博　士　論　文

A STUDY ON BIOELECTRICITY GENERATION IN MICROBIAL FUEL CELL BY USING ORGANIC WASTE

(有機廃棄物を用いた微生物燃料電池によるバイオ発電に関する研究)

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A dissertation submitted to the Department of System Design and Engineering, Graduate School of Science and Engineering,Yamaguchi University Japan by Tun Ahmad Gazali, student number : 15-9352-502-7. It has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering.

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1. Professor YUKIO NAKATA ………………..
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4. Professor NORIMASA YOSHIMOTO ………………..

DECLARATION

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(有機廃棄物を用いた微生物燃料電池によるバイオ発電に関する研究)

This dissertation or any part of it is my original work and it has not been submitted for any degree in any other University (except for publication).

Date: February 19,2018

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ABSTRACT

Present-day, we are faced to the situation where energy resources are becoming limited and it causes the energy to become a rare and expensive item. Energy is vital to the quality of our lives. It provides us with heat and electricity, and powers our industry, transport and modern way of life. Energy consumption is steadily increasing and this trend is set to continue due to rises in the world's population and living standards. The demand for energy is predicted to increase by approximately 60% on current levels by 2030, with the developing world accounting for two-thirds of this increase. With approximately thirty percent of the global population not having access to modern energy services and against a backdrop of depleting fossil fuel reserves and climate change concerns, one of the main challenges of our time is to meet our energy needs and in a sustainable manner. The activity relating to development of renewable energy is something urgent to do immediately. Some research on microbial fuel cells (MFC) as a simple cell that can produce environmentally friendly electricity has been developed.

However, generally the result is still varied and unstable continuously. Additionally, we should consider that most of the waste around us which popularly is directly burned with other flammable waste, and residual ash is thrown away in landfills. Throughout the time that the incineration of waste containing water is very energy-consuming. So, can we imagine how much energy is " wasted " just to cultivate this garbage. Based on this reason,

the utilization of organic waste values to generate bioenergy is a most interesting-challenging thing to be constantly researched to increase greater chances of generating renewable energy without neglecting environmental degradation, limited potential resources and future.

Organic waste is economical as the material sources for producing bioelectricity where it could be found easily and it is realized that the raw materials of organic wastes are still very abundant, even some of them using raw materials derived from food, then will certainly be limited as well. In organic waste contains organic matter, this has great potential's source of bioelectricity by using microbial fuel cells (MFCs).

In Microbial Fuel Cells (MFCs), we use active microorganisms (bacteria) as biocatalysts to oxidize / biodegrade organic and inorganic content with anaerobic processes which at the same time they produce bioelectricity. The electrons produced by bacteria from the substrate are transferred to the anode and continued to the cathode which is connected to the external circuit. These MFCs are promising technologies to produce sustainable energy. In this research, we tried for increase the value of organic as a bioelectricity generation. Thereby reducing the adverse effects of current waste management limitations and refining some of the things in previous research that have not yielded optimal, stable and sustainable results.

The aims of these studies are to develop and explore the organic aste as a low cost feasible MFC which set up mixing with soil to generate bioelectricity as an efficient and eco-friendly solution for organic waste especially by using persimmon fruit wastes mixing with soil and another kind of organic wastes. Leaf mold and rice bran were used as organic waste and as comparison materials.

While the persimmon waste production in Japan is relatively abundant and causes a waste disposal problem. The results showed that all MFCs successfully generated electricity with the maximum values of 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for MFCs containing persimmon waste and soils, leaf mold and rice bran respectively. Moreover, the electromotive force of mixed sample of persimmon waste and soils was approximately 22 ± 0.01 V/m^2. Moreover, it shows that some organic wastes of cow dung, leaf mold and chicken dropping mixing with soil is taken as substrate for electricity generation. The best results is 10980 ± 11.32 mV/m^2 for a mixed sample of Test V (leaf mold and soil), while for the pure samples showed at 10880 ± 4.784 mV/m^2 for Test IV (chicken dropping). Some good results for the power and current values of this study will be explained in more detail in the next chapter.

Finally, we need an environment friendly energy development which can reduce environmental impact of organic waste, utilization of organic wastes mixing with soil in MFC, to find out the effect of the scale-up of MFC, to observe the capability of electrode material for electricity generation as well as to observe the effect of environmental factors in electricity generation in MFC.

Thus, this study will develop a bio-energy without using food product which reduce some environmental impact of organic waste, applicable everywhere as low cost and safe bioelectricity generation system.

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I am grateful to all my friends, my host family, all Japanese friends in Ube city, Yamaguchi city, Shimonoseki city, Saga city, Ureshino city for your nice friendship, our togetherness. Appreciation is also addressed to Indonesian Embassy in Tokyo, Indonesian Consulate General at Osaka for their great helps. Gratitude is given to my colleagues in The East Java Provincial Government for their great encouragement and support during my study in Japan.

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until March 2018.

Finally, I hearty dedicate my degree to my late father (Maksum HA.), my great mother (Siti Bandiyah), my dearest beautiful wife (Ekasari Selvyanyta Gazali) and our huge lovely children (Mas Ananta, Kakak Ataqsa, Cece Saga, Aiko chan and Sakura Chan who will be born in a short time around my graduation) for their great understanding, pray, support, patience, and a lot of sacrifices during difficult times of my doctoral study.

TUN AHMAD GAZALI
Ube city, March 2018

Dedicated to :

My Great Lovely Parents

My late father MAKSUM HA.

My Great mother SITI BANDIYAH

and

My lovely family

My wife EKASARI SELVYANY

ANANTA Kun

AQSA Kun

SAGA Chan

AIKO Chan

SAKURA Chan

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CHAPTER 1

INTRODUCTION

1.1 Background

Energy is needed in every human life. All countries are thinking hard how to make enough energy supply for their energy needs. Globally, about 1.06 billon people do not have access to electricity or it just 85.312% of population access to electricity (The World Bank, 2017). Figure 1.1a and 1.1b illustrated for that situation.

