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Epipremnum aureum (money plant) as cathode candidate in microbial fuel cell treating domestic wastewater

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Abstract

Microbial fuel cells are the bioelectrochemical systems which convert chemical energy of chemical compounds into electricity by catalytic aid of microorganisms. Plant microbial fuel cells are the fuel cells which apply plants in any way to assist electricity generation. In present study, a house plant *Epipremnum aureum* was used in cathodic chamber of two chamber microbial fuel cell designed to treat wastewater. The performance of plant microbial fuel cell was compared with conventional microbial fuel cell. *E. aureum* efficiently provided oxygen in cathode chamber and the resulting plant microbial fuel cell system showed remarkable performance during sunlight. Present system shows an alternative of mechanical aeration or mediator in cathodic chamber.
Keywords: *Epipremnum aureum*, microbial fuel cells, photosynthesis, plant, wastewater treatment.

Introduction

Increasing energy demand and pollution load is a serious problem in modern society. Microbial Fuel Cells (MFCs) can provide promising solution for both of the problems. MFCs are the systems which convert chemical energy of chemical compounds into electricity by catalytic aid of microorganisms (Oh and Logan 2005; Mathuriya and Sharma 2009; Mathuriya 2013). A prototype MFC contains an anodic chamber and a cathodic chamber separated by a cation exchange membrane (PEM) (You et al. 2006). Bacteria metabolize substrate, present in the anodic chamber and during metabolism produce electrons and protons. The electrons are then transferred to the anode surface, and flow across an external circuit to reach to the cathode. The protons migrate towards cathode through membrane to maintain charge neutrality. At cathodes, oxygen is the terminal electron acceptor and both electrons and protons couple with the reduction of oxygen to water (Oh and Logan 2005; Mathuriya and Sharma 2009). Oxygen is preferred as the most sustainable electron acceptor because of its inexhaustible availability and no toxicity. The reduction of oxygen is the most dominant electrochemical factor and it limits the overall process.

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In earlier studies, dissolve oxygen concentration in the cathodic chamber was maintained by mechanical aeration in a dual-cell MFC or by atmospheric air for a single cell MFC, with the cathode directly exposed to air (Pham et al. 2004; Cha et al. 2009; Rodrigo et al. 2010). Other option is to use mediators or catalysts (Oh et al. 2004), which increases material costs and hinder sustainability. Recently some studies applied biocathodes due to their lower cost, efficient performance and better sustainability (He and Angenent 2006; Heijne et al. 2010). Many studies utilised microorganisms as biocatalysts to mediate the reduction of an oxidant either directly or indirectly (Huang et al. 2011; Lovley 2011; Rosenbaum et al. 2011). Another promising option is the use of photosynthetic cathode (Rosenbaum et al. 2010) which is adopted in present study.

Epipremnum aureum, popularly known as money plant in Asian countries, belongs to *Araceae* family is one of the easiest houseplants. It is best grown in bright indirect light or in the area with protection from afternoon sun and can easily propagated from stem cuttings (Sonawane et al. 2011). The money plant is an herbaceous plant and categorized as C4 plant because it has mechanism of converting carbon dioxide (CO_2) during photosynthesis with the release of Oxygen (O_2) (Sharma 2013) . With less consumption of O_2 by the photo respiration releasing CO_2 as other C3 plant do, it uses oxygen only during cellular respiration for photo respiration. So the net production of O_2 by photosynthesis is greater than the consumption of O_2 during respiration with the net increase in oxygen concentration in the atmosphere (Sharma 2013).

The aim of the current study was to continue investigations in the field of cathodic efficiency enhancement by means of providing non mechanical oxygen source to cathode. Here, plant photosynthesis was used as the source of oxygen in the cathodic chamber of MFC (PMFC). *E. aureum* was used as the oxygen provider to the cathodic chamber in two chamber MFC treating domestic wastewater. The PMFC was studied for its sustainability and was compared with conventional MFC (CMFC) to check the effect of plant in MFC.

Materials and Methods

Plant

Stem cutting of *E. aureum* was took from campus garden (Agra, India). *E. aureum* was grown in potable water (1400 ml) at open-air conditions and losses from evaporation and water uptake by the plant was daily compensated.

