recent years has accelerated and this triggers a global energy crisis. One of the ways to alleviate the current global warming crisis is renewable energy resources. Developing alternative electricity production methods are given prime importance. New electricity production from renewable resources without a net carbon dioxide emission is much desired [5, 12]. Bacteria can be used in MFCs to generate electricity while accomplishing the biodegradation of organic matters or wastes [17, 20]. Figure.1 shows a schematic diagram of a typical MFC for producing electricity. It consists of anode and cathode chambers partitioned by a proton exchange membrane (PEM) [6, 28].

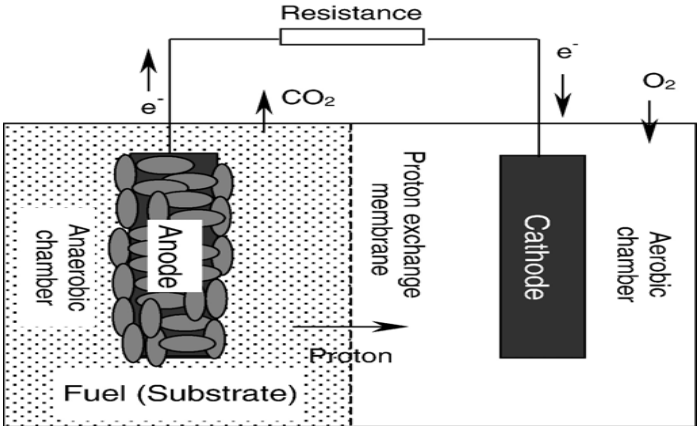

Figure: 1. Schematic diagram of a typical two-chamber microbial fuel cell.

Microbes in the anodic chamber of an MFC oxidize added substrates and generate electrons and protons in the process. Carbon dioxide is produced as an oxidation product. However, there is no net carbon emission because the carbon dioxide in the renewable biomass originally comes from the atmosphere in the photosynthesis process. Unlike in a direct combustion process, the electrons are absorbed by the anode and are transported to the cathode through an external circuit. After crossing a PEM or a salt bridge, the protons enter the cathode chamber where they combine with oxygen to form water. Microbes in the anodic chamber extract electrons and protons in the dissimilative process of oxidizing organic substrates [24]. Electric current generation is made possible by keeping microbes separated from oxygen or any other end terminal acceptor other than the anode and this requires an anaerobic anodic chamber. The overall reaction is the breakdown of the substrate to carbon dioxide and water with a concomitant production of electricity as a by-product. Based on the electrode reaction pair above, an MFC

bioreactor can generate electricity from the electron flow from the anode to cathode in the external circuit. In recent years, rapid advances have been made in MFC research and the number of journal publications has increased sharply in the past three years with more researchers joining the research field. Several reviews on MFC are available, each with a different flavour or emphasis. Logan et al. (2006) reviewed MFC designs, characterizations and performances. The microbial metabolism in MFCs was reviewed by Rabaey and Verstraete (2005). Lovley (2006) mainly focused his review on the promising MFC systems known as Benthic Unattended Generators (BUGs) for powering remote-sensing or monitoring devices from the angle of microbial physiologies. Pham et al. (2006) summarized the advantages and disadvantages of MFCs compared to the conventional anaerobic digestion technology for the production of biogas as renewable energy. Chang et al. (2006) discussed both the properties of electrochemically active bacteria used in mediator less MFC and the rate limiting steps in electron transport. Bullen et al. (2006) compiled many experimental results on MFCs reported recently in their review on bio-fuel cells. This work here presents a state of the art review on MFC with emphases on the recent advances in MFC reactor designs, MFC performances and optimization of important operating parameters. A brief MFC history is also presented.