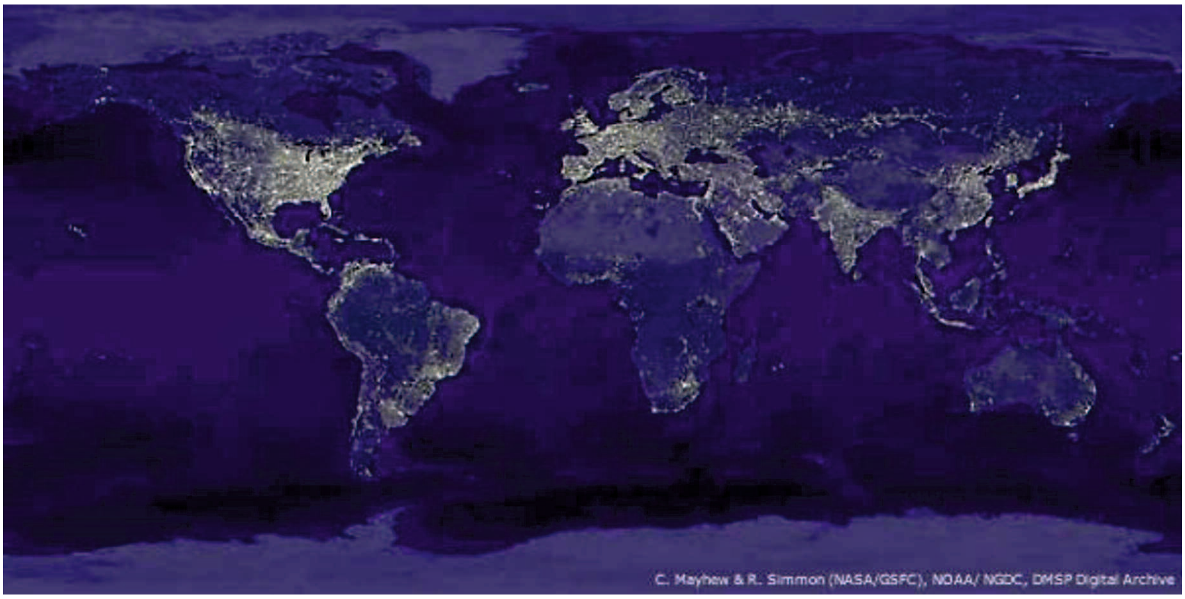

Figure 1.1a World at Night (Source : NASA)

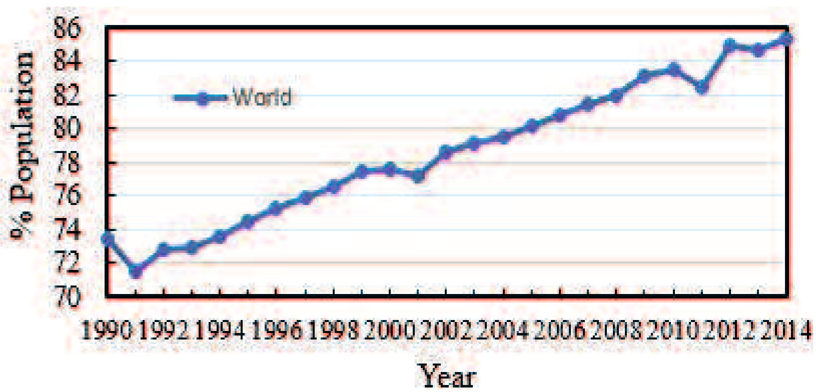

Figure 1.1b Population Access to Electricity (Source : The World Bank, 2017)

Energy is a strategic commodity that affects the sustainability of development which in its management requires the accuracy and wisdom in managing and using it. To meet the increasing energy demand when the fossil fuel reserves are declining, it needs a substitution strategy to potential renewable energy sources but still not developed in maximum use and sustainable. We desperately need a new renewable, clean and environmentally friendly form of energy. Meanwhile, in some developing countries facing population growth far beyond planned, so many of the remaining countries do not have enough energy resources

So far, we only use petroleum as fuel for daily needs. Global energy demand is increasing, as is the environmental damage due to fossil fuel use. And we know, the source of fossil energy is very limited in number and can run out. Consumption of fossil energy sources that continue to increase from year to year and uncontrolled it can backfire that impact on economic losses and welfare of the people widely. In the past, burning fossil fuels, deforestation and other human activities have released large amounts of greenhouse gases into the atmosphere. In the last 35 years global energy supplies have nearly doubled but the relative contribution from renewables has hardly changed at around 13% (IEA, 2009). Society will be greatly burdened by rising fuel prices due to the oil crisis that hit the world. This increases the world's energy consumption drastically and results in the depletion of energy reserves, especially fossil energy.

Reduction of dependence on non-renewable fossil energy, especially oil and natural gas, by substituting it into new and renewable energy sources, especially biofuels (biodiesel, bioethanol, biomass, and biogas). However, the process of fulfillment of alternative energy, especially that derived from biofuel could lead to world food crisis. Therefore, the provision of biofuel requires the conversion of plants and land that was originally for food is converted into a function of energy fulfillment. With the high demand for biofuels, farmers around the world prefer to grow crops used for biofuel rather than food crops. In the long run, this will lead to reduced food production. World food prices will rise. The impact will be felt by the poor in developing countries. Next, the world's population continues to grow and, over the next 40 years, agricultural production will have to increase by some 60% (FAO, 2011). Meanwhile a quarter of all agricultural land has already suffered degradation, and there is a deepening awareness of the long-term consequences of a loss of biodiversity with the prospect of climate change. Higher food, feed and fibre demand will place an increasing pressure on land and water resources, whose availability and productivity in agriculture may themselves be under threat from climate change. The additional impact on food prices of higher demand for crops as energy feedstock is of real concern. Furthermore, special attention to the emergence of biofuels as alternative energy has resulted in threats to food security because land previously used for agriculture is converted to biofuel (J. Popp et al, 2014) As a result, the quantity of food production decreases. We must be prepared to face the shortage of food.

The development of oil and natural gas at a rate to meet the future worldwide demand requires exploratory development investment, especially in a few key resource-rich countries. It is predicted that the OPEC countries supply the majority of world petroleum increase in the future (IEA World Energy Outlook, 2009). While U.S. Energy Information Administration estimated that up to 2030 the world's energy consumption is still depending on the non-renewable energy of petroleum (U.S. Energy Information Administration, 2017).

In the context of the region, Asia Pacific with its economic growth. Dynamic oil has only a small reserve and causes the oil needs in this area is very large and very dependent on other areas. And the situation is also experienced by almost all countries around the world. The current world energy conditions generally still rely on oil and gas as a source of foreign exchange and to supply domestic needs. For new and renewable energies, although various countries have diverse potential, yet their management and use are not yet optimal. These energy potentials include: vegetable energy sources, gas, geothermal, nuclear energy, solar energy, wind energy and marine energy. Although their contribution is still a marginal component of total global renewable energy supply, they are continuously growing.

The world's future challenge is to strengthen new and renewable energy development to achieve mix energy, including improving energy efficiency and conservation. This means that development needs to be closely integrated with sustainable development, especially in relation to maintaining a sustainable environmental carrying capacity through efforts to develop new and renewable energy sources that can be further optimized to produce sustainable and environmentally sustainable energy sources as well as the objectives to use resources more efficiently. One of them is biofuel. Biofuels are tools that can change direct chemistry into electrical energy through electrochemical reactions which involves biochemistry. Unlike chemical fuel cells, biofuel cells operate in room conditions, such as temperature and ambient pressure. Biofuel cells also use electrolytes neutral and using enzymes or microorganisms as catalyst. Microbial fuel cells (MFCs) use microorganisms rather than enzymes to generate electricity from organic matter. MFCs provide advantages that are more resistant to poisoning, it has been widely used for water quality testing through monitoring dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD) (Tuoyu Z. et al, 2017) as well as it can oxidize organic matter more thoroughly.

