AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Increasing the Energy Output from Living-plants Fuel Cells with Natural Photosynthesis.

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ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form
8 July 2014
Accepted 14 September 2014
Available online 27 September 2014

Keywords:
Living plants, living-plant fuel cell, weak energy source, photosynthesis

ABSTRACT

In the earlierstudy, a source of energy (living plants) has been proven able to harvest electricity by embedding a pair of different metal electrodes into them. This source of energy is termed as Living-plants Fuel Cells (LFCs) that convert chemical energy to electrical energy through the electrochemical reaction. In order to increase the harvesting of electricity from living plants, a new strategy to employ efficiently both solar energy and chemical energy simultaneously in an environmental-friendly manner is introduced. By usingthe sun as the energy source and takingnatural photosynthesis into account, an increase in energy output is observed. The current responses under artificial illumination of 200W m^{-2} using desk lamp, and under natural sunlight are investigated and compared to in the dark environment. It was found that when the artificial illumination is switched on, there is an increase between 10-20% in harvested electrical current output. The electrical current output is further increased under natural sunlight with the increment of 43%, which is corresponding to the increment of 111% in harvested electrical power. The current output increment is hypothesized to be associated with photosynthesis process. The mechanism of energy production of LFC based on electrochemistry and photosynthesis process is modeled and illustrated.

To Cite This Article: Choo Ying Ying and Jedol Dayou, Increasing the Energy Output from Living-plants Fuel Cells with Natural Photosynthesis. ***Adv. Environ. Biol., 8(14),*** *20-23, 2014*

INTRODUCTION

Plant-based energy generation is emerging as a new method that harvesting electrical energy from living plants. A team of electrical engineers from the University of Washington had devised a voltage boost converter for energy harvesting from trees [1]. This development has the potential to provide an unlimited supply of clean energy [2]. These have been extensively investigated to generate cleaner, inexhaustible, abundant and environmentally friendly power. The environmental concern has greatly increased the interests of switching to renewable energy sources [3-6]. The safety concerns of fossil fuels not existing in the plant-based energy source.There is always a need to find out alternatives in a more environmentally friendly way.

Following to this, researchers taking photosynthetic processes into consideration as the abundance of solar energy.Researchers have developed a way to manipulate the proteins contained in the thylakoids and interrupt the pathway along which electrons flow before they are used to make sugars [7-8]. Ryu et.al inserted a nanoscale and attempted to probe photosynthesis with their main focus on energy extraction [8]. Sunlight transformation into bioelectricity based on photosynthesis process in a living plant for observing and understanding photosynthesis kinetics also discussed by Flexer and Mano [9].Even though the electrical output directly from plants is stillunpretentious, it is a promising and certainly worth exploring further [10].

In the previous work, some fundamental procedures to harvest the weak electricity from living plants which consist detail of harvester selection, type of plants and with potential application was presented [11]. The electrochemistry process is believed to be responsible for the mechanism of the energy production in their living plant cell, which is termed as Living-Plant Fuel Cells or LFCs [12].The power output of LFCs is low, thus to integrate and increase the energy output of LFCs, both electrochemical and photosynthetic are involved to generate practical electricity. It is hypothesized that photosynthesis process probably increases the power production of plant-based energy source. In this paper, the energy output under artificial and natural sunlight

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illumination were investigated. The paper is also intended to model the energy production in LFCs based on electrochemistry and photosynthesis mechanisms.

Materials And Methodology:

This section described thedetailed procedures of experimental set-up. The energy source of LFC used is the aloe Vera plant by embedding a pair of electrode (copper and zinc) into it. The measurement is measured by using the data acquisition card and recorded in a personal computer.For the preliminary test, a schematic diagram of the connection between the anodeand cathode (electrodes) with 1kΩ resistor (load) through a data acquisition system is shown in Figure 1. The aloe Vera plant was first taken into a dark room devoid of illumination for at least 48 hours before experiments.From the preliminary test as a common precaution practice, the voltage value was found reaches a stable baseline after a continuous measurement period of about 60 minutes.

