Review Article

A Review on selection of electrodes and its effects on Microbial Fuel Cells for the electricity generation

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Abstract
Microbial fuel cells (MFCs) are the devices which convert organic matters especially organic wastes into energy in the form of electricity with the help of microorganisms. Various types of MFCs were constructed using different types of electrodes, organic substrates and microorganisms. The common MFC design having electrodes (anode and cathode) and an electric circuit. So that Selection of electrodes play vital role in this field. In this review, different types of electrodes and their effects on the production of electricity using MFCs is discussed.

Keywords: Microbial fuel cell, electricity generation, Electrodes.

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Introduction

In MFC, chemical energy released from the organic substances is used to produce electricity with the help of microorganisms (Bacteria). M.C. Potter was the first researcher who retrieved electricity from MFC using Esherichia.Coli culture [1]. Usually bacterial community present along with organic substances which are placed in anodic compartment produce electrons due to the biological process. The electrons released from this process then transferred to cathode through external circuit that cause current. The anodic compartment should be maintained under anaerobic conditions because oxygen inhibits electricity generation where as cathodic compartment is exposed to oxygen atmosphere [2]. For example, the reactions at MFC using acetate as a substrate are depicted as follows [3].

Reaction at anode: $$CH_3COO^- + 2\,H_2O \longrightarrow 2CO_2 + 7\,H^+ + 8\,e^-$$

Reaction at cathode: $$O_2 + 4\,e^- + 4\,H^+ \longrightarrow 2\,H_2O$$

In general, different types of MFCs are there. They are Single chambered MFC (**Figure 1**), Dual chambered MFC (**Figure 2**), Up-flow MFC (**Figure 3**) and Stacked MFC (**Figure 4**).

So that, choice of organic substances, microorganisms, electrodes and design are affecting the performance of Microbial fuel cells. This current review mainly focussing on various electrodes used by the researchers in the construction of different types of MFCs and their effects for electricity production.

Review

H.P. Benneto [4] used single compartment fuel cell to generate electricity by microorganisms (Escherichia coli). In this work, Fe-graphite anode and Mn-graphite anode were used instead of using of conventional graphite electrode. Finally, it was concluded both these electrodes could enhance the amount of electricity with lower cost.

Doo Hyun Park, et al., [5] developed three new electrodes such a Mn^{4+}-graphite anode, a neutral red (NR) covalently linked woven graphite anode and an Fe^{+-}graphite cathode which could replace normal graphite electrode for one –compartment microbial fuel cell. At the end of the research, it was stated that these three electrodes greatly enhanced electrical energy production by using sewage sludge / Escherichia coli as the biocatalyst.

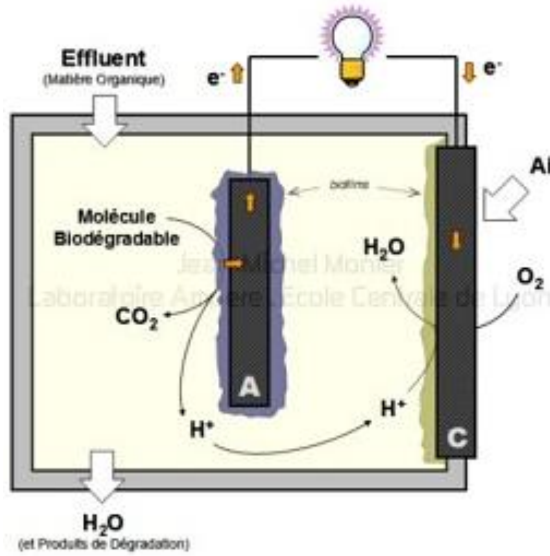

Figure 1 Single compartment MFC (www.genomenenviron.org)