Wastewater

Domestic wastewater was collected from primary effluent collection tank of college's sewage treatment plant. Sample was transported immediately to institute's laboratory for physicochemical analysis. These parameters include pH, total dissolved solids, total suspended solids, colour, odour, chemical oxygen demand (COD), and biological oxygen demand (BOD). Sample was left undisturbed for 24 h at 4◦C under anaerobic conditions before analysis, to allow settlement of solid contents and kept in a refrigerator at 4◦C, when not in use. The plain wastewater (without any modifications such as addition of nutrients, mediator, and any other microbial inoculum or trace metals) with COD value of 1800 mg l^{-1} was used as the inoculum for all MFC tests. COD value of wastewater was adjusted by diluting wastewater with de-ionized water. Experiments were conducted at 35◦C, pH 7.0 and stagnant condition.

MFC setups

The MFCs were constructed from two plastic jars with total inner volume of 2000 ml and working volume of 1400 ml. The anode and cathode chambers were separated using a pipe frame having 3x3 cm hole. The hole was tightly sealed by Nafion 117. Stainless steel rod (7x2 cm) and graphite rod (7x2 cm) were used as anode and as cathode respectively. The electrodes (both anode and cathode) were connected to copper wire and exposed copper metal surface at the joints, were tightly sealed with non conductive epoxy resin. Both anode and cathode were suspended in their respective chambers. The anodic chamber was filled with 1400 ml domestic wastewater. The anodic chamber was flushed with a mixture of N_2/CO_2 (80:20) for few minutes to maintain anaerobic conditions. In CMFC, cathode chamber was filled with 1400 ml of potable water and pH maintained at 7.0 by 0.5 N NaOH. Natural aeration was allowed to permit oxygen contact with water. In PMFC, cathode chamber was filled with 1400 ml of potable water (pH 7.0) and *E. aureum* was planted in it. No external aeration/pH treatment was provided to cathodic chamber. The loss of water due to evaporation compensated daily and water in cathodic chamber was changed after every 5 days.

MFC operations

After the attachments were completely dried, both the cathode and anode electrodes were soaked in deionised water for 1 h before assembling the MFC. Initially MFCs were inoculated with water containing glucose (10 g l^{-1}) as carbon source. After two cycles of ten days, feed solution containing 50% (v/v) glucose water and 50% (v/v) domestic wastewater sample, inoculated into MFCs separately. After four cycles, feed solution was switched to domestic wastewater sample.

The experimental setup was run in fed-batch mode. The performance of all the MFCs was evaluated by measuring current, current density, potential, open circuit voltage (OCV) and power density along with COD removal efficiency. Constant substrate (COD) removal efficiency and voltage output were considered as indicators to assess the stable performance of the MFC. Electrode fouling was not observed and the electrodes could be used in further experiments without remarkable activity loss. Exhausted feed (350 ml) was replaced with fresh feed under anaerobic condition when remarkable voltage drop was observed. The anode chamber was sparged with N_2/CO_2 (80:20) gas for a period (4 min) to maintain anaerobic microenvironment after every feeding event. A steady increase in OCV output was observed with additional feed. The MFC operated by connecting the anode and cathode electrodes through an external load (500 Ω) until stable voltage was achieved. Then, the circuit was disconnected to monitor the OCV and obtain the polarization and the power density curves. The polarization curves for each batch were obtained after the initial stabilization of OCV.

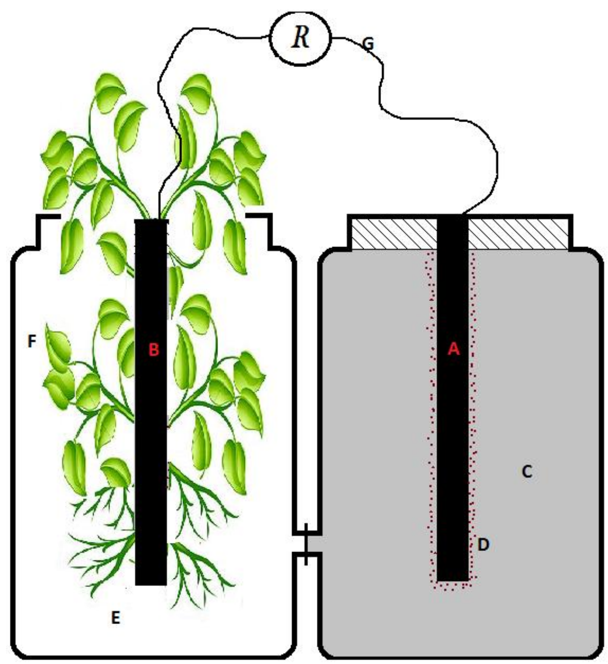

Figure 1: Schematic representation of plant microbial fuel cell. A) Anode, B) Cathode, C) Anode Chamber, D) Microbial biofilm on anode, E) Cathode chamber, F) Money plant, G) External load.