The use of bacteria has been done in many fields. One of the bacterial treatments is as a catalyst that can produce energy as a source of alternative energy sustainable. This is a bio electrochemical system in which microorganisms interact with electrodes using electrons that are released or supplied (electron transfer) through electrical circuits. And the most widely used types of BESs are microbial fuel cells (MFCs) (Rabaey et al, 2007). Microbial fuel cells (MFCs) are devices that using active microorganisms (bacteria) as biocatalysts in the anode with an anaerobic process to produce the biolyte. The electrons are produced by bacteria from the substrate transferred to anode and to the cathode connected to the conduction material which contains a resistor. This system operates under conditions such as temperature, pH, electron receiver, electrode surface area, reactor size and time of operation (Logan et al., 2006). MFCs use microorganisms that biologically oxidize organic matter and transfer electrons to the electrode which defined as exoelectrogens by Logan (Logan, 2008) and Ravinder K. et al (Ravinder K. et al, 2006). While exoelectrogen is the predominant name, it has a variety of names including electricity bacteria (Debabov V.,G, 2008), electricity-generating microorganisms (Lovley and Nevin, 2008), electrochemically active bacteria (Chang et al, 2006), anode respiring bacteria (Moon H. et al, 2004) and electricigens (Logan, 2004 ; Reddy et al, 2010). Over 20 exoelectrogen, such as Geobacter, (class of Deltaproteobacteria); Rhodopseudomonas (class of Alphaproteobacteria*);* Rhodoferax (class of Betaproteobacteria); Shewanella Oneidensis and Pseudomonas (class of

Gammaproteobacteria), Clostridiaceae, (class of Clostridia); Geotrix (class of Acidobacteria); Arcobacter (class of Epsilonproteobacteria); Propionibacterium (class of actinobacteria); Clostridium (class of Firmicutes); and Planococcaceae (class of Bacilli) (S.Xu and H.Liu, 2011).

Organic waste is believed to contain many organic components. Organic waste comes from the rest of living things or nature such as humans, animals, and plants through the process of decay or decay. This type of waste is considered environmentally friendly because it can be decomposed by bacteria decomposers naturally and take place quickly. Thus, the organic carbon content of the sediment there are sufficient power sources in some locations. These ingredients can be consumed by exoelectrogens and gradually directly transporting the outer electrons of the cell (Rahimnejad et al, 2015). In addition, the utilization of organic waste of economic value (cheap) can be considered as an alternative source of energy because its existence is very abundant and easy to find.

In addition, discussions on global warming issues, have been given much attention these days. Scientific temperature observations, begun in the 19^{th} century, have shown that the pace of temperature increase in the latter half of the 20^{th} century has been faster (Thomas S., 2016). Currently, the amount of fossil fuel origin carbon dioxide discharge has been increasing, with the corresponding increase in energy demand.

Due to this increase, it has been strongly claimed that the artificial greenhouse effect is the main cause. For these global warming problems, the United Nations Framework Convention on Climate Change was issued in 1994, and Kyoto Protocol was issued in February of 2005. The protocol called for efforts to reduce the amount of greenhouse type gas emissions from in advanced countries from 2008 to 2012, ultimately aiming for 1990 levels. For biomass and bio-fuels, CO_2 is absorbed during the growth process of the plants and then the same amount is ideally generated when the fuel is burned. This is considered carbon-neutral when we consider CO_2 exhaust emissions. Thus, the importance of biomass and bio-fuels is evident because they not only increase diversification of energy supply sources but also aid in CO_2 reduction. Some effort appears to be focused on CO_2 reduction in society. Considering renewable energy forms like bio-fuels, their introduction has been promoted as a core program towards a low carbon social structure.

Based on some previous considerations explanation, this study was conducted to know more for how potential of electrical green energy source that can be developed from the utilization of organic waste, particularly to reduce the environmental impact of organic wastes. In another hand this study also wants to explore a research work which applicable in Japan, my home country and other parts of the world, as low cost and safe bioelectricity generation system which use an organic waste as a source of energy without using food product. As well as through this study which more understand for the capability of electrode material inside deliver electrical energy and how does the environment affect electrical energy generated.

1.2 Research Objectives

Some objectives in this study as follows:

1. To study the potential of green electrical energy that can be developed by the utilization of organic wastes mixing with soil in MFC
2. To find out the effect of the scale-up of MFC

3. To observe the capability of electrode material for electricity generation
4. To observe the effect of environmental factors in electricity generation in MFC.

Thus, this study will develop a bio-energy without using food product which reduce some environmental impact of organic waste , applicable everywhere as low cost and safe bioelectricity generation system.

1.3 Research Structure and Outline

The layout of research step is shown in Fig.1.2. The work is divided based on three stages as follows:

First Stage: A development bioelectricity generation by using mixed sample of organic waste and soil in microbial fuel cell designed as first research. This study is to explore some mixed samples of organic waste and soil as a low-cost potential substrate for bioelectricity generation so that this organic waste can be recycled and provide still some sort of basic solution to populations experiencing electricity shortage. It is an efficient and eco-friendly simple solution for organic waste management, provide green and safe electricity. Next, some various reasons for improving the recyling of some organic waste on agricultural land has done. These include:

- To recycling of organic matter and mineral nutrients,
- Conservation of naturally available but limited supplies of nutrient resources.
- Avoidance of alternative disposal methods which are environmentally damaging, expensive, or limited by space.

- To utilize of organic waste principally to create clean energy through the development and operation in some advance study.

Second Stage: In addition to more consider that the MFC has emerged as an efficient and eco-friendly solution for organic waste management. In this stage, we developed a microbial fuel cell (MFC) as an emerging renewable technology, which is designed to exploit the degradation of biological substrates to produce sustainable bioenergy in the presence of active microorganisms. Therefore, during this stage, my objective was how to explore and to evaluate bioelectricity generation by reusing persimmon waste as a low cost feasible potential substrate for bioelectricity generation. In this stage, we prove the good result in environmentally friendly degradation of persimmon waste. This low cost and abundant by-product can alternatively be tested in MFCs for efficient and economical conversion to bioenergy. The performance parameters using such as maximum power density, current density has done well.

Third Stage: Based on increasing the data result, we conducted of next study was to develop and explore the persimmon fruit waste as a low cost feasible MFC bioreactors which set up with organic waste mixing with soil to generate bioelectricity as an efficient and eco-friendly solution for organic waste management.