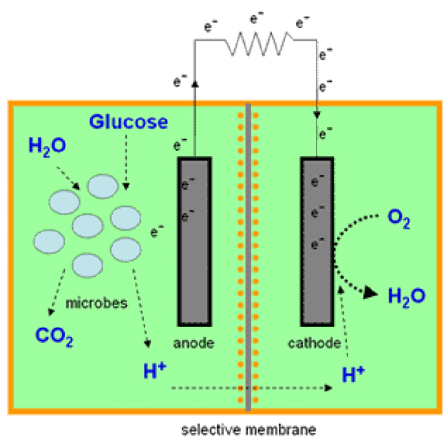

Figure 2 Dual-chambered MFC (www.globalmongabay.com)

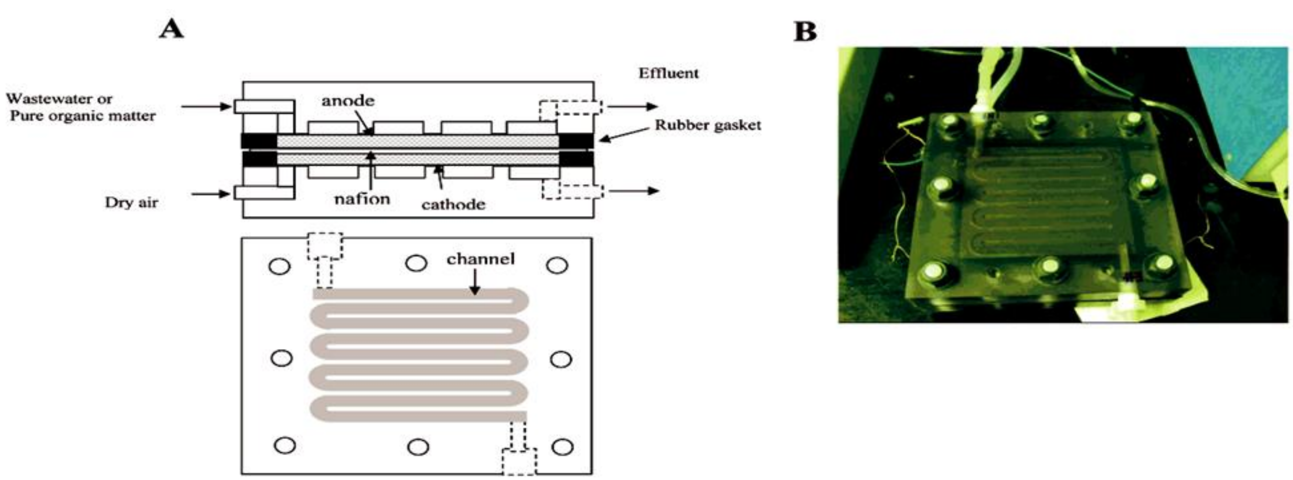

Figure 3 Schematic (A) (upper, side view; lower, top view) and laboratory-scale prototype (B) of the FPMFC

