HARVESTING ELECTRICITY FROM LIVING PLANTS USING ELECTROCHEMISTRY APPROACH WITH THE AID OF PHOTOSYNTHESIS PROCESS.

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FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH
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DECLARATION

I hereby declare that the material in this thesis is my own except for excerpts, equations and references, which have been dully acknowledged.

05 September 2014

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LIST OF PUBLICATIONS

Journal Paper

Choo, Y. Y. & Dayou, J. 2013. A Method to Harvest Electrical Energy from Living Plants. *Journal of Science and Technology.* **5** (1): 79-90.

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LIST OF SYMBOLS

CO_2	Carbon dioxide
H_2O	Water
$C_6H_{12}O_6$	Hydrocarbon / Carbohydrates
O_2	Oxygen
P	Power output
V_{in}	Low input voltage
V	The changes of voltage
e_{abs}	Absolute error
e_{rel}	Relative error
a_{cal}	Accuracy of the calibration
P/T	Capability Index
σM	Standard deviation of the system
E	Electrochemical potential
λ_{max}	Maximum wavelength
x	Plant that immersed with metal
y	Fresh plant
%	Percentage of accuracy
r	Pearson's coefficient
ppm	Part per million
σ	Standard deviation
E^o	Standard potential
m	Mass of zinc released into the media
Q	Total electrical charge flowing in the circuit
e	Electronic charge, 1.6×10^{-19} Coulombs
M	Molar mass of zinc
N_A	Avogadro's number, 6.023×10^{23} mol^{-1}
R	Resistance value of the resistor used
t	Time measured
Q_o	Total electrons charge that flow through the load
Q_I	Total electrons charge (input charge) that released by the zinc electrodes

Q_{Eff}	Total charge efficiency
R_{int}	Internal resistance
R_{load}	Resistor used as load
MFCs	Microbial Fuel Cells

ABSTRACT

Living plants have been proven to have a potential in generating electricity, which offers a green approach that harvest electricity from sources that are abundantly available. The principal idea is that organic matters of the living plants are used as the electrolyte with the combination of electrodes to generate electricity. The monitoring system (data acquisition system) for electrical potential measurement was first developed for the actual data collection of low voltage and current continuously. A comprehensive knowledge regarding the mechanisms of energy generation is found, which the electrochemistry process is accountable for its mechanism of energy production. The behavior of the ions flow in this electrode-plant system is modeled and illustrated with a detailed discussion to support the proposed model. Then, a new strategy to employ efficiently both solar energy and chemical energy simultaneously is introduced. By using the sun as the energy source and taking natural photosynthesis into account, it is hypothesized that the power production of the Living-Plant Fuel Cell (LFC) is increased. It is found that the electrical current output 43%, which is corresponding to the increment of 111% in harvested electrical power. The mechanisms of energy production of LFC based on electrochemistry and photosynthesis process is also modeled and illustrated. Overall findings provide a better understanding of the energy production mechanism in the LFC system. In addition, LFC is shown to have its ability to power up some low power electronic instruments such as Light Emitting Diode (LED), digital clock and calculator.

ABSTRAK

PENUAIAN TENAGA ELEKTRIK DARIPADA TUMBUHAN HIDUP MENGGUNAKAN PENDEKATAN ELEKTROKIMIA DENGAN BANTUAN PROSES FOTOSINTESIS

Tumbuh-tumbuhan hidup telah terbukti berupaya menjana tenaga elektrik, ia menawarkan pendekatan hijau di mana elektrik boleh diperolehi daripada sumber-sumber yang tiada batasnya. Konsep utamanya ialah bahan organik daripada tumbuh-tumbuhan hidup digunakan sebagai elektrolit dengan kombinasi elektrod untuk menjana tenaga elektrik. Sistem pemantauan (sistem perolehan data) untuk pengukuran keupayaan elektrik telah bina untuk mengumpulkan data sebenar bagi voltan dan arus yang rendah secara berterusan. Pengetahuan yang menyeluruh diperlukan untuk memahami mekanisme penjanaan tenaga, proses elektrokimia bertanggungjawab terhadap mekanisme penghasilan tenaga. Oleh itu, pengaliran ion dalam sistem elektrod-tumbuhan ini telah dimodelkan dan digambarkan berserta dengan perbincangan yang terperinci untuk menyokong model yang dicadangkan. Seterusnya, pendekatan baru telah diperkenalkan dengan mengambilkira kedua-dua tenaga solar dan tenaga kimia secara serentak. Hipotesisnya, dengan menggunakan cahaya matahari sebagai sumber tenaga dan mengambilkira proses fotosintesis, pengeluaran kuasa daripada sel bahan-api tumbuhan hidup (Living-plant Fuel Cell, LFC) dapat ditingkatkan. Didapati bahawa arus elektrik meningkat 43%, iaitu sepadan dengan kenaikan 111% dalam kuasa elektrik yang dituai. Mekanisme penghasilan tenaga LFC berdasarkan elektrokimia dan proses fotosintesis juga dimodelkan dan digambarkan. Secara keseluruhannya, penemuan ini menambahbaik pemahaman mengenai mekanisme penghasilan tenaga dalam sistem LFC. Tambahan pula, keupayaan LFC telah ditunjukkan dalam menghidupkan beberapa peralatan elektronik berkuasa rendah seperti Diod Pemancar Cahaya (LED), jam digital dan kalkulator.

