Photocurrent Generation through Plant Microbial Fuel Cell by Varying Electrode Materials

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(Received on 6th February 2015, accepted in revised form 23rd July 2015)

Abstract: World is suffering from severe energy crisis and require an efficient renewable energy source.To meet global energy demands, the conservation of renewable energy sources is inevitable. Significant renewable energy can be produced from organic matter that is otherwise considered waste in the form of clean bioelectricity.A less mediator plant microbial fuel cell designed for comparative analysis,power density of two different electrodes; Nickel and Graphite and tested using different local salt marsh grass species Sporobolasarabicus and Cynodondactylon. Both electrodes generated the power density of 23 mW/m^{2}and 10.7 mW/m^{2}respectively withoutusing feed solution.In other experiments using feed solution, the power output was also recorded during the period of two months. The maximum power density recorded as 120 mW/m^2 and 58mW/m^{2}respectively from S. arabicus and C. dactylonspecies. Electrodes coupling with same or different electrode materials checked and current voltage relationship with power recorded before and after the application of plant nutrient solution from 1-8th weeks. Maximum current voltage relationship with power measured around 4-6th week for different electrodes and plant species. Graphite proved best electrode material as compared to Nickel for production of electricity.Two conditions existed in the single chamber configuration, one in which cathode was placed inside the soil near roots to consume oxygen and other was to improve power enhancement using plant nutrient solutions. Ohmic resistance and mass transfer losses could be decreased using membrane-lessconfiguration that in fact makes it cost effective because membrane is the primary cost of plant microbial fuel cell. The main reason for not using membraneis that the concentration of oxygen decreases very much in the depth of water or sediment which reduces the need for a membrane. Moreover, the soil or sediment might filter oxygen, acts as PEM and the redox potential of soil also decreases.

Key Words: Comparative analysis, Nickel, Graphite, PMFC, *S. arabicus, C. dactylon*.

Introduction

Microbial fuel cells do function as biocatalysts and generate electricity using microorganisms. In this way, biochemical energy of substrate can be converted into bioelectricity. A majority of microorganisms have tendency to transfer electrons produced from the metabolism of organic debris to the anode. These are abundant in freshwater, wastewater, marine, soil sediments and also in activated sludge.Plant microbial fuel cell is an off shoot of microbial fuel cell that can convert solar energy into green electricity by simply harvesting energy through the anaerobic degradation of organic matter and biomass via bacteria.Living plants and bacterial species are used to generate electricity in plant microbial fuel cell [1]. Plants, instead of consuming nutrients for photosynthesis,release certain nutrients compounds into the soil through their roots, mostly in the form of exudates, lysates, and other secretions asrhizodeposits. Bacteria present in the soil near plant roots degrade the rhizodeposits. The P-MFC generates electricity through the anaerobic degradation of these rhizodeposits and biomass present in the soil. About 20% of the carbohydrates produced by photosynthesis are converted into rhizodeposites [2].In plant microbial fuel cell; the microorganisms present in the soil anaerobically degrade small carbohydrates and sugars and release electrons to produce electricity [3].During photosynthesis, the carbon dioxide is utilized by plants through the leaves and is transformed into small carbohydrate. Protons, electrons and carbon dioxide are produced as results of microbial electrons are used for the production of electricity as in the microbial fuel cell [4].Soil provides anaerobic substrate containing both aerobic and anaerobic microorganisms. The aerobic bacteria filter oxygen and facilitate anaerobic bacteria to donate electrons to anode [5]. Marine sediment is the nutrient rich medium. In this fuel cell, anode is placed inside of sediment and cathode on soil or water surface. Power is generated by the oxidation of sulphides and organic matter although; it has some difficulties regarding its implementation on marine sediments.In this microbial fuel cell, Photosynthetic microorganisms like cyanophyta and chlorophyaetic make a biofilm on the surface of anode. It has a tendency to donate electrons as well as to produce organic metabolites of photosynthesis [6].There are

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two major configurations of PMFCs, single chamber and double chamber.Double chamber PMFC consists of two chambers, anode and cathode chamber. They are usually separated by a proton exchange membrane which may be of Na ion [7] or a typical salt bridge. The choice of membrane is important in this configuration that allows the selective transport of protons and does not transport oxygen or substrate through it from anode to cathode. The presence of membrane is not necessary in single chamber configuration and the cathode is placed on the overlying surface of substrate to utilize atmospheric oxygen or air. Whenever, oxygen is used as electron accepter, large amount of power generation or current density can be obtained and by exposing cathode to air [8]. The membrane less single chamber configuration might be cost effective with less mass transfer and ohmi closses.The microbial fuel cell operation requires low temperature as compared to high temperature molten carbonate fuel cells and expensive hydrogen fuel cell [9].In these types of fuel cells, power efficiency could be above 60% because the exudates are low molecular weight carbohydrates or sugars. The process does not imply on Carnot cycle because there is no heat loss or gain takes place during the process [10]. With the help of aquatic plants and algae, green power stations can be designed [11]. Such types of green power plants can supplement already existing source like wind turbines and can serve as auxiliary source [12].Their global implementation will produce green electricity while reducing harmful greenhouse gases. They can prove an efficient source of energy in rural areas.