Polarization curve measurement

Polarization curve analysis was done to study overall fuel cell performance under specific operating conditions. For each test run, when the MFCs reached steady state (i.e., constant COD concentration and voltage output), a polarization curve experiment was carried out to determine the power generation at different external resistors, R_{ext} (Ω). The R_{ext} was changed from 100 Ω to 1000 Ω during the measurement and the voltage and current on each R_{ext} was recorded by a digital multimeter (kusam electrical industries, model–108). Various external resistances connected for a few minutes and readings were noted after stabilization. The power output (P) generated was calculated according to $P = V^2/R$ and plotted with respect to R_{ext}.

Chemical oxygen demand (COD) measurement

COD measurements were conducted using standard methods (Greenberg et al. 1992). All samples were filtered through a

0.22 µm (pore diameter) membrane filter prior to COD measurements. COD removal efficiency was calculated as E_{COD}= (COD_{in}–COD_{out}/COD_{in}) x 100%, where COD_{in} is the influent COD and COD_{out} is the effluent COD.

Statistical analyses

All experiments were conducted in triplicate either using separate MFCs or the experiments were repeated at least 3 times, when single MFC was used. The results were presented as average values and all data presented were subject to tests significantly.

Results and discussion

Wastewater characterization

The characteristics of the wastewaters were found as: *pH: 7.9*; *COD: 3031* mg l^{-1}; *BOD: 1621* mg l^{-1}; *TSS: 3944* mg l^{-1}; *VSS concentration: 2172* mg l^{-1}; *TDS: 14638.5* mg l^{-1}; *odour: foul*; and *colour: brownish.* Results indicate that the domestic wastewater is one of the major sources of environment pollutants and can be used in microbial fuel cell due to its high COD value.

System sustainability

To study sustainable MFC operation, for both MFCs polarization data were collected. MFCs readings were taken in two time slots. 1) between 3 to 5 pm (day slot) 2) between 8-9 pm (night slot). The reason for different slots was to check the system sustainability during different light slots. Polarization curves of both MFCs, was plotted as function of current density, potential and power density. Under low resistances, smooth flow of electrons compared was allowed by fuel cell circuit than to higher resistances. These electrons neutralized the protons (H^+) present at the cathode, easily in comparison to higher resistance, which resulted in rapid stabilization of potential at higher resistances. In similar manner, decreasing current generation trend with increase in the resistance was observed in both MFC types and at 1000 Ω relatively less current generation was recorded. This typical current and potential decreasing trend with increase in resistance was found to be in consistence with earlier studies (Oh et al. 2004; Kaewkannetra et al. 2011; Mathuriya 2013), and thus defines typical fuel cell behaviour.

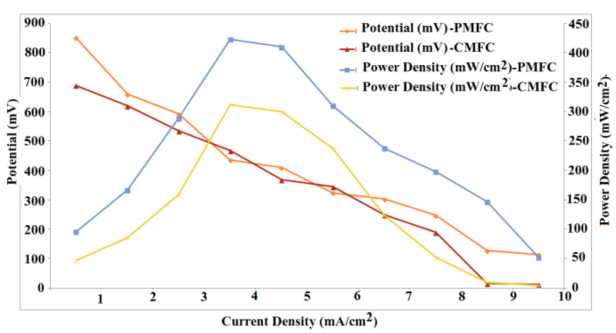

Figure 2a: Polarization data of PMFC and CMFC in day slot.