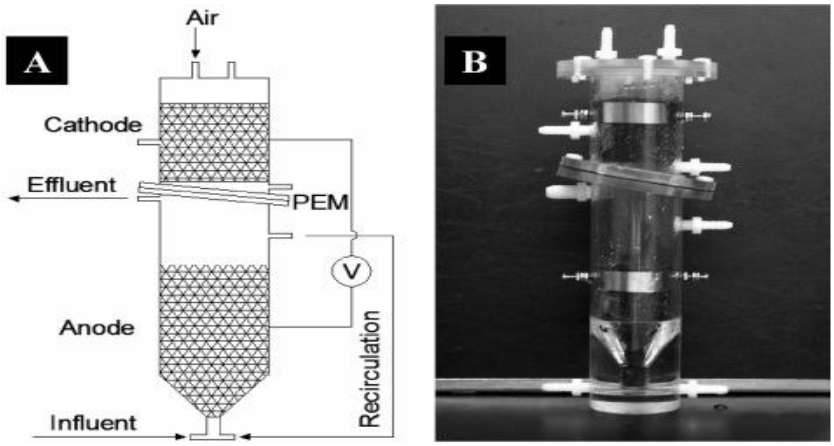

Figure 4 Schematic (A) and picture (B) of the lab-scale UMFC

Korneel Rabaey, et al., [6] identified that electricity could be generated from glucose by a microbial fuel cell using plain graphite electrode and a microbial consortium. In this work, dual chamber MFC was used. Glucose (anaerobic sludge originating from a methanogenic reactor at a potato processing company) was loaded in anodic compartment and and a phosphate buffer was prepared and enriched with potassium hexacyanoferrate was dosed in cathodic compartment. In this investigation they studied how the loading rate affected the applicability of the system and metabolism of the enriched microbial consortium.

Dentel SK, et al., [7] found electricity could be generated from sludges and other liquid wastes using a reactor with graphite foil electrodes. It was concluded that after adding additional organic substrate (acetate), the electricity generated was further enhanced.

Booki Min, et al., [8] designed a flat plate MFC(FPMFC) (Figure 3)using carbon paper as anode and carbon cloth coated with platinum as cathode. In this study, the domestic waste water was continuously fed into the anode chamber for electricity generation. The system was found to be versatile with various organic substrates and the power was generated at a high rate in a continuous flow reactor system.

Zhenhe, et al., [9] introduced an up flow MFC(UMFC) (Figure 4) using stainless steel electrodes for generating electricity and also for the waste water treatment. In their studies, the UMFC was fed with a sucrose solution continuously and electricity was generated over the entire operating period and simultaneously removal of soluble chemical oxygen demand (SCOD) was also achieved.

Booki Min, et al., [10] reported that animal waste waters can be used for power production in MFC. Preliminary tests were carried out using swine waste water in a two-chambered MFC indicated that power generation was feasible using carbon paper as electrodes. Further, they extended their work with single chambered MFC using swine waste water and the results were compared with domestic waste water. Finally they concluded that swine waste water produced more power generation than normal domestic waste water due to the presence of higher organic matter concentration.

Aelterman P et al., [11] achieved continuous electricity generation from stacked microbial fuel cells using a hexacyanoferrate cathode. They connected 6 MFC units in series and parallel to increase the voltage and current capacity. A relationship between the electrochemical performance and microbial composition of MFC was demonstrated.

Hyunsoo Moon et al., [12] done a performance analyzation using a mediator – less MFC through the polarization curve method under different conditions using platinum – coated graphite felt as the cathode and graphite as anode. For this study they used artificial waste water made up of glucose and glutamic acid. They have achieved maximum power which was over 60 times higher than those reported in the previous mediator-less MFCs.

Dumas C et al., [13] designed a MFC using stainless steel anode and cathode for marine sediments as substrate for power production and achieved better performance than MFCs assembled with graphite electrodes.

DU Zhuwei et al., [14] designed an upflow mode membrane-less microbial fuel cell using granular graphite electrodes. They used artificial waste water as substrate using anaerobic activated sludge as biocatalyst. At the end of their research, it was found that higher feeding rate and longer electrode distance both increased the electricity generation.

S. Venkata Mohan et al., [15] have used a dual chambered microbial fuel cell for the bioelectricity electricity generation from composite chemical waste water treatment using mediator less perforated plain graphite electrode in anode chamber and potassium ferricyanide in phosphate buffer, plain graphite electrode in cathode chamber. Finally they concluded utilizing chemical waste water for the production of bioelectricity from anaerobic treatment is feasible, economical and sustainable method.

Annemiek ter Heijne et al., [16] studied about the performance of microbial fuel cells using four different non-porous materials such as flat graphite, roughened graphite, Pt-coated titanium and uncoated titanium as anodes. The kinetic studies using these electrode materials were studied by de-voltammetry and electrochemical impedance spectroscopy (EIS). Finally it was reported that performance of these anodes decreased in the order of roughened graphite> Pt-coated titanium>flat graphite>uncoated titanium. They also concluded that uncoated titanium was unsuitable as anode materials.