Experimental

Collection of Plants

Salt marsh grass species *Sporobolasarabicus* and *Cynodondactylon* were collected from Kallarkahar Lake near salt range of Pakistan.

Alongwith underground root deposit biomass containing soil, power generation could be increased by selecting an appropriate plant. These species were selected due to their stable behavior toward solution conductivities being salt marsh species and ability to tolerate waterlogged conditions. Both of them follow C_4 photosynthetic pathway and were perennial species reducing the expected cost of installation.

Preparation of Electrodes

Two types of materials were used as electrodes, Nickel and Graphite. Graphite rod electrodes of (10 × 0.5 cm) were used as anode and cathode.

Similarly, a (1cm × 1cm) and 1mm thick Nickel plate supported on a brass rod was used as cathode in other two plants.

Plant Nutrient Solution

A plant nutrient solution was made by dissolving the appropriate quantities of essential micro and macro nutrients for plants in de-mineralized water. These were either in mg/L or g/L Table-1.

Table-1: List of micro and macro nutrients for making Plant nutrient solution

S. N.	Chemicals	S. N.	Chemicals
1	5gNaCl	9	2 mg H_3BO_3
2	0.40g K_2HPO_4	10	100 mg $MnSO_4$
3	0.5g KCl	11	2 mg $ZnCl_2$
4	0.30g Glucose	12	2.5 mg $NiCl_2$. 6 H_2O
5	2g $NaHCO_3$	13	1.5 mg $CoCl_2$. $6H_2O$
6	0.05g $CaCl_2$	14	0.5 mg Na_2MoO_4. $2H_2O$
7	0.25g NH_4Cl	15	1.5 mg $CuCl_2$
8	0.5g $MgSO_4$. 7 H_2O		

Magnesium and Ferric were used in the form of Sulphate compounds because sulphate probably had less influence on electrochemically active bacteria and had a positive effect on power output. To increase solution conductivity, NaCl solution was added to the soil. Being salt marsh species, these plants could withstand highly saline environment which positively affected the conductivity and columbic efficiency [13].

Substrate

Soil was used as substrate in this experiment. Being abundant nutrient rich medium, soil had a wide variety of microorganisms and root deposits like lysates, exudates, dead organic debris, biomass, mucilage and gases [13]. Among them, amino acids and carbohydrates were vulnerable to microorganisms and probably took the responsibility for electron donation [13].

Electron Accepter

Oxygen served as electron accepter in our experiment, because cathode was placed overlying on the surface of soil to utilize atmospheric oxygen [14]. Air exposed cathode generated the exceptional power density due to the abundant availability of oxygen. Current production depended on directly upon the availability of pure oxygen on cathode which might be produced by the photosynthetic biofilm and atmospheric oxygen could also be utilized [15]. Oxygen produced by photosynthesis could be four times greater than oxygen produced by conventional aeration method. Different methods had been used to maintain the availability of oxygen at cathode either by providing air bubbles into the catholyte or using an air exposed cathode in addition with the photosynthetic oxygen produced by the biofilm. The process of aeration in the form of air bubbles required energy. So this could not be implemented successfully. The photosynthetic biofilm on either side of cathode aids to overcome the limitation of low concentration of oxygen in air or water exposing cathode [16].

Single Chamber Vertical Configuration

To improve the efficiency of the PMFC, vertical configuration was selected because it facilitated the anaerobic environment which is necessary for better anode performance. For this purpose, a 2.5 cm sediment layer was provided on the outer surface of anode which had a positive influence on the current production. It had a positive effect on the anode performance because it limits the access of oxygen at anode during photosynthetic period. This strategy was confirmed experimentally by [17] He *et al.,* (2006). He used 0.5 cm thick sediment layer and found a decreased current production which may be due to the presence of oxygen during normal day times. Similarly, Malik *et al.,*(2009) [18] used a sediment layer of 1.2 cm thickness and observed the increased anode performance. AsCommault*et al.,* (2014) [19] created a 2cm sediment layer on anode surface and observed the enhancement of current output and also the positive influence of light. Therefore, it might be concluded that the anode surface must be covered with a sediment layer of > 0.5 cm to minimize or eliminate photosynthesis in the sediment and also the generation of oxygen in the vicinity of anode. In lieu of this, anode containing portion of the chamber was wrapped with aluminum foil to prevent photosynthesis and oxygen production in the sediment.

Microbial Community on the Electrodes

Soil has a wide variety of microbial strains naturally present in it. Flooded soil was added to make a mixed culture of microbes. Among there was electricigenic bacteria required for MFC operation. Although Nickel and Graphite electrodes did not have any mediator or catalyst but it was covered with mixed strains of micro algae and microorganisms.

Experimental Procedure

Four plant microbial fuel cells were constructed. Each of them consisted of a PVC plastic container of height 25 cm and a diameter of 10 cm. They were based on single chamber configuration. A graphite anode of (10cm × 0.5cm) was placed inside the soil near plant roots to acquire anaerobic conditions in two P-MFCs containing *cynodon* and *sporobolas* species. Two similar graphite rod cathodes were placed on overlying surface of soil or water to utilize oxygen as electron accepter. Experimental setup of plants and electrodes is given in Fig. 1 and its schematic diagram is given in Fig. 2.

Fig. 1: Experimental set of P-MFC.