The dissertation outline is described below.

Some literature reviews about MFCs have been examined after done by Potter in 1911, but MFC using organic waste did not get much attention

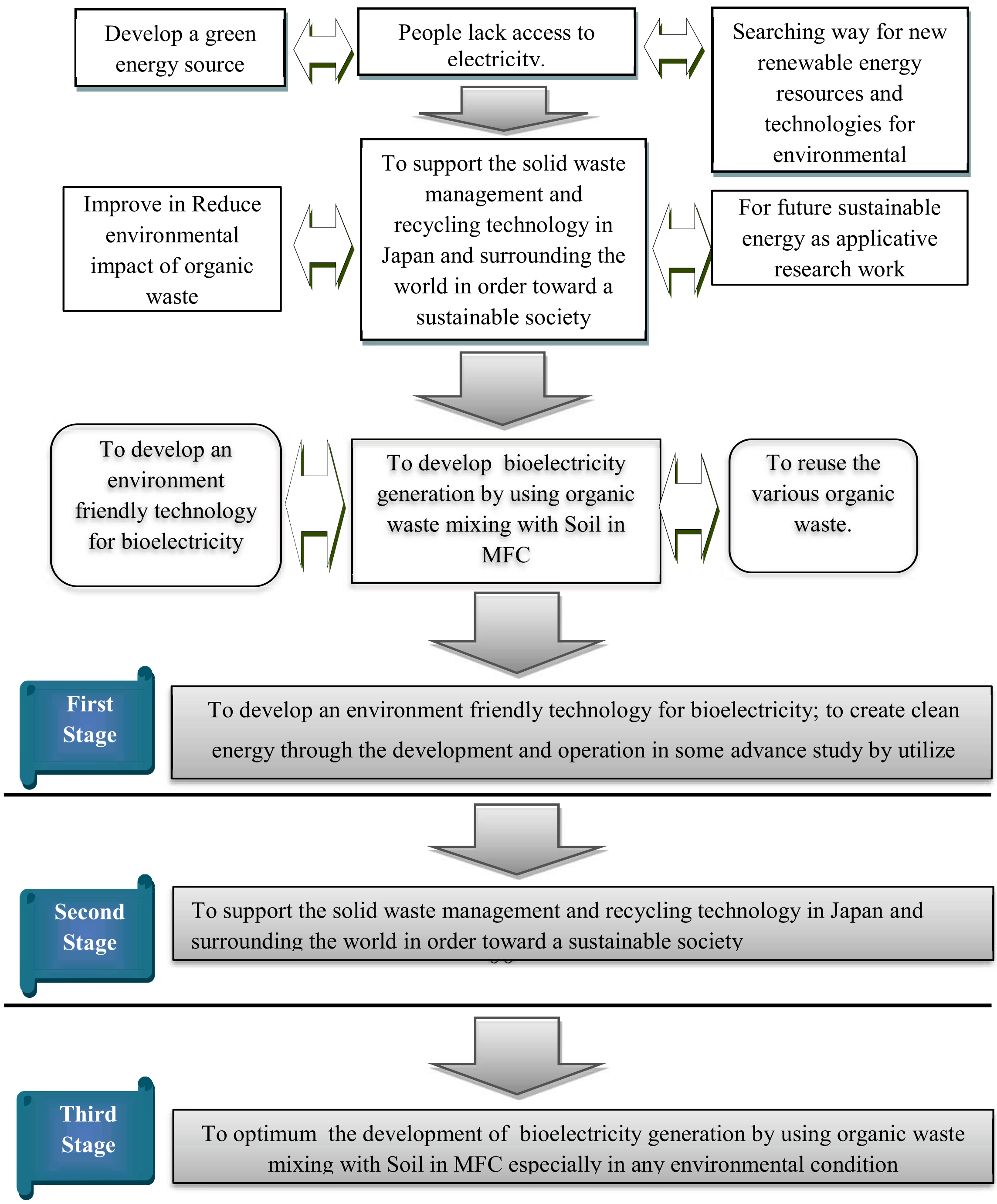

Fig. 1.2 The Layout of Research Stages

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CHAPTER 2

LITERATURE REVIEW

2.1. Overview of World Energy Situation

Energy is needed in every human life. According to the IEA World Energy Outlook, the world's primary energy supply has increased by 58% in 25 years, from about 7.2 billion TOE (tons of oil equivalent) in 1980 to about 17.01 billion TOE in 2030 (Benchmarking of Biodiesel Fuel Standardization in East Asia Working Group, 2010) as shown in Table 2.1.

Table 2.1 Perspective of World Energy Demand

Items	Energy Demand (M_{toe})				
	1980	2000	2005	2015	2030
Total primary energy demand	7,223	10,034	11,429	14,121	17,014
Petroleum Oil	3,107	3,649	4,000	4,525	5,109
Transport	1,245	1,936	2,011	2,637	3,171
Petroleum	1,187	1,844	1,895	2,450	2,915
Biofuels	2	10	19	74	118
Other fuels	57	82	96	113	137

(Source: IEA World Energy Outlook 2007, 2008)

In the future, it is expected that energy demand will increase based on economic growth of emerging market countries like China, India, and the Middle East. It is estimated to increase by 48% over 25 years from about 11.43 billion TOE in 2005 to about 17.0 billion TOE in 2030. The share of petroleum demand in the world's primary energy supply will decrease from 34% to 30%, however in the absolute quantity is estimated to increase by 27.7%, from 4.0 billion TOE in 2005 to about 51 TOE in 2030 (Benchmarking of Biodiesel Fuel Standardization in East Asia Working Group, 2010). To minimize dependence on fossil energy, as main energy source, we can apply alternative energy as an environmentally friendly solution and view the future of life.

2.1.1 General Situation

Total world energy consumption rises from 575 quadrillion British thermal units (Btu) in 2015 to 736 quadrillion Btu in 2040, an increase of 28%. By 2040, energy use in non-OECD Asia exceeds that of the entire OECD by 41 quadrillion Btu as illustrated in Figure 2.1. While Figure 2.2 illustrates the world consumption of marketed energy from all fuel sources—except coal, where demand is essentially flat—through 2040. Although consumption of nonfossil fuels is expected to grow faster than fossil fuels, fossil fuels still account for 77% of energy use in 2040, renewables consumption are increasing by an average 2.3%/year between 2015 and 2040 (U.S. Energy Information Administration, 2017).