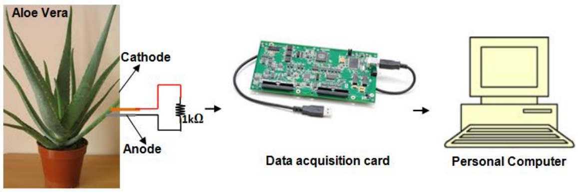

Fig. 1: Schematic diagram of experimental setup.

A conventional desk lamp was used as an artificial light source with the intensity of 200 W m^{-2}, which isplaced at 10cm from the aloe Vera leaf to carry out the experiment for the current responses upon darkness/illumination cycles. This provides a preliminary confidence check on the effect of light onto the harvested electricity from living plants. The electrochemical measurement always began in the dark state (in a dark room and light OFF). The light intensity was measured with a power meter .The plant was illuminated only when the baseline current in the dark had been stable for at least 20 minutes and 100 seconds of continuous illumination. The darkness/illumination responses were repeated for about 4 cycles and average values were used.

The contrast between conventional desk lamp of 200 W $m^{-2}$and exposed under the sunlight of approximately 800W m^{-2}[13] was performed to check the difference in power increments of LFC. The reading was recorded for both circumstances, dark room and under sunlight respectively up to60 minutes.The current reading of LFC under sunlight was measured with the multi-meter (Peak-Tech 3140) and the current output was measured through the 1kΩ resistor.

RESULTS AND DISCUSSION

It is understood that under sunlight, a plant produces electrons [14].Therefore, it is hypothesized that LFC under sunlight would show an increment in harvested current due to a natural photosynthesis process which is termed as photosynthetic current, whereas thecurrent harvested in dark termed as electrochemistry current in this paper. To prove this, intermediate ON and OFF illumination is first investigated following the procedure described in the methodology. Figure 2 shows the current responses upon darkness/illumination cycles. The dashed lines represent only the electrochemistry current (dark current) and solid lines represent both photosynthetic current and electrochemistry current.

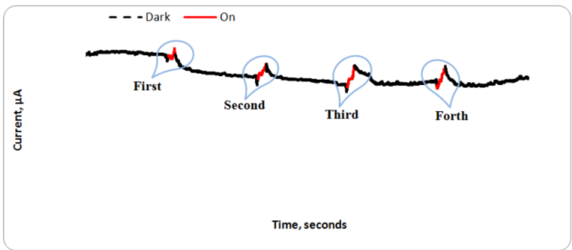

Fig. 2: Four cycles of darkness/illumination current responses with 200W m^{-2} desk lamp.

The figure presents the current variation for 100 second illumination periods (marked as ON) followed by in the dark periods continuously up to 4 cycles. When the plant is illuminated, the current gradually increases to certain value which believedis related to the light-dependent changes of the plant cell membrane current (photosynthetic current). For the first cycle, upon illumination, the current output increases to approximately 8%

compared to electrochemistry current. Once the light is turned off, the current drops to its original level. For the second, third and forth cycle, there is about 16%, 21% and 18% of current increment, respectively, compared to electrochemistry current. This shows that for 200W m^{-2} cool daylight bulb of illumination that is maximum 21% increment can be harvested. This observation pattern is similar to the previous investigation reported in [9] where the LFC was responded dynamically to the visible light as an external stimulus triggering photosynthesis.

The electrochemistry current can be interrelated to the previous investigation that electrochemistry process has been identified as the origin of theelectricity generation in LFC [12]. In view of this, the modeling of the aloe Vera according to the mechanism with necessary consideration of the efficiency effect was illustrated in Figure 3 [15]. The electrons flow through an external wire which leads from zinc to copper because zinc gives up electrons (oxidation) more readily than copper. There is also a group of stranded electrons that accumulated at the zinc electrode due to the higher oxidation rate compared to the electrons flow.

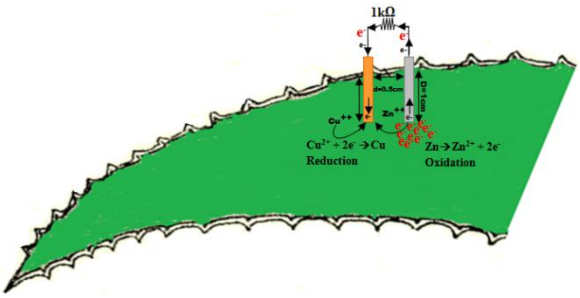

Fig. 3: Modelling of the behaviour of ions flow in aloe Vera according to the principle of electrochemistry with consideration of the efficiency effect.