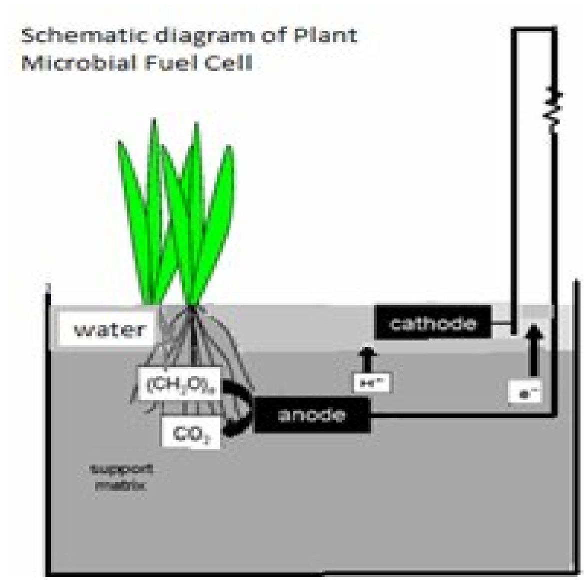
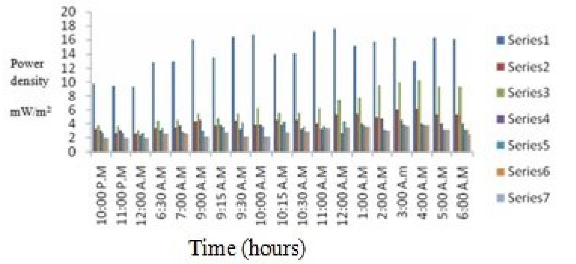


Fig. 2: Schematic diagram of P-MFC.

Similarly, in other two plant-MFCs holding *sporobolas* and *cynodon* plants, graphite anodes of (10cm × 0.5cm) were buried inside near plant roots to consume root deposits as fuel. Nickel electrodes of (1cm × 1cm) and 1mm in thickness were used as cathodes in these two fuel cells. An external fixed resistance of 800 Ω was connected with anode and cathode and by using copper wires, an electrical circuit was made. The illumination period was 14h/day. The temperature was recorded between 22-28ºC, which was sufficient for growth of plants and microorganisms.



Series 1 Monday
Series 2 Tuesday
Series 3 Wednesday
Series 4 Thursday
Series 5 Friday
Series 6 Saturday
Series 7 Sunday

Fig. 3: Power Generation in weekly days from Plant Microbial Fuel Cell containing *Cynodondactylon* and Graphite electrodes

P-MFC Measurements and Operation

Current and voltage was measured across the external resistor connected between cathode and anode. A Digital multimeter (DT-830B) was used to measure the current and voltage of plant-MFC at the start of the experiment during day and night circadian cycles. The power output of all the plant-MFCs was measured before the application of nutrient solution uptoaweek. The variation of power generation between two salt marsh grass species was also measured.

After one week, the nutrient solution was fed to the plants at a flow rate of 1µL/s to 5µL/s. The quantity of the solution was gradually increased due to the growth of plants. The power output was again measured after the application of feed solution. After 3 days of application of nutrient solution, P-MFCs gradually increased their power output. Power density was recorded upto 2 months.

Two *Sporobolas* plants with a fresh weight 0f 474 grams was planted in a PVC container of 25 cm height and a diameter of 10 cm along with the root deposit biomass containing soil. 20 grams of flooded soil was mixed to make a mixed microbial culture. In PMFC1, a graphite electrode of (10×0.5cm) was buried inside the soil near plant roots in anaerobic conditions. For cathode, a similar graphite electrode was placed on the surface of substrate to use oxygen. In PMFC2, a similar graphite electrode of (10×0.5cm) was submerged inside the soil near roots as anode. Unlike PMFC1, a Nickel cathode was used. It was (1cm×1cm) and 1mm in thickness supported on a brass rod of 5cm. Both of the PMFCs were wrapped with aluminum foil to avoid the production of algal oxygen by photosynthesis in soil. Two plant microbial fuel cells with similar plants but with different electrode materials was prepared to study the behavior of different electrode materials to see whether a combination of different electrode materials could prove helpful or not as compared to similar type of graphite electrodes. In the same way, in two similar sized PVC containers, *Cynodondactylon* plants with a total fresh weight of 376 grams and 422 grams respectively with underground rhizodeposits containing soil was planted. Similar strategy of varying electrodes was applied in these PMFC 3 and 4 which were also covered with aluminum foil. The difference of current and voltage between PMFC 1 and 2 holding same plants but different electrodes was determined with the help of digital multi meter. Similarly, voltage and current variation between PMFC 3 and 4 was tested containing *Cynodon* plants. These calculations were carried out during the first week of experiment and no any kind of plant feed solution was used. Likewise, to study the impact of day and night circadian rhythm or diurnal cycle on PMFC performance, power and current output was measured during dark reaction duration of plants with a variation of 1 hour at 10:00 PM, 11:00 PM and 12:00 PM. It was again measured at the start of sunlight exposure of plant microbial fuel cells at a difference of half an hour from 6:30 AM to 7:00 AM. Power output was measured at an interval of 15 minutes from 9:15 to 10:30. Time interval was increased and the power density was measured after a gap of 1 hour consecutively from 11:00 AM to 6:00.