It is very clear from the figure (2a), that in the day slot comparatively higher performance was found to be associated with PMFC than CMFC. This higher performance may be because of lower cathodic limitations in PMFC. As plants are well known for photosynthesis, and therefore release of oxygen; this higher availability of oxygen utilized more protons which ultimately resulted in higher power output. PMFC showed 1.35 times higher power density (423 mW cm^{-2}) than the power density obtained from CMFC (312 mW cm^{-2}) in day slot. On the other hand, the performance of PMFC was severely hampered during nigh slot (Figure 2b). In night slot PMFC showed only 221 mW cm^{-2} which was 1.42 times lower than that of CMFC data (315 mW cm^{-2}). The reasons are almost clear and are the scarcity of oxygen due to plant respiration process during night. It is notable here that CMFC did not show any remarkable data fluctuation. Although this power fluctuation (during day and night slots), was observed to be consistent in many data recording (data not shown), therefore system sustainability cannot be claimed. In fact it can be state here that it was PMFC trend to release different power output in different light slots. The PMFC trend was found to be more or less similar with other study (Walter et al. 2013).

Electricity generation

After attaining stable start-up, MFC's performance was measured by running the PMFC and CMFC for 30 days under identical conditions. MFCs started electricity generation soon after inoculation and a gradual rise in the OCV was observed, which might be due to readily degradable components in wastewater. Later a drop in OCV was observed which might be associated to exhaustion of these easily degradable substrates, yet the presence of other degradable components supported microbial metabolism and less OCV was observed. When the voltage output dropped remarkably, 50 % of fresh wastewater was replaced with old, into MFCs to maintain the COD of 1800 mg l^{-1}. A linear increase in OCV output was observed with every additional feed.

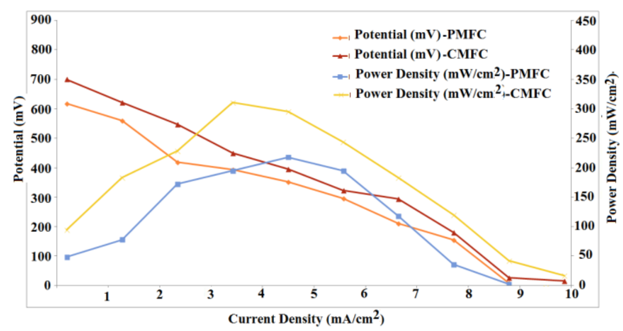

Figure 2b: Polarization data of PMFC and CMFC in night slot.

When compared with CMFC, PMFCs exhibited remarkably higher performance in day slot, while the performance was affected in night slot. It was observed that PMFC continuously exhibited ascending and descending trend during day and night slot respectively. On the other hand, CMFC attained less fluctuated OCV output. Similar with polarization study, the higher OCV of PMFC in day slot is associated with higher cathodic support for proton consumption. The primary reason is the oxygen production in cathodic chamber during day slot (Figure 3).

On the other hand, night slots results showed lower OCV output than that of CMFC. Still the OCV fluctuation had a pattern, which shows the scarcity of free available oxygen in cathodic chamber. Still competitive OCV to CMFC was observed which might be due to the fact that plant utilized available oxygen of environment mainly than which was dissolved in water. Therefore in night slot, PMFCs acted more or less like CMFCs. Meanwhile CMFC exhibited comparatively consistent OCV pattern which is indicative of its typical performance as earlier (Mathuriya 2013).

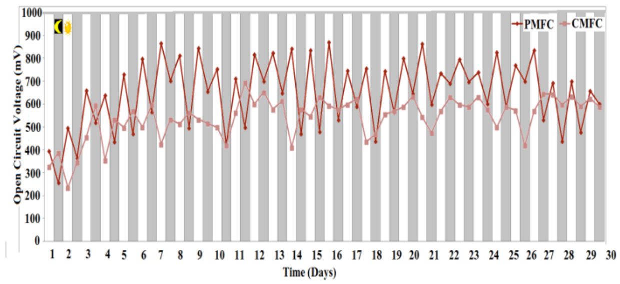

Figure 3: Open Circuit Voltage output of PMFC and CMFC during day and night slots.

Dissolve oxygen (DO) shift

In order to better understand the reason for OCV pattern and behaviour of MFCs, DO was measured for both the setups. Initially in both the systems DO was maintained. DO in PMFC showed a fluctuating pattern which was linear with the OCV generation. DO in cathodic chamber was increased remarkably in day time slot while dropped dramatically in night slot (Figure 4). The assigned reason might be the respiration of plant during night which consumes available oxygen. On the other hand the DO was almost constantly maintained in CMFC, which was also linear to its OCV output. Here it is noted that in both MFCs no external oxygenation was provided and it is clear from figure that plant provided oxygen in day slot. However the Less DO in night slot requires attention and is of further scope of study.