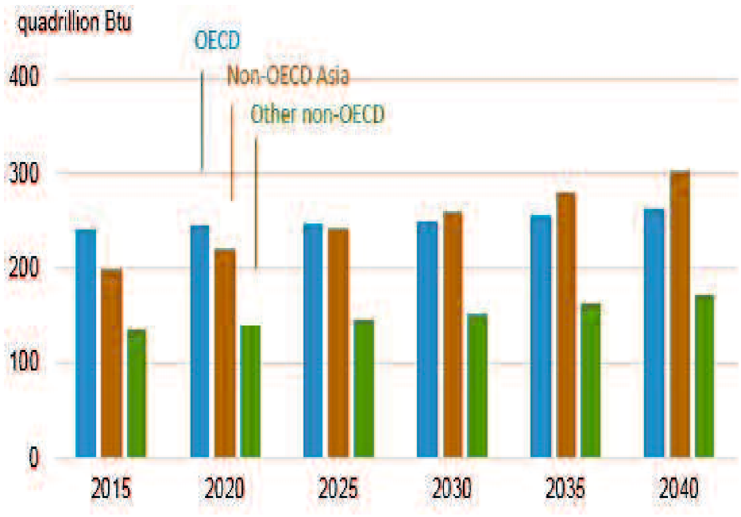

Figure 2.1 World Energy Consumption by Country Grouping

(Source : U.S. Energy Information Administration. International Energy Outlook. 2017)

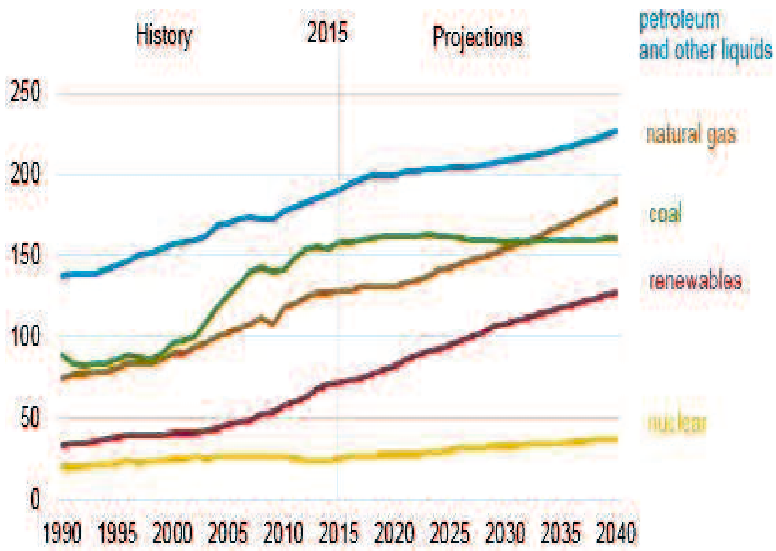

Figure 2.2 World Energy Consumption by Energy Source

(Source : U.S. Energy Information Administration. International Energy Outlook. 2017)

2.1.2 World Energy Needs

The world will need greatly increased energy supply in the future that is clean, safe, and sustainable. With the United Nations predicting world population growth from 7.3 billion today to 9.2 billion by 2040, demand for energy must increase substantially over that period. Electricity demand is increasing twice as fast as overall energy use and is likely to rise by more than two-thirds 2011 to 2035. In 2012, 42% of primary energy used was converted into electricity (World Nuclear Association, 2017).

2.1.3 Energy and The Challenge of Global Climate Change

Today, we are at a critical juncture in its efforts to combat climate change. Without reliable sources of global energy, civilization as we know it cannot exist. Our fossil fuel resources are finite, while the way we use our current resources is placing an increasing burden on our planet. Which is why we are convinced that renewable raw materials are the future. Now, all parts of the world, energy demand continues to increase year by year due to economic growth and development, International Energy Agency writes that Total global primary energy supply (TPES) increased nearly 150% between 1971 and 2013 primarily relying on fossil fuels (Figure 2.3).

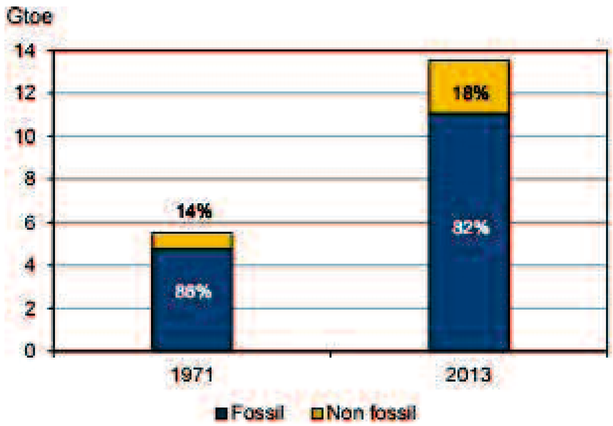

Figure 2.3 World primary energy supply

(source: it processed from https://www.iea.org/publications)

We certainly feel and according to observations climate scientists that carbon dioxide (CO_2) in the atmosphere has increased significantly over the past century, compared to the pre-industrial era (about 280 parts per million, or ppm). CO_2 concentrations continued to increase from the mid-1800s with an average growth of 2 ppm / year in the last ten years Significant increases also occurred in methane (CH_4) and nitrous oxide (N_2O) levels.

Alternatives to fossil fuels are desperately needed not only for energy purposes, but also for the countless end products where they appear as key ingredients. And as we attempt to develop and create sustainable alternatives, we also strive to reduce greenhouse gas emissions and energy usage across the value chain - and develop high-performance solution that create more value with less environmental impact.

2.2.Organic Wastes

The organic waste stream is composed of waste of a biological origin such as paper and cardboard, food, green and garden waste, animal waste and biosolids and sludges. Organic waste is usually generated as a component of most waste streams. There are two common sources of confusion about the term organic waste. Firstly, the term is generally not intended to include plastics or rubber even though to an organic chemist, these polymers are certainly organic.

Secondly, putrescible wastes are a subset of organic wastes with the distinction being that putrescible wastes, for instance food scraps, tend to biodegrade very rapidly whereas some other organic wastes, for instance paper, tend to require lengthy times or special conditions to biodegrade. In landfills, organic wastes decompose anaerobically to produce biogas (predominantly methane, a significant greenhouse gas) and leachate that contains nutrients and soluble organics. The leachate has the potential to pollute groundwater and may release and mobilise heavy metals from landfills. Some organic wastes such as sludges and biosolids can contain heavy metals or nutrient pollutants. Uncontrolled disposal of biosolids may lead to site contamination or water pollution. To protect our water resources, we need to prevent pollution arising from uncontrolled treatment and disposal of organic waste. Open burning of organic wastes pollutes the air and contributes to the smoke haze problem in any part of country surround the world. Organic wastes are resources and can be processed into various useful products.