Investigation on how much the actual gain in electricity when the plant is exposed under sunlight is a prerequisite for making LFC a future electrical source. The measurement ofcurrent output in the dark room and after exposing under sunlight with intensity of about 800W $m^{-2}$for an hour, respectively plotted in Figure 4a.From the figure, the average electrochemistry current is approximately 30µA when in a dark environment, then it has gradually increased up to 43µA when exposed under the sunlightthat inculdes both photosynthetic and electrochemistry current. The plant was kept in dark for 24 hours until its metabolism is stable.In order to comprehensively understand, the power output profile for the LFC is also calculated and plotted as shown in Figure 4b. The power output after kept in the darkfor an hourreached its stable power which is about 0.9µW. The average photosyntheticpower increases up to 1.9µW after exposedunder sunlight for an hour. From the figure, the response time from stable electrochemistry current to stable photosynthetic current takes approximately 25 minutes. There is a remarkable increment, which is 43% in harvested current, corresponding to 111% increment in harvested power through 1kΩ external load. It is clearly seen that the photosynthesis process remarkably increases the output of electrical current and power.

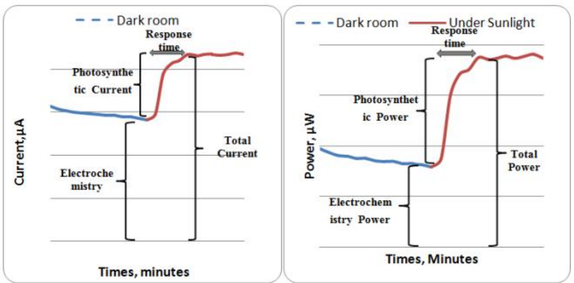

Fig. 4: The a) currentand b) power profilethrough 1kΩ external load of LFC inthe dark room and under sunlight.

Figure 5 presents the model of the behaviour of ions flow in LFC based on the electrochemistry process and the extracellular photosynthetic electrons from photosynthesis process. In the electrochemistry process, electrons can be transferred from anode to cathode through an electrically conducting path as an electric current. Meanwhile, during the photosynthesis process when water molecules split into oxygen gas and two protons, they donate two electrons. Then, chlorophyll molecules in photo-systems IIpicks up the electrons and releasing oxygen to the environment as a waste product. The electrons then pass to photo-system I through an electron transport chain. The electrons are believedflow to the LFC anode as additional electrons that transferred through the external load to cathode as converted into electricity. The electrons that used for the extracellular photosynthetic electrons in the LFC are termed as the photosynthetic current (Figure 5).

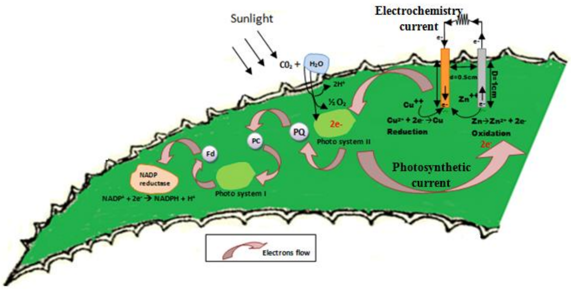

Fig. 5: Modelling of the behaviour of ions flow in LFC according to the principle ofelectrochemistry and photosynthesis.

Conclusion:

This paper established a significant increment energy output of LFC in both harvested current (43%) and harvested power (111%) with the natural photosynthesis. It is believed that the energy origin of LFC with illumination is taking into account for both electrochemistry and photosynthesis process. The solar energy captured by living plant converted into chemical energy and during this photosynthesis process the splitting of water molecules donates the electrons which can be transferred to the LFC anode (zinc) and as an addition electrons flow (photosynthetic current) through the external load as electricity. The mechanism of energy production of LFC is modelled based on the principles of both electrochemistry and photosynthesis process.

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