Theoretically, most microbes can potentially be used as a biocatalyst in MFC. The earliest MFC concept was demonstrated by Potter in 1910 [8]. Electrical energy was produced from living cultures of *Escherichia coli* and *Saccharomyces* by using platinum electrodes [22]. This didn't generate much interest until 1980s when it was discovered that current density and the power output could be greatly enhanced by the addition of electron mediators. Unless the species in the anodic chamber are anodophiles, the microbes are incapable of transferring electrons directly to the anode. The outer layers of the majority of microbial species are composed of non-conductive lipid membrane, peptidoglycans and lipopolysaccharides that hinder the direct electron transfer to the anode. Electron mediators accelerate the transfer [5]. Mediators in an oxidized state can easily be reduced by capturing the electrons from within the membrane. The mediators then move across the membrane and release the electrons to the anode and become oxidized again in the bulk solution in the anodic chamber. This cyclic process accelerates the electron transfer rate and thus increases the power output. Good mediators should possess the following features [8]: (1) able to cross the cell membrane easily; (2) able to grab electrons from the electron carries of the electron transport chains; (3) possessing a high electrode reaction rate; (4) having a good solubility in the anolyte; (5) non-biodegradable and non-toxic to microbes; (6) low cost. And how efficient the oxidized mediator gets reduced by the cells reducing power is more important compared with other features. Although a mediator with the lowest redox would in theory give the lowest anodic redox and thus maximize the redox difference between anode and cathode (i.e. give biggest voltage difference) it would not necessarily be the most efficient at pulling electrons way from the reduced intracellular systems (NADH, NADPH or reduced cytochromes) within the microbes. A mediator with a higher Eo redox would give a higher overall power than a mediator with the lowest redox [8]. Typical synthetic exogenous mediators include dyes and metallo-organics such as neutral red (NR), methylene blue (MB), thionine, meldola's blue (MelB), 2-hydroxy-1,4-naphthoquinone (HNQ), and Fe(III)EDTA[1,8,19,25,27]. Unfortunately, the toxicity and instability of synthetic mediators limit their applications in MFCs. Some microbes can use naturally occurring compounds including microbial metabolites (Endogenous mediators) as mediators. Humic acids, anthraquinone, the oxyanions of sulphur (sulphate and thiosulphate) all have the ability to transfer electrons from inside the cell membrane to the anode [15]. A real breakthrough was made when some microbes were found to transfer electrons directly to the anode [4, 9]. These microbes are operationally stable and yield a high Coulombic efficiency [4, 24]. *Shewanella putrefaciens* [10], *Geobacteraceae sulferreducens* [3], *Geobacter metallireducens* [16] and *Rhodoferax ferrireducens* [4] are all bioelectrochemically active and can form a biofilm on the anode surface and transfer electrons directly by conductance through the membrane. When they are used, the anode acts as the final electron acceptor in the dissimilatory respiratory chain of the microbes in the biofilm. Biofilms forming on a cathode surface may also play an important role in electron transfer between the microbes and the electrodes. Cathodes can serve as electron donors for *Thiobacillus ferrooxidans* suspended in a catholyte [23] for an MFC system that contained microbes in both anodic and cathodic chambers. *G. metallireducens* and *G. sulfurreducens* [7] or other seawater biofilms [2] may all act as final electron acceptors by grabbing the electrons from cathode as electron donors. Mediator-less MFCs are advantageous due to reduction in cost of mediators [8].