In the second step, the power density was determined after the application of plant nutrient solution. The amount of feed solution was increased gradually from 1µL to 5µL due to the increase in plant growth. Along with plant nutrient solution, salt solution of 5 gram/L was fed to the plants to maintain saline environment. A tremendous increase in current generation was observed. Now again bioelectricity production was observed for all plant microbial fuel cells comparatively and minimum and maximum power output was recorded separately up to 2 months. Growth of the plants was carefully monitored since at the start of the experiment and an exceptional shoot: stem length was noticed after the application of plant nutrient solution accompanied by leaf and root elongation. Since in situ non-destructive bioelectricity production was made possible. At the end of the experiment, all plant microbial fuel cells were connected in series and their power density was measured collectively which was slightly less than the theoretically estimated power density of all PMFCs.

Results and Discussion

The stable current production was first obtained by microbial fuel cell containing *sporobolasarabicus* plant with graphite electrodes. It generated the maximum power density of 23 mW/m^2 during the first week of experiment. The other sporobolas plant containing microbial fuel cell in combination with Nickel and graphite gave maximum of 10.7 mW/m^2 and a minimum of 2.24 mW/m^2. Its lower output as compared to the first one can be attributed to the presence of metallic cathode which offers high metallic resistance.

Similarly, *Cynodon*species with graphite anode and cathode generated the maximum power density of 9.2 mW/m^2 during the first week and a minimum of 1.85 mW/m^2. The second microbial fuel cell with *Cynodondactylon* in combination of Nickel and graphite electrodes produced the lower power output in comparison with later. The maximum reported power output by this plant microbial fuel cell was 5.42 mW/m^2 and the minimum of 1.26 mW/m^2. This power density was measured before the application of plant nutrient solution. After the application of nutrient solution, the highest power density was recorded by the PMFC having sporobolas plant and graphite electrodes. It was 120mW/m^2. The lowest 82.44 mW/m^2 was given by the same PMFC. Another PMFC generated the power density of 37 mW/m^2 using *Sporobolas* plant and graphite and Nickel electrodes. Similarly, PMFC using another plant *Cynodondactylon* and Graphite electrodes gave a maximum of 58.65 and a minimum of 41.58mW/m^2. The similar plant with Nickel and Graphite electrodes produced the lower output as compared to the first one.

Power Generation in weekly days from Plant Microbial Fuel Cell containing *Cynodondactylon* and Graphite electrodes revealed that power generation increased progressively after three days and this power density was at maximum on Wednesday (Fig. 2).

Power generation in weekly days from plant microbial fuel cell containing *Cynodondactylon* and Graphite and Nickel electrodes generated maximum power density on the day of Wednesday (Fig. 4).

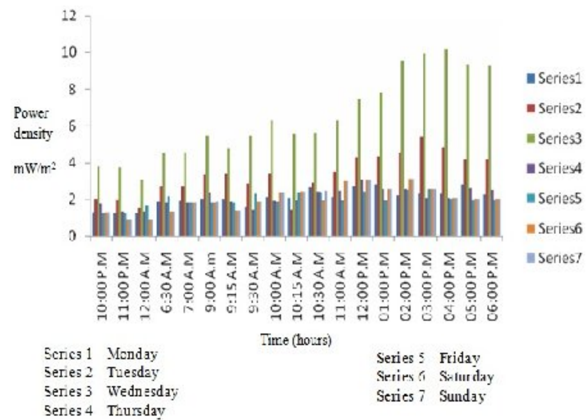


Fig. 4: Power Generation in weekly days from Plant Microbial Fuel Cell containing *Cynodondactylon* and Graphite and Nickel electrodes.

Similarly, Power Generation in weekly days from plant microbial fuel cell containing *Sporobolasarabicus* and Graphite electrodes. In this microbial fuel cell the highest power output was measured on Saturday (Fig. 5).

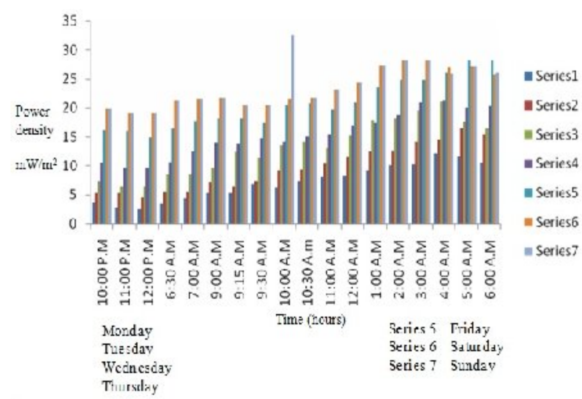


Fig. 5: Power Generation in weekly days from Plant Microbial Fuel Cell containing *Sporobolasarabicus and Graphite electrodes.*

Power generation in weekly days from plant microbial fuel cell containing *Sporobolasarabicus* and Graphite and Nickel electrodes was observed and it revealed that *S. arabicus* plant microbial fuel cell generated the maximum power density on Saturday (Fig. 6).

All of these measurements took before the application of plant nutrient solution upto a week and these plant microbial fuel cells gradually increased the power production as the amount of biomass and rhizo deposits had increased.