Recycling and composting of organic materials such as animal waste, crop residues and green manures has a long tradition in some part of the world. In the past, the application of organic manures guaranteed a high return of organic materials and plant mineral nutrients and thus maintained soil fertility and crop yield. Because of rapid economic development coupled with the increasing urbanization and labour costs, the recycling rate of organic materials in some country agriculture has dramatically declined. Improper handling and storage of the organic wastes is causing severe air and water pollution. In addition, one of the major causes is the increasing de-coupling of animal and plant production. This is occurring at a time when "re-coupling" is partly being considered in Western countries to improve soil fertility and reduce pollution from animal husbandry. Re-coupling of modern organic waste generation is urgently needed in some country. A comprehensive plan to develop intensive organic waste management while considering the environmental impact is necessary.

2.3 Microbial Fuel Cell (MFC)

Fuel cell is an electrochemical technology that continuously convert chemical energy into electrical energy if there is fuel and oxidants (Shukla et al, 2004). MFCs are being constructed in a diversity of architectures, and different types. Many studies emphasize on exploring performance of MFCs with different substrate. The substrate which oxidized by bacterial is a significant factor in any biological process because it serves as carbon (nutrient) and energy source. Besides, Liu and Logan regarded substrate as one of the most important biological factors affecting electricity generation in MFCs (Liu H. and Logan B., E., 2004a). Many previous study used some categories substrates as fed of MFCs, such as domestic wastewaters (Min and Logan, 2004), brewery wastewater (Feng et al, 2008), waste sludge

(Jiang et al., 2009), rice paddy fields (Moqsud et al., 2015). In this study, I want to more focus and more explore to used feedstock or organic waste (especially) persimmon fruit waste for MFC.

2.3.1 Exoelectrogens

Exoelectrogens are catalytic microorganisms competent which transfer the electrons either directly to the electrode surface and/or mediate them by shuttle the electrons exogenously to the electrode surface without utilizing artificial mediators (Ravinder K. et al, 2016). An exoelectrogen normally refers to a microorganism that has the ability to transfer electrons to the electrode (Logan, 2008). While exoelectrogen is the predominant name, other terms have been used, such as electrochemically active bacteria, anode respiring bacteria, electricity bacteria; and electricigens.

2.3.2 Electron Transfer Mechanism

As a possible candidate for long-term, sustainable, energy generation, MFC concept is possible due to exocellular electron transfer where electrons are passed on from the organism via different mechanisms to insoluble extracellular electron acceptors. MFCs are devices that convert chemical energy of feedstock into electricity through the metabolic activity of microorganisms. MFCs generally consist of two compartments; an anode and a cathode separated by an ion-permeable material. In the anode, microorganisms oxidize organic matter (fuel) and release CO_2, electrons and protons. Electrons produced in the anode flow to the cathode via an external circuit as the result of electrophilic attraction from the cathode electrode, whilst protons migrate from the anode to the cathode through the separator between the two compartments.

The electrons and protons subsequently combine with oxygen (final electron acceptor) and this reduction reaction completes the circuit. The quantity of electrons flowing through the external circuit is the electricity being produced i.e. current. (Li et al., 2008; Chae et al., 2008). A reaction formula occurs as :

Positive: $6O_2 + 24H^+ + 24e- \rightarrow 12H_2O$

Negative: $C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$

2.3.3 MFC and Waste Management

Anaerobic microorganisms which can consume waste while generating electricity in a type of microbial electrochemical cell known as a microbial fuel cell. Some research explores the ability of these microbes to clean up waste and produce useful energy in the form of electricity or hydrogen. In MFC, they are used for electricity production and also they are transformed into less toxic metabolites, which demonstrates its another potential use in waste management and pollution control. Till now, many microbes and a waste variety of substrates (including waste and xenobiotics) have been used to produce electricity.

2.3.4 Development of MFC

Renewable bioenergy is one way to reduce the global warming crisis. Electricity produced by using microbial fuel cells (MFCs) is the latest development in energy biology. Microbial Fuel cells put forward is a possibility to get electricity from organic waste and renewable biomass. Microbial electrochemical system (MES), including microbial fuel cells (MFCs), microbial electrolysis cells (MECs), microbial reverse-electrodialysis cells and microbial electrosynthyesis (MES) is a way to get energy from organic waste materials and convert waste into materials chemistry.

Applications MFCs are very widely included in power sources, production of bio-hydrogen, wastewater treatment, bio-sensors and bioremediation. MFCs can change biomass into electricity at low temperatures and concentrations substrate. The proton exchange system can affect the system resistance in MFCs and loss of polarization and concentration can affect the power output of MFCs (Reddy, 2010). Electrons are charged subatomic particles negative where these electrons are used to generate electricity.

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CHAPTER 3

MATERIALS AND METHODS

3.1. MFC Design

While MFCs are a relatively new technology, the concept of utilizing microorganisms to generate electricity was first recognized in the 18th century. Potter was the first person to demonstrate a half cell using microorganisms to generate electricity in 1912. The results of these experiments were not reported for almost 20 years. Some studies on microbial and bio-fuel cells were reported between the 1950s and the 1980s, though little attention was paid to this technology until recently (Bullen et al, 2006).

Early MFC designs utilized two separate chambers, one for the anode side and one for the cathode side (Bullen et al., 2006). The single chamber design was annular in nature, consisting of a central, hollow cathode, separated from the anolyte by the proton exchange membrane. Multiple anode rods existed in the anode chamber, while the whole structure was encapsulated in an acrylic glass cylinder. The electron acceptor was oxygen that passed through the centre of the hollow cathode. The greatest advantage of this design is the exploitation of the relatively large concentration of oxygen in air as opposed to water. Subsequent studies of MFCs by this research group involved the single chamber MFC.

A prototype of the MFC was first designed using a simple Microsoft word. This basic design was then constructed as a working model in the laboratory Figure 3.1 illustrated the basic design of prototype MFC which developed.