II. MATERIALS AND METHODS

A. Microbes Used in MFC

Many microorganisms possess the ability to transfer the electrons derived from the metabolism of organic matters to the anode. Marine sediment, soil, wastewater, fresh water sediment cow dung and activated sludge are all rich sources for these microorganisms [17, 29]. The anodic electron transfer mechanism in MFC is a key issue in understanding the theory of how MFCs work. As mentioned above, microbes transfer electrons to the electrode through an electron transport system that either consists of a series of components in the bacterial extracellular matrix or together with electron shuttles dissolved in the bulk solution. *Geobacter* belongs to dissimilatory metal reducing microorganisms, which produce biologically useful energy in the form of ATP during the dissimilatory reduction of metal oxides under anaerobic conditions in soils and sediments. The electrons are transferred to the final electron acceptor such as Fe_2O_3 mainly by a direct contact of mineral oxides and the metal reducing microorganisms [14, 26]. The anodic reaction in mediator-less MFCs constructed with metal reducing bacteria belonging primarily to the families of *Shewanella, Rhodoferax,* and *Geobacter* is similar to that in this process because the anode acts as the final electron acceptor just like the solid mineral oxides. *S. putrefaciens, G. sulferreducens, G. metallireducens* and *R. ferrireducens* transfer electrons to the solid electrode (anode) using this system. Though most of the real mediator-less MFCs are operated with dissimilatory metal reducing microorganisms, an exception was reported with *Clostridium butyricum* [18, 21] . Mediators such as dye molecules and humic

substances also have some effects on the mediator-less MFCs even though the anodophiles can transfer the electrons to the anode directly especially in the early stage of bio-film formation. Electron mediators like Mn^{4+} or neutral red (NR) incorporated into the anode noticeably enhance the performance of MFCs using anodophile *S. putrefaciens* [20]. Mediators play an important role in electron transport for those microbes that are unable to transfer the electrons to the anode. Basic processes are shown as follows [8, 13]. Mediators shuttle between the anode and the bacteria transferring the electrons. They take up the electrons from microbes and discharge them at the surface of the anode. *Actinobacillus succinogenes*, *Desulfovibrio desulfuricans*, *E. coli*, *Proteus mirabilis*, *Proteus vulgaris*, and *Pseudomonas fluorescens* need extraneous mediators while some microbes can provide their own. For example, *Pseudomonas aeruginosa* produces pyocyanin molecules as electron shuttles.

B. Mechanism

The bacteria live on the surface of anode and convert a substrate such as glucose, acetate but also waste water into CO_2, protons and electrons. Under aerobic conditions, bacteria use oxygen or nitrate as a final electron acceptor to produce water. However, on the anode of a MFC, no oxygen is present and bacteria transfer electrons from their natural electron acceptor to an insoluble acceptor, such as the MFC anode. Due to the ability of bacteria to transfer electrons to an insoluble electron acceptor, we can use a MFC to collect the electrons originating from the microbial metabolism. The electron transfer can occur either via membrane-associated components, soluble electron shuttles or nano-wires. The electrons then flow through an electrical circuit with a load or a resistor to the cathode. The potential difference (Volt) between the anode and the cathode, together with the flow of electrons (Ampere) results in the generation of electrical power (Watt). The protons flow through the proton or cation exchange membrane (Selective permeable membrane) to the cathode (Oh and Logan 2004). At the cathode, an electron acceptor is chemically reduced. Ideally, oxygen is reduced to water.

C. Construction and Operation

Canister drums of 2 liters capacity were used to mix the slurry and place the electrodes for dual chamber MFC design. Canister drums of 500ml capacity were used for six chamber MFC design. Multimeter was used to detect and measure electricity generated from MFC. Copper, brass and magnesium sheets of 0.2mm thickness and 6”X6”dimensions were used as electrodes. Insulated copper wires were used to connect the electrodes to external circuit. Solder iron and solder wire were used to connect the copper wire to electrodes. Cow dung and urine were used as fuel and as source of microbes. Cow dung slurry was prepared by mixing with water in 2:3 proportions and stirred well till uniform slurry is formed. The surface of the metal sheets used as electrodes were rubbed with sand paper to make them rough. Figure.2 shows the dual chamber and six chamber MFC design used on lab scale.