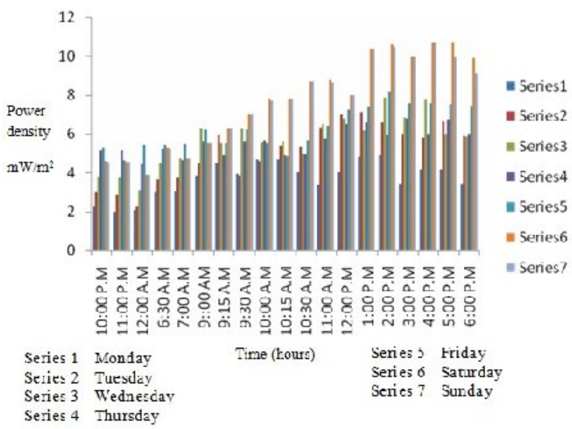


Fig. 6: Power Generation in weekly days from Plant Microbial Fuel Cell containing *Sporobolasarabicus Graphite* and Nickel electrodes.

After that, the plant nutrient solution fed to the plants in minute quantities and its quantity gradually enhanced after one week due to the growth of plants. Similarly, the power output was measured during two months of experiment and the maximum and minimum values reported as indicated (Fig. 7-10) Minimum and maximum values I-V relationship up to two months using *Cynodondactylon* and Graphite electrodes revealed maximum current voltage relation at period of sixth week (Fig 7). Minimum and maximum values of I-V relationship up to two months using *Sporobolasarabicus* with Graphite electrodes indicated maximum I-V relationship at period of fifth and sixth week (Fig 8). Minimum and maximum values of I-V relationship up to two months using *Cynodondactylon*with Nickel and Graphite electrodes showed maximum I-V relationship at period of fifth week (Fig 9). Minimum and maximum values of I-V relationship up to two months using *Cynodondactylon*with Nickel and Graphite electrodes revealed maximum current voltage relationship at 4^{th} to 6^{th} week (Fig 10).

Impact of Circadian Rhythm and Dark Reactions

The power density was measured during the day and night circadian cycles and a sharp fluctuation was noticed. Because the oxygen concentration was too low during dark reactions of plants, a swift decline of current was observed but it was gradually increased as the rate of photosynthesis and oxygen increased during day times. Oxygen served as electron accepter on cathode side in this mechanism. The increased concentration of oxygen had tremendously increased the current outputs. The low concentration of oxygen during dark reactions adversely affected the current and power density.

Role of Electrode Materials

Electrode material was a limiting factor in power generation. Graphite electrodes proved most efficient electrodes in this experiment due to low internal resistance while metallic electrodes were not proved as much efficient due to high metallic resistance.

Effect of Plant Nutrient Medium

In the second step, a plant nutrient solution containing all micro and macro nutrients essential for plant was prepared and applied to the plants in minute quantities. The quantity of solution was gradually increased due to increasing growth of plants. The current and power outputs were measured by changing the external resistance. It was found that the current output was more than at low resistance. The highest power density was given by the microbial fuel cell containing *Sporobolasarabicus* plant using graphite electrodes. It was 120 mW/m^2, the lowest output was given by this cell (82.44 mW/m^2). Similar type of plant with Nickel and graphite electrodes produced the maximum power density of 37 mW/m^2.

The third microbial fuel cell with Cynodondactylon and graphite electrodes generated the maximum output of 58.65 mW/m^2 and the minimum was obtained as 41.58 mW/m^2. The fourth one with same plant and different electrode produced the highest of 29.2mW/m^2 and a lowest of 19.9 mW/m^2. In all these plant microbial fuel cells, a sharp increase of in columbic efficiency and reduction of internal resistance was observed that simultaneously led to the highest power density of 120 mW/m^2.

Cost Effectiveness of Single Chamber Membrane-Less Configuration

For plant microbial fuel cell, membrane was the main cost so this single chamber membrane-less configuration made it cost effective [20]. To decrease the concentration of oxygen and provided efficient anaerobic conditions, single chamber configuration was adopted and this had reduced the need for a membrane [21]. Two conditions existed in the single chamber configuration, one in which cathode was placed inside the soil near roots to consume oxygen released from roots. Ohmic resistance and mass transfer losses could be decreased using membrane-less configuration that in fact makes it cost effective due tosoil acts proton exchange membrane which reduces the expenses of proton exchange membrane (PEM) [22].