Tushar Sharma et al., [17] constructed a novel microbial fuel cell using novel electron mediators and carbon nano tubes(CNT) based electrodes. The novel mediators were prepared by dispersing nano crystalline platinum anchored carbon nanotubes in water. The performance of MFC using CNT based electrodes compared with plain graphite electrode based MFC and it was found that CNT based electrodes showed six times greater power density compared to graphite electrodes.

Junqiu Jiang, et al., [18] used a two-chambered microbial fuel cell (MFC) with potassium ferricyanide as its electron acceptor and generate electricity from sewage sludge. In this work, electricity was produced continuously during operation for 250 hrs using anode and cathode as graphite fibre brush. Simultaneously, total chemical oxygen demand (TCOD) of sludge was also reduced by 46.4% during this process. They also studied about the effect of substrate concentration, cathode catholyte concentration and anodic pH.

Cha J, et al., [19] generated electricity using a single – chambered MFC able to submerge into the aeration tank of the activated sludge process. They tested MFC with different electrode materials and finally concluded that the MFC with a graphite felt (GF) anode and GF cathode showed the highest power generation.

Jeonghwan Kim et al., [20] reported that anaerobic membrane bioreactors could be used for domestic and other waste water treatment with simultaneous power production. But membrane fouling is a major hurdle for this application. They found that fouling can be controlled if membranes are placed directly in contact with granular activated carbon (GAC) in an anaerobic fluidized bed bioreactor.

Yezhen Zhang et al., [21] used Microbial fuel cells (MFCs) based on Escherichia coli and studied about the electrochemical activities electrode made up of plain stainless steel mesh (SSM), polytetrafluoroethylene modified SSM (PMS), and graphene modified SSM (GMS) using cyclic voltammetry discharge experiments and polarization curve measurement. It was found that GMS showed better electrochemical performance than those of SSM and PMS.

Aishwarya D, et al., [22] made comparative study of bioelectricity generation from paneer whey degradation using different microorganisms in a two compartment without mediators using carbon as both anode cathode. The final results have shown that micro organisms were able to utilize carbohydrates (lactose). The voltage by different organisms were examined and was identified that maximum voltage was shown by *Klebsiella pneumonae*

M. Rahimnejad et al., [23] developed a novel stack of MFCs using *saccharomyces cerevisiae* as an active biocatalyst for the continuous production of electricity. Here, graphite was used both anode and cathode material. Pure glucose was used as substrate along with natural red as a mediator in anode and potassium permanganate as oxidizing agent in the cathode.

Mostafa Ghasemi, et al., [24] synthesized carbon nanotube/platinum (CNT/Pt) electrode and made comparative study of this CNT/Pt electrode efficiency with other electrodes. Finally they concluded that this CNT/Pt composite electrodes would increase MFC power out by 8.7-32.2% with respect to Pt electrodes.

Santoro et al., [25] used carbon nanofibres (CNF) based cathodes instead of Platinum based cathode in single chamber microbial fuel cells(SCMFCs). Synthetic waste water (Phosphate buffer (PBS) plus sodium acetate) and real waste water (mixed liquor suspended solid (MLSS)) were fed in to the MFCs and the studies were carried out. The experimental results showed that life time durability of CNF was greater when compared with Pt cathodes and higher power generation could be obtained by using SCMFCs fed with PBS rather than with MLSS solution.

Qusay Jaffer K, et al., [26] showed the effect of ferric oxide on the electricity production and waste water treatment. The use of 2.5% of ferric oxide nano particles and characterization of that were done by using X-ray Diffraction (XRD) and Scan electron Microscopy (SEM).They used Anaerobic sludge obtained from Koyembedu sewage treatment plant, Chennai, Tamilnadu, India as substrate. The graphite sheets were used as electrodes. The results concluded that ferric oxide in combination with microbial fuel cell technology was an efficient method.

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