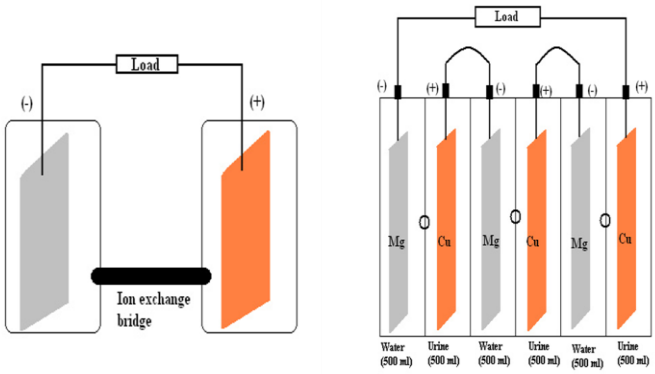

Figure: 2. Dual and six chamber MFC designs

Following table shows the design in terms of operating condition, combination of electrodes and type of fuel used.

Table: 1. Magnesium electrodes are inserted in container containing cow dung under aerobic condition slurry and other electrodes in container containing water.

Dual chamber design	Anode	Cathode
Design 1	Brass	Magnesium
Design 2	Copper	Magnesium

Table: 2. Magnesium electrodes are inserted in container containing water and other electrodes in container containing cow dung slurry under aerobic condition.

Dual chamber design	Anode	Cathode
Design 3	Brass	Magnesium
Design 4	Copper	Magnesium

Table: 3. Magnesium electrodes are inserted in container containing water and other electrodes in container containing cow dung slurry under anaerobic condition.

Dual chamber design	Anode	Cathode
Design 5	Brass	Magnesium
Design 6	Copper	Magnesium

Table: 4. Magnesium electrodes are inserted in container containing water and other electrodes in container containing cow urine under anaerobic condition.

Six chamber design	Anode	Cathode
Design 7	Magnesium	Brass
Design 8	Copper	Magnesium

III. RESULTS AND DISCUSSION

Generation of electricity was detected and measured for 15 days. Graphical representation of the results, taking number of days of observation on X-axis and voltage measured in volt on Y-axis is given below:

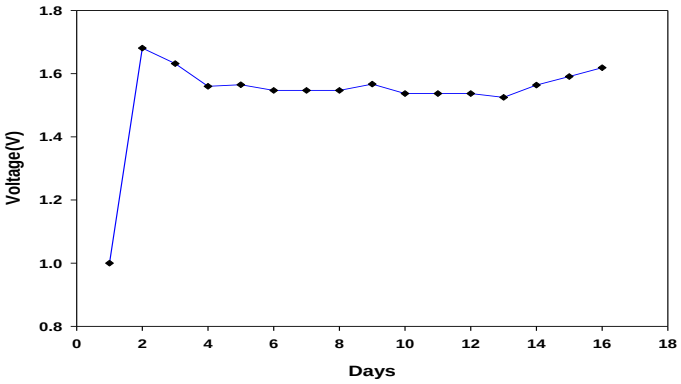

Figure: 3.1. Results of design 1

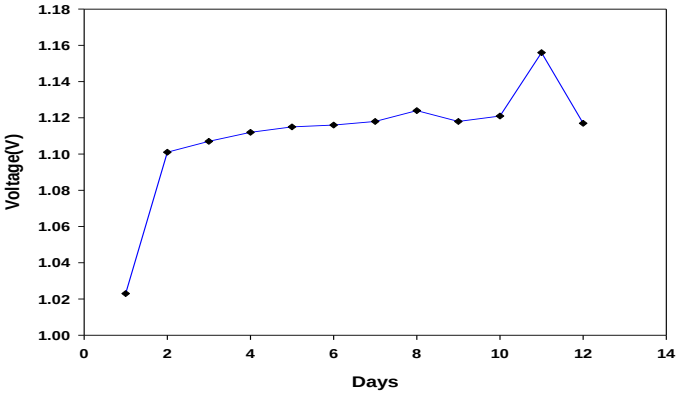

Figure: 3.2. Results of design 2

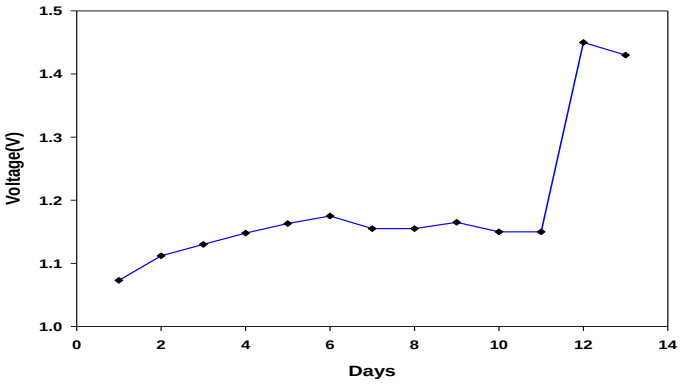

Figure: 3.3. Results of design 3

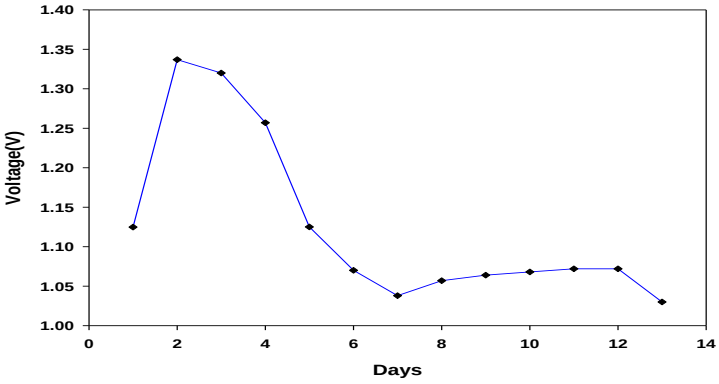

Figure: 3.4. Results of design 4

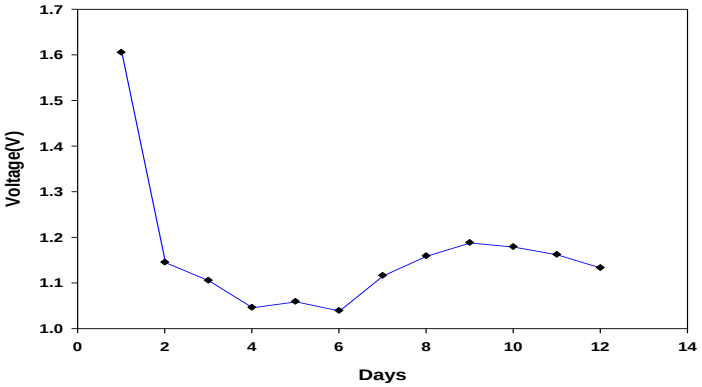

Figure: 3.5. Results of design 5

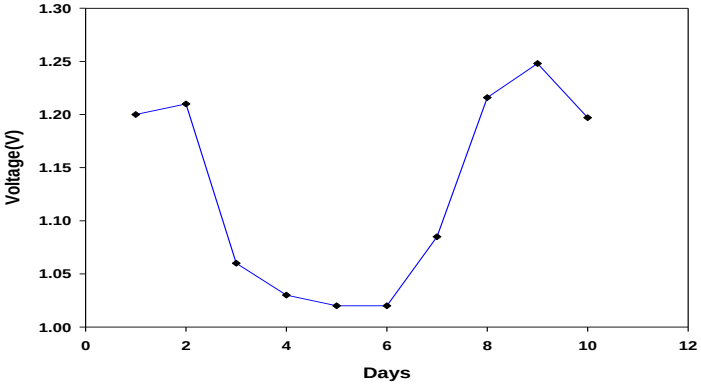

Figure: 3.6. Results of design 6

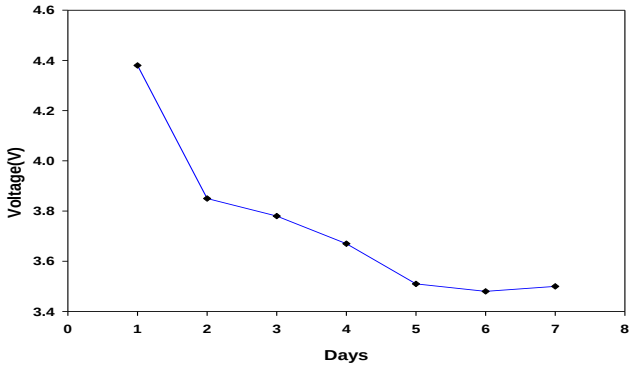

Figure: 3.7. Results of design 7

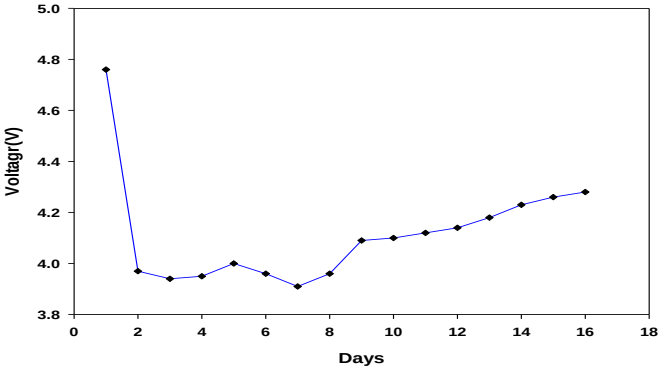

Figure: 3.8. Results of design 8

Cow dung slurry was used as fuel in design 1, 2, 3, 4, 5 and 6. Design 1 showed a steady output of 1.6 volt from day 2 till day 15, whereas design 2 gave an output of 1.12 volt up to day 11. Design 3 showed an output of 1.1 volt from day 2 till day 11 which later showed a peak of 1.4 volt on day 12. Design 4 initially showed a better result with 1.35 volt but showed a negative slope from day 3 till day 7, giving steady state value of 1.05 volt. All above designs were operated with electrode inserted in cow dung slurry under aerobic conditions and hence design with magnesium electrode inserted in chamber containing water were selected for further testing under anaerobic conditions as they gave better results compared to the one with magnesium electrode inserted in chamber with cow dung slurry. Design 5 showed a more steady output compared to the output from design 6 with. Design 5 gave a steady output of 1.1 volt whereas design 6 initially showed a peak of 1.2 volt on day 2 then output as low as 1 volt till day 6 and sudden increase in output till day 9 of 1.23 volt.

Cow urine was used as fuel in design 7 and 8 which was a six chamber design MFC with each chamber connected in series. Design 7 showed a gradual decrease in output from 4.4 volt to 3.5 volt till day 7 and the trend continued like this. Design 8 showed a peak of 4.8 volt on day 2 then decrease to 4 volt till day 8 and then a gradual increase till day 15 to 4.2 volt. The result shows that design 8 is a better choice with steady output of 4.2 volt. The output of design 8 was used to illuminate LED of 1.35 volt which showed a positive result.

IV. CONCLUSION

It can be concluded that from the biogas plant of higher capacity, sufficient amount of electricity can be generated which can be used for various small domestic needs. With modification in the electrode design and the biogas plant design, there is a good prospect of tapping unconventional energy source from biogas plant. By including certain natural organic waste in the slurry of biogas plant, there is possibility of enhancing the voltage output, which would add to the economy of biogas plant and increase the fertilizer property of exhaust slurry.

Studies of the anode bio-film community composition of MFC from cow dung slurry would throw the door open for exploration of efficient way of harvesting electrical energy from the biogas plant as a new method for renewable and sustainable energy production. The waste generated from MFC can further be processed to produce manure and white coal.

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