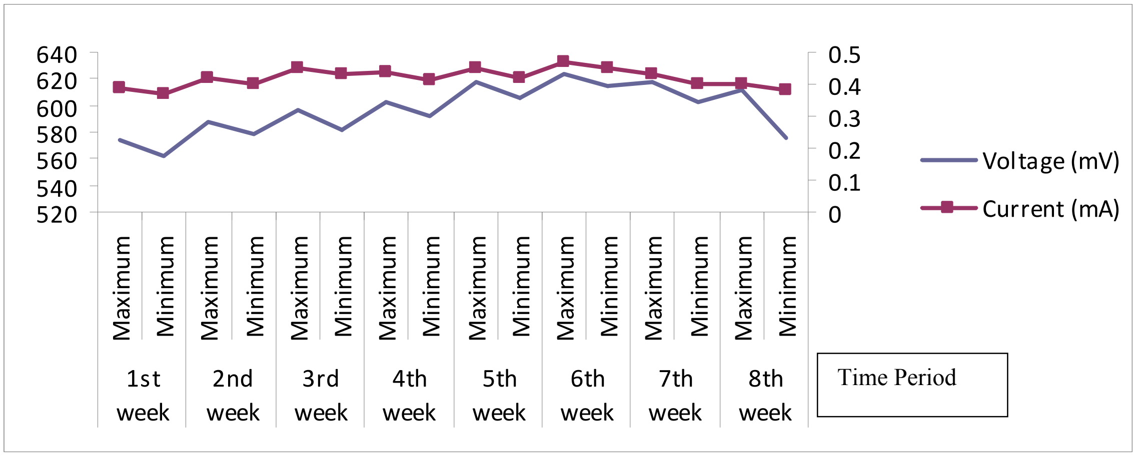


Fig. 7: Minimum and maximum values I-V relationship up to two months using *Cynodondactylon* and Graphite electrodes.

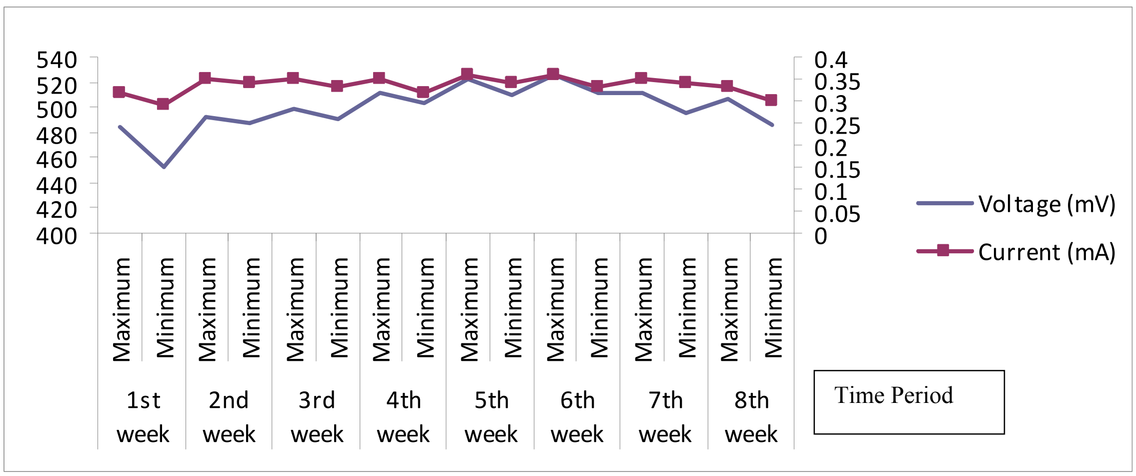


Fig. 8: Minimum and maximum values of I-V relationship up to two months using *Sporobolasarabicus* with Graphite electrodes.

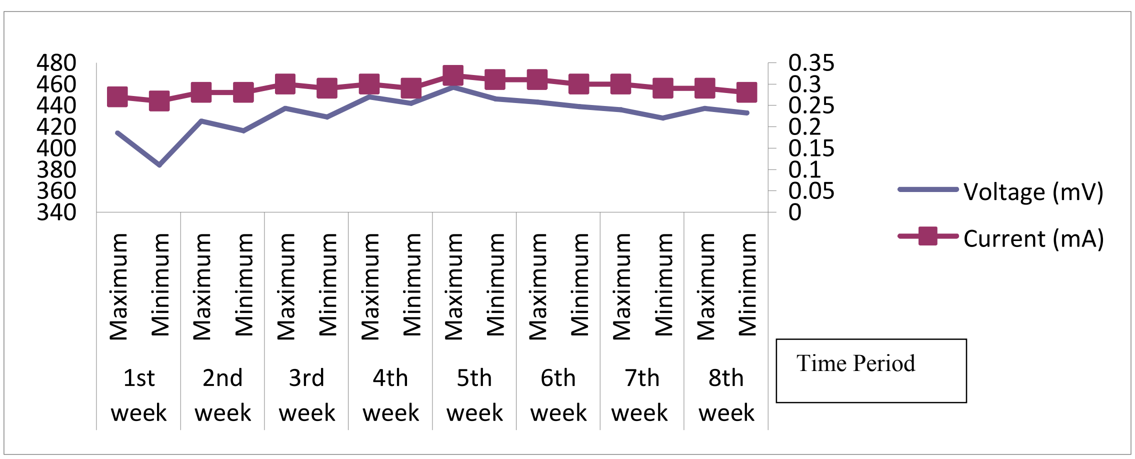


Fig. 9: Minimum and maximum values of I-V relationship up to two months using *Cynodondactylon*with Nickel and Graphite electrodes