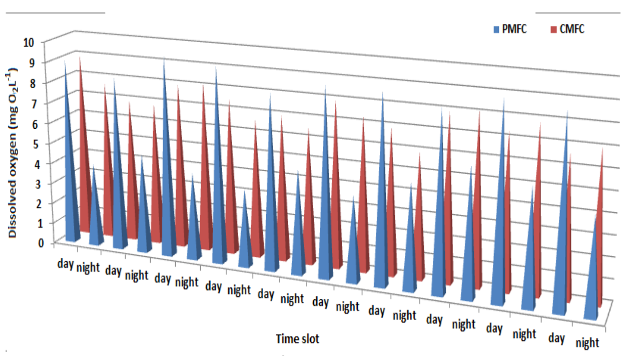

Figure 4: Dissolve oxygen level of PMFC and CMFC in day and night slots.

Wastewater treatment efficiencies

As the aim was to observe the efficiency of MFCs as waste treatment system, during operation, MFCs were continuously monitored for waste (as COD) removal. COD value was fixed at 1800 mg l^{-1} in both MFCs. PMFC and CMFC; both showed their potential for COD removal indicating the function of microflora in metabolizing the waste in wastewater as electron donors. Microbes enriched for 30 days in an MFC removed organic contaminants in wastewater almost completely, with the concomitant generation of electricity. It can be seen from figure 5, that COD removal was higher in PMFC than CMFC.

This study describes the application of plant (*E. aureum*) in cathode chamber. As *E. aureum* has the ability to grow in water and less space, it may be applied in cathode chamber of MFCs. Polarization data showed the system sustainability and electricity generation trend supported candidature of *E. aureum* as cathode candidate. In 30 days of operation, *E. aureum* was observed to be grown in potable water efficiently, without need of mechanical aeration and specific nutrient. Although many earlier studies described appreciable results in algae grown cathodes (Powell et al. 2009;

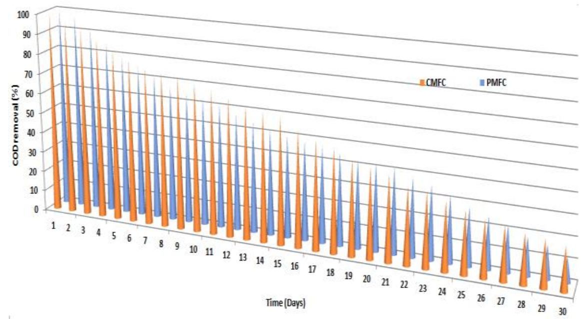

Figure 5: Comparative COD removal efficiencies of PMFC and CMFC.

Candidacy of E. aureum as oxygen provider

Juang et al. 2012; Walter et al. 2013; Wu et al. 2014), yet major limitation with algae grown cathodes is the specific growth media and conditions of algae, which hinders their application in real field applications. Recently Powell et al. (2011) have coupled the algal cathodic half-cell (*Chlorella vulgaris*) to a yeast anodic half-cell. The resulting system attained a power density of 0.95 mW.m^{-2}. Yet the algae were under agitation and 2-hydroxy-p-naphthoquinone (HNQ) was used as a mediator, therefore system bore agitation and mediator cost. In addition, the parallel effects of HNQ cannot be ignored. Present system is waived from any mechanical aeration (as in Rodrigo et al. 2010) and addition of any toxic chemical in cathode chamber, which claims its enhanced sustainability. Moreover, treatment of wastewater in anodic chamber leads to accretion in PMFC's efficiency. Present system was able to run for six months without remarkable maintenance (data not shown).

Conclusion

Present study described the candidacy of applying plant as oxygen provider in cathode chamber of MFC. The resulting PMFC system showed remarkable performance during sunlight and claimed to be viable replacement of toxic and expansive oxidising chemicals and mechanical aeration. However, the PMFC faced many limitations; viz. the performance of PMFC was hindered in night slot. In addition, the long term effect of electrodes on plant growth is unknown. Selection of more suitable plants is also a need. These parameters are needed to be studied in order to claim sustainability of plant cathode in MFCs.

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