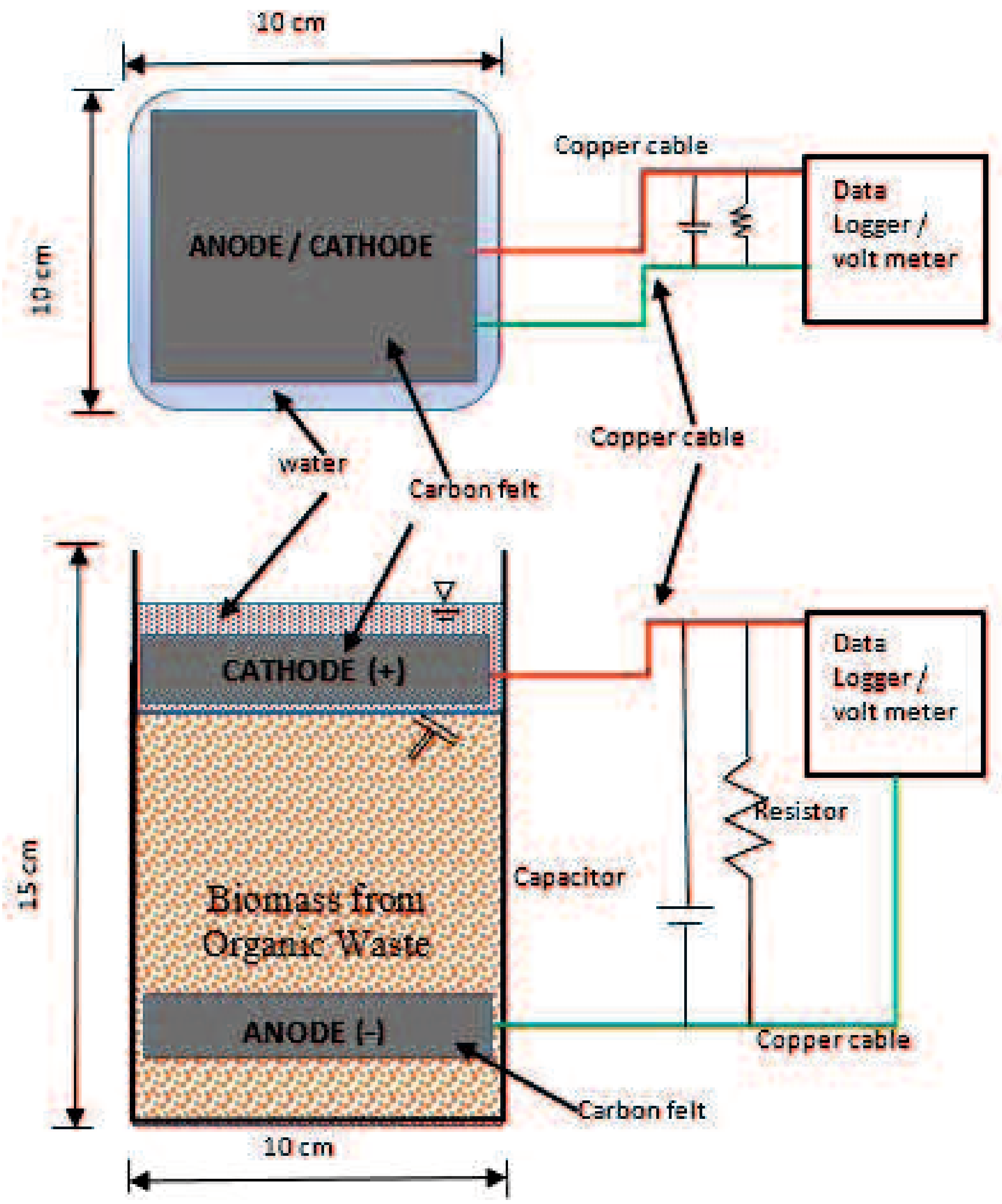

Figure 3.1 Basic Design of Prototype MFC which Developed.

3.2. MFC construction and operation

The basic design of the microbial fuel cell consists of carbon felt, soil, some organic wastes, effective microorganisms / EM (commercially available from EM Kenkyusho, Shizuoka, Japan), acrylic rectangular chambers, volt meter, resistors, iron wires, alligator clips, capacitor and some supporting test equipment. The EM which used was for each case to start the bioelectricity generation (as microbial seed) and to reduce possible odour from organic wastes during the investigation. The soil was collected from Yamaguchi Prefecture and classified as Tokiwa Park soil. The organic wastes such as cow dung taken from the Department of Agriculture, Yamaguchi University at Yoshida campus, Japan while the chicken droppings and leaf mold are used coming from Japan Agricultural Office, Ube city branch. In microbial fuel cell (MFC), bacteria used as biocatalyst to convert biodegradable organic substrates harmless by-products with the simultaneous production of electricity energy. The blended sample was poured into the container. Electrodes were used for both electrodes (anode and cathode). Some materials for the electrodes such as carbon fiber, bamboo charcoal, carbon felt and carbon cloth.

The anode was set approximately 5 cm below the surface of the compost, while the cathode was placed immediately above the compost surface, but under the water. The area of electrodes (anode and cathode) were kept the same as the cell areas (100 cm^2). Then they were connected by a single iron wires and had a fixed external capacitor and a resistance (100Ω) used as the load for the power being generated which measured by volt meter daily. A 16V 1000μF capacitor was used in this research to store the electric energy, to reduce the voltage with less power wasted and to keep constant voltage. Experiments were conducted with pure samples and mixed samples under a constant room temperature of 25^0 C. The voltage which generated across the resistor and capacitor was monitored every day at 1 pm. It is estimated that at that time is the most appropriate time for research measurement. Polarization curve and power density–current curves were investigated by using different resistors and internal resistances and power densities were calculated as described elsewhere (Logan and Regan, 2006). Electrode output was measured in volts (V) against time. The current I in amperes (A) was calculated using Ohm's law, as well as the current density and current density.

Furthermore, the root-mean-square deviation (RMSD) is used as a statistical analysis which is a good accuracy measurement. It serves to aggregate the magnitudes of various errors into a single measure. The RMSD is used to compare differences that may vary, neither of which is accepted as the result within the total period of the experiment.

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CHAPTER 4

Bioelectricity Generation by Using Mixed Sample of Organic Waste and Soil in Microbial Fuel Cell

4.1 Introduction

Energy problems and resolving

Electricity is the essential important thing for all aspects of human life, but the current supply is still not able to meet the increasing of electricity demand in almost all parts of the world. According Rakesh et al, 2014 in recent decades, world energy consumption has a progressive trend. At present, this energy requirement is satisfied mostly by fossil fuels. Depletion of conventional energy sources and also its negative effect on environment has led many researchers to look for alternative energy sources. The new sources of energy should be renewable and also environmental-friendly. Resource recovery from waste material is an important topic in both developed countries and developing countries. A major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery (Moqsud, 2003; Sujauddin and Hoque, 2008; Zurbrugg et al., 2005). The future of energy sustainability and supply is likely to rely on renewable energy sources. The production of electricity or biofuels using innovative technologies and renewable sources is a global priority in terms of energy strategies (Resch et al., 2008).

One of the renewable energy sources for the production of electricity is fuel cells (FC) (Mostafa et al, 2011). Microbial fuel cells (MFCs) are bio-electrochemical transducers that convert microbial reducing power (generated by the metabolism of organic substrates) into electrical energy (Allen and Bennetto, 1993; Bennetto, 1984;

Habermann and Pommer, 1991; Logan and Regan, 2006; Hong et al., 2009). They use the available substrates from renewable sources and convert them into harmless by-products with simultaneous production of electricity. Many other forms of waste biomass exist, each containing large amounts of energy and can be a better source of power generation in MFCs. These remain generally unexploited and yet to be tested in MFCs for microbial degradation and ultimately bioelectricity generation. From the characteristic analysis of the solid waste of many developing countries it is found that the major portion (more than 80%) of the total solid waste comprises of organic waste, which does not usually get much attention for recycling or resource recovery. The annual organic waste generated from the food industries and kitchen waste in Japan is about 20 million tons per year (Koike et al., 2009). Most of this waste is directly incinerated with other combustible waste, and the residual ash is disposed of in landfills. However, incineration of this water-containing waste is energy-consuming. MFC in hybrid composting method by reusing kitchen waste as a raw material has also been proposed (Moqsud and Omine, 2010).

There has already been some research of microbial fuel cells (MFCs) to generate electricity from organic wastes or wastewaters (Daniel et al.,2009; Khalid et al., 2011; Jiang et al., 2010; Logan, 2007; Luste and Loustarinen, 2011; Li et al. 2013; Zang et al., 2013; Spiegel and Preston, 2003) and from cheap biomass sources, such as raw corn stover (Wang et al., 2009), rice (Hassan et al., 2014) and wheat (Zhang et al., 2009) straw hydrolysate, and algae powders (Velasquez-Orta et al., 2009).

Reduce environmental impact of livestock waste

A characteristic of livestock waste is that it entails unique problems other than water pollution such as stink and noise. The livestock waste surrounding the world especially in Japan has expanded rapidly over the last few decades. Based on data from

Ministry of Agriculture, Forestry and Fisheris Japan (MAFF,2010), from 1973 to 1990, the number of cases of trouble decreased to one-third, or around 2,000 cases, and the number of cases has remained essentially stable since then. The composition of the problems that occurred in 2010 shows in Table 4.1.

Table 4.1 Environmental Problems due to Livestock Farming in Japan (2010)

	Stink	Water pollution	Pest	Others	Total
Dairy cattle	390	199	24	151	685
Cow cattle	220	114	22	70	394
Hog	466	246	8	50	663
Poultry	254	44	87	33	399
Others	27	11	4	7	44
Total	1,357	614	145	311	2,185
Percentage	62.1%	28.1%	6.6%	14.2%	100.0%

(Source: MAFF, Department of Production,2010)

Notes: 1) The number of problems indicates the number of local residents' complaints on environmental problems to local government in the given year.
2) The percentage is the rate of livestock farmers in trouble out of the total number of livestock farmers
3) 'Others' includes noise and inflow of animal waste.

While the total number of animals has increased, a vast amount of animal wastes is being produced, it has become a serious problem of organic waste, it should be utilized and recycled as a valuable resource. According to related statistics, the amount of livestock waste produced in Japan in 2010 reached 86.95 million tons, of which that from cattle occupied 58.9% and and 10% of it was abandoned in the environment without any treatment (MAFF, 2011). The wastes should be utilized, reuse and recycled as a valuable resource. These organic wastes contain large amounts of nutrients and various other minerals. Advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Cristiani et al., 2013).

Objectives of study

The objective of this study is to explore some mixed samples of organic waste and soil as a low cost potential substrate for bioelectricity generation so that this organic waste can be recycled and provide some sort of solution to populations experiencing electricity shortage. It is an efficient and eco-friendly solution for organic waste management, provide green and safe electricity.

4.2 Materials and Methods

4.2.1 Experimental materials and laboratory instruments.

To conduct the first experiment, some materials were prepared, such as carbon felt, mulch, cow dung, chicken droppings, breaker, data logger, resistor, cable, some alligator clips and some equipment test used in loss on ignition test. Cow dung was collected from the Department of Agriculture, Yamaguchi University at Yoshida campus, Japan. Some chicken dropping was collected from Japan Agricultural Office, Ube city Branch. However, if cow dung, chicken dropping and leaf mold is recycled properly then it could be a good source of compost, as well as soil conditioner after obtaining bioelectricity.

4.2.2 Design of MFC for 1st experiment

Figure 4.1 illustrates the structure of MFC acrylic rectangular chamber for my first time experiment. A rectangular (10x10x15 cm) acrylic container was used in the laboratory as a cell. Then 20 g and 40 g respectively of organic waste were mixed with 400 g of soil and 100 g of water and 3 g of effective microorganisms were blended properly by a blender. The blended sample was filled in the container. Carbon feld was used for both the anode and cathode. The anode was inserted into the sample and the cathode was placed on the top. The area of the electrode (carbon feld) was kept same with the cell areas (100 cm^2). Both the anode and cathode were connected with a data logger (Graphtec midi Logger GL 200) which was set to measure the voltage at 20 min intervals. The laboratory test was conducted in a constant room temperature of 25^0 C.

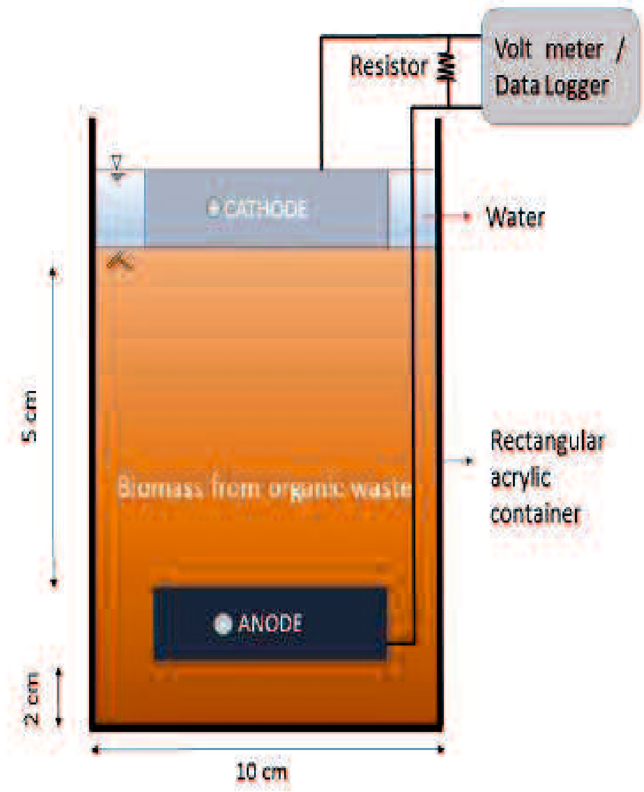

Figure 4.1 The experiment structure of the microbial fuel cell

Length of the anode and the cathode was set about 5 cm. In the microbial fuel cell, water plays a role of separator. The value of resistance was used of 100Ω. Experiments conducted with a single sample and in mixed samples.

4.2.3 Experiments in single and mixed sample

In this experiment we compared the three samples in 20g and 40g of cow dung, chicken droppings and leaf mold respectively as well as mixed with soil fill in each sample.

4.2.4 Loss on ignition test of the sample

The content of organic matter is I thought to be involved heavily on the amount of power generation for power generation of this microbial fuel cell. Since microorganisms reason that