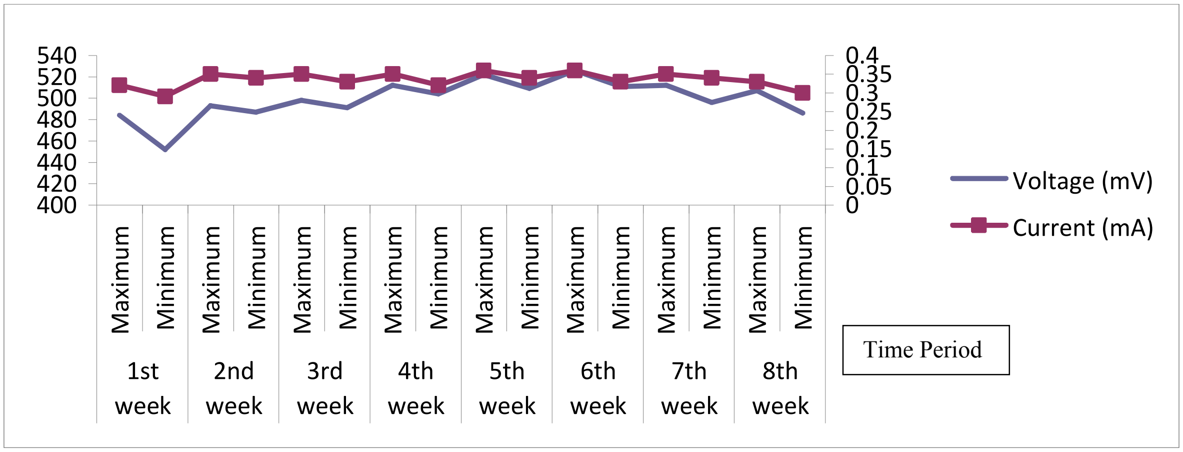


Fig. 10: Minimum and maximum values of I-V relationship up to two months using *Sporobolasarabicus* with Nickel and Graphite electrodes.

Role of Photosynthetic Pathway

Photosynthetic pathway played an important role in power efficiency of plant microbial fuel cell. For C_3 and C_4 plants, the maximum efficiency of photosynthesis is estimated to be 4.6 and 6.0% respectively. This is theoretical estimation [23]. Because theoretical limit was always less than actual one, so these estimations could be hardly achieved. That's why, 3.2 and 4.2 were the limits of photosynthetic efficiency for C_3 and C_4 plants simultaneously [24]. Since, *sporobolas* and *cynodon* plants followed C_4 photosynthetic pathway, so their photosynthetic efficiency limits were 4.2% which corresponded to high power and current density. C_4 photosynthetic pathway was more efficient than C_3.

Possibility of Hydrogen Production

Now days, hydrogen is gaining popularity as alternative fuel. Hydrogen gas can be generated from the proper modification of microbial fuel cell. An external energy source is applied to the microbial fuel cell for the complete conversion of organic matter into hydrogen and CO_2 [25]. An external electric supply of 0.25 volts was supplemented by keeping the anode and cathode in anaerobic condition in a standard MFC to produce H_2 gas [26]. The purpose to supply voltage externally is that the pure hydrogen gas can be collected at cathode where electrons and protons recombine as hydrogen gas [27]. It has been found experimentally that almost 90% of electrons and protons produced from bacteria at the anode can be converted into hydrogen gas [28]. This voltage of 0.25 V is much less than the expensive water hydrolysis which theoretically need 1.8 volts of electricity to form hydrogen.

Although hydrogen gas can be produced from plant microbial fuel cell by supplying an external source of electricity, since an abundant organic matter is present to produce H_2 but its implementation is not as successful because the growth of plants will be ceased by keeping it in the complete absence of oxygen which is compulsory for MFC producing hydrogen. However in the absence of plant, hydrogen can be produced in a conventional microbial electrolysis cell.