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CHAPTER 1

INTRODUCTION

1.1 Photosynthesis

In living plants, the process of photosynthesis occurs in organelles called chloroplasts, especially using chlorophyll. The chlorophyll is a pigment that absorbs visible spectrum and capture energy from sunlight as well as responsible for the numerous proteins that make up the electron transport chain. It is capable to channel the energy of sunlight into chemical energy. This process consists of many physical and chemical reactions that involve biochemical components which enable organisms to exploit solar energy (Lawlor, 2001). The overall chemical reaction involved in photosynthesis is (McCarty and Johnson, 2003) :

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

This process occurs firstly while the light is captured by chlorophyll and is used to make energy carrying molecules, these are then used to capture carbon dioxide and water to transform them into carbohydrates and oxygen. The actual chemical mechanisms depend on a set of complex protein molecules that are located and around a highly organized membrane (Whitmarsh and Govindjee, 1999).

There are two parts of photosynthesis, which are light reactive (energy-fixing reaction) that consist of electron and proton transfer reactions and dark reaction (carbon-fixing reaction) which consist of the biosynthesis of carbohydrates from carbon dioxide. Light reactions take place in the thylakoid membrane, use light energy to make Adenosine-5′-triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH). Both of them are used in the dark reactions to produce sugar. The energy of the sunlight is captured and activates electrons jump out of the chlorophyll molecules in the reaction center and pass through a series of cytochromes in the nearby electron-transport system (Lawlor, 2001).

According to Miles, there are two photosystems within the thylakoid membranes of the chloroplast. Photosystem II uses light energy to oxidize two molecules of water into one molecule of molecular oxygen, which is the byproduct of photosynthesis. Then, four electrons removed from the water molecules, and are transferred from Photosystem II through an electron transport chain that terminates at Photosystem I (Miles, 2003). These energy-rich electrons reach a high energy level when eventually are carried from the cytochrome enter the photosystem I protein complex by a small water soluble protein. The dark reaction takes place in the stroma of the plant cell and uses energy derived from these compounds to make Glyceraldehyde-3-phosphate (GA_3P) from CO_2 where glucose and other carbohydrates are synthesized (Srivastava, 2005).

1.2 Problem Statements

The electrical output directly from living plants is still unpretentious, anyhow, it is a promising and certainly worth exploring further. In order to measure and sampling the electric potential in the living plants for better analysis, the necessity of providing an instantaneous monitoring system of electrical potential should be apparent.

Other than that, with the comprehensive knowledge regarding the mechanisms of energy generation is believed to aid in order to increase the energy harvested directly from the living plants. It will come across as being a potential revolution in green energy, which with huge implications where it could be used. Unfortunately, the mechanisms of the energy production are not understood yet and its model has not been established. Hence, there is much to be done to fully understand the origin of the electricity generated from the plants.

In view of this, here comes the motivation of this work to investigate the mechanisms of energy production from living plants that aiming to optimize its power output. Few would disagree with the intention behind this offer, but its feasibility is the concern. With this in mind, several potential applications have been set up to examine the practical feasibility of this plant based energy source.

1.3 Research Objective

More specifically, the objectives of the research are listed as follows:

1. To develop a monitoring system (data acquisition system) during the harvesting of electricity.
2. To investigate the origin mechanism of electrical energy production from Living-Plant Fuel Cell (LFC) based on both electrochemistry and photosynthesis process.
3. To show the feasibility of using energy from living plant to operate several low power electronic instruments.

1.4 Scope of the Research

This was merely a living plant as the energy source and the harvesting electrode pair that built up the Living-Plant Fuel Cell (LFC). However, both living plants and electrode pair are with a conditional. Among the living plants, sample selection of the research is limited to the plants that commonly found, higher moisture contents and easy embedding of electrodes into the stem. Besides that, the harvesting electrode pair has to be restricted to the cost effective, easily acquire and appropriate for the conditions.

Due to how LFC has been built up, its energy production is limited to several types of a related investigation on the electrochemistry process. It has also been understood that free electrons were available during the photosynthesis process. Taking the abundance of the solar energy into account is hereby included. The verification on this examination is limited to the artificial white light source and the natural sunlight.

1.5 Hypothesis of the Research

In this research, two hypotheses were speculated while requiring to be verified through the experiments. This could be accepting or refuting them. The hypotheses are listed as follows:

1. The living plants can produce the electricity through the electrochemistry process.
2. The electrical power output harvested from Living-plants Fuel Cell (LFC) can be increased with the irradiation of light due to the photosynthesis process.

1.6 Thesis Contributions

Within this work, a protocol to harvest electricity from living plant was established and proposed as a plant-based energy source. This includes the best combination of electrode pair and energy source (the type of the plants) that set up the living-plant fuel cell, the origin of the electricity generation and a theoretical model for electricity generation and harvesting.

The main advantage of the LFC is the abundance of living plants which are toxic free and environmentally friendly that the globe most needed. The selection procedure attempts to comprehend the fundamental mechanisms of the LFC. In regard to the mechanism of this plant-based energy source, an analytical model was first constructed according to the principle of electrochemistry with considers the efficiency effect on the behavior of ions flow.

Following to this, with the particularity of living plants, a new strategy to employ efficiently both solar energy and chemical energy simultaneously in an environmental friendly manner is introduced. In this way, the energy output from living plants was increased and integrated by involving both electrochemical and photosynthetic to generate a practical electricity.

Due to the abundance of the living plants, especially widely available in many rural and sub-urban areas, should make good uses of these strengths. In the financial aspect, this new plant-based energy source which requires no additional high-priced equipments are advantageous in this prospect. By using the electrochemistry approach with the aid of the proposed photosynthesis process has contributed to the increase of the output power and provides an important approach in the future energy harvesting system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literatures related to the weak energy sources in three sections. The first section reviews the conversion and energy harvesting using piezoelectric. The second section discusses on a broad range aspects of microbial fuel cells as a transformative solution for integrated waste treatment and resource recovery. The last section discusses previous studies that related to plant-based energy generation that harvests electrical energy from living plants.

2.2 Weak Energy Sources

2.2.1 Piezoelectricity

a. Introduction

In the late nineteenth century, the phenomenon of piezoelectricity was discovered and it was found that certain materials generate electricity when they are under mechanical stress. These materials produce mechanical stresses when they are subjected to an applied voltage. This property provides the ability to absorb mechanical energy from ambient vibration and transform that wasted energy into electricity. Piezoelectricity is a property of certain classes of crystalline material, including natural crystals and artificial piezoelectric crystals such as barium titanate and lead zirconate titanate. A particularly cut electrode piezo crystal detects the longitudinal, transverse vibration, whereas converting these mechanical vibrations into electrical signal that displayed on an oscilloscope. When crystals are pressurized, an electric field is generated.

Piezoelectric effect exists in two domains, direct piezoelectric effect and converse piezoelectric effect. Direct piezoelectric effect depicts the ability to convert mechanical to electrical energy while the converse piezoelectric effect depicts the ability to transform electrical to mechanical energy. The direct piezoelectric effect is responsible for the material's ability to function as sensor and the converse piezoelectric effect is accountable to function as an actuator. The electrical energy generated can be stored to power electronic devices and known as "energy/power harvesting" (Vatansever et al., 2012). The deflection with an electrical energy input in a usual piezoelectric is almost invisible to the naked eye, as to increase the deflection, stacked device or bender device is used (Kim, 2002).

Piezoelectric material used as a non-conductive material which does not have free electrons, but they made up of crystals that have many "fixed" electrons. These fixed electrons can move slightly as the crystals deform by an external force. This movement of electrons alters the equilibrium status in adjacent conductive materials and creates an electric force that will push and pull the electrons in the electrodes attached to the piezoelectric crystals.

Piezoelectricity can be seen in different structures, which are naturally occurring biological piezoelectric materials, naturally occurring piezoelectric crystals, manmade piezoelectric ceramics and man-made piezoelectric polymers. Man-made piezoelectric materials are more efficient due to their complex crystalline structure, the process with which they are made is very precise. Piezoelectric materials have been widely used due to their wide bandwidth, relatively low power requirements, fast electromechanical response and high generative forces.

b. Types of Piezoelectric

i. Quartz (SiO_2)

A strong piezoelectricity due to its crystalline structure. When a pressure is applied to a quartz crystal, an electrical polarization can be observed along the pressure direction.

ii. Gallium orthophosphate ($GaPO_4$)

It has almost the same crystalline structure as quartz, with the same characteristics. Its piezoelectric effect is double the value of the quartz, making it a valuable asset for mechanical application. It is not found in nature, therefore, a hydrothermal process must be used to synthesize the crystal.