In early twentieth century, it was thought that microorganisms could be used to produce electricity in microbial fuel cells. After that in 1911, M. Potter did some basic work on this idea [24]. Researcher used *E. Coli* to generate electricity. After that, in 1931, Barnet Cohin was able to design a microbial fuel cell. He connected a number of microbial fuel cells in series and produced a current of 2 mili-amperes and a voltage of more than 35 volts. [29]. Later on, the work on microbial fuel cells progressed slowly by many scientists. It has been found recently in the last few years that organic matter can also be used in a microbial fuel cell to generate electricity through degradation by microorganisms. Just like a conventional fuel cell, microbial fuel cell has anode and cathode compartment and are connected to each other internally through a proton exchange membrane to complete the circuit. But in a sediment type plant microbial fuel cell, membrane is not necessary due to the decreasing oxygen gradient. A prototype MFC was designed in 2007 by the researchers of university of Queensland Australia for the treatment of brewing wastewater to produce electricity, carbon dioxide and clean water. Now days, MFCs found their excellent use for the application of wastewater treatment. There are two basic types of microbial fuel cells, mediator and mediator free microbial fuel cells. Certain mediator compounds are often used to facilitate electron transfer in the MFCs where electrochemically active bacteria are absent. But these mediators are toxic and expensive. In mediator-less microbial fuel cells electrochemically active microorganisms are present to facilitate electron transfer to the electrodes. Shewanellaputrefacience is found among electrochemically active bacteria and many others are included in this category like Geobactorsulferreducence [30]. Certain electro-chemically active bacteria have pilli on their outer surface or electron transferring protiens like cytochromes and have the ability to transfer electron through these structures, so they do not require mediating compounds. Mediator-less MFCs has wide applications and can be used to generate electricity from certain plants. This modification is called plant microbial fuel cell. Until now, different plants have been used in plant microbial fuel cells including many grasses, rice plant, blue green algae, lupines and tomatoes. Microbial fuel cells are also useful for treating wastewater. Similarly, sediment microbial fuel cell is also an example of mediator-less fuel cells and it uses soil as nutrient rich medium which have hundreds of strains of electricigenic bacteria useful for bioelectricity production [27]. It is well said that could electricity be dirt cheap. In this fuel cell, organic debris is degraded by bacteria through anaerobic respiration. Despite of having organic matter in the soil, plant microbial fuel cell has an additional advantage of having plant root deposits called rhizodeposits which they release into the soil through their roots. Electricity production can be increased many folds by the application of proper design and selection of an appropriate plant species. Plant microbial fuel cell is a photo microbial fuel cell that carries out the transformation of solar energy into electrical energy by consuming rhizodeposits as fuel. There are various factors that affect the performance and efficiency of fuel cell, including the selection of most suitable plants, highly efficient electrode materials and to maintain the PH of the system so as to optimize the microbial activity and simultaneously decrease the Ohmic losses and internal resistances. Cost effectiveness is the major limiting factor while designing of plant microbial fuel cell. The PMFC efficiency could be increased many folds while maintaining the saline aquatic environment. Considerable current production could be achieved by fulfilling these parameters that directly or indirectly affect the performance of plant-MFC. At the start of the experiment, we used the terrestrial broad leaved plant species in plant-MFC. Nickel electrodes were tested to study the electrical properties of plant-MFC, but they did not give the substantial amount of current. Although, they produced the significant voltagebut very low current. In the second experiment, two different salt marsh grass species were tested and their output was studied by using graphite electrodes solely and also by using a combination of Nickel and Graphite. Four PMFCs were constructed. Two of them are bearing the same plant. One of them contained the combination of Nickel and graphite and the second one had the graphite electrodes only. Similar strategy was applied on the others two having *Cynodondactylon*. The first two plant-MFCs had *Sporobolasarabicus*. The fuel cell with *Sporobolasarabicus*and whole graphite system gave the stable current production. Thus Graphite proved the best electrode material as compared to Nickel. In this research, two different plant species were used: *Sporobolasarabicus* and *Cynodondactylon*. These two species were salt marsh species and tended to grow and survive under waterlogged environment fulfilling the criteria for PMFC. In earlier studies, *Spartinaanglica* was studied and tested due to its saline tolerance and was found suitable. The PMFCs performances were determined comparatively without applying nutrient feed solution for a week. The power output was monitored during day and night circadian cycles. These reflected sharp fluctuations due to different factors. Oxygen deficiency was the major limiting factor of decreasing current and voltage during dark reactions. Highest power output was reported during day times when the photosynthesis was at maximum and oxygen was abundant during first week of experiment. The maximum power density of 23 mW/m^2 was observed from the *sporobolas* plant containing microbial fuel cell with graphite electrode system. The second PMFC with similar plant and mix electrode system generated a maximum of 10.7 m W/m^2 and the lower being 2.24 m W/m^2. The lower output of second PMFC might be due to metallic electrode. This factor was further confirmed by constructing two other microbial fuel cells. The salt marsh grass species *cynodondactylon* was used in these two PMFCs. One bearing the whole graphite electrode system, while the other holding Nickel-Graphite system. There voltage and current output was measured up to a week without the application of nutrient feed solution. The PMFC with graphite electrodes generated a maximum 9.2 m W/m^2 and a minimum of 1.85 m W/m^2. The other microbial fuel cell with nickel cathode generated 5.42 m W/m^2 as highest output and 1.26 m W/m^2 as lowest one. In all these plant microbial fuel cells, the current and voltage values measured during both night and day times. It was first noticed at 10:00 and 11:00 PM and

12:00 AM. These three readings were very much close to each other. The amount of oxygen was in a narrow range due to lack of photosynthesis. After that the power output was again measured at 6:30 AM, 7:00 AM and 9:00 AM. After 9:00 AM, the current and voltage was again measured consecutively after an interval of 15 minutes up to 10:30 AM. The time interval was increased up to 1 hour from 11:00 to 5:00 PM. The current density was at maximum from 6:30 to 3:00 PM.

Conclusion

The plant microbial fuel cell with Graphite electrodes and *cynodondactylon* gave the maximum power density fig as compared to the PMFC with Nickel and Graphite electrodes fig. The PMFC with graphite electrodes and cynodon plant gave the highest output at the start of the experiment, but this increased output was not continuous because the release of rhizodeposits was not so regular or not sufficient as it was in other species *Sporobolasarabicus*. The PMFC with *Sporobolasarabicus* and Graphite electrodes gave exceptional power output continuously fig. but the plant microbial fuel cell with Nickel and Graphite electrodes generated the power density slightly less than those with whole Graphite system. The grass species *Sporobolasarabicus* generated the maximum power output with Graphite system as compared to the *cynodon* species. Due to this reason, we may conclude that *Sporobolasarabicus* a salt marsh species has sufficient release of rhizodeposits to aid electron transport. Secondly, the electrode materials plays vital role in the performance of plant microbial fuel cell. Metallic electrodes are not as efficient as Graphite. The plant microbial fuel cells with Graphite system generated the maximum power density as compared to the Nickel electrodes in combination with Graphite. Moreover, the photoperiod is also a limiting factor, the current output increased during day times when oxygen supply was sufficient as electron accepter as a result of photosynthesis. There was a sharp decline of current and power density during night when plants mostly undergo dark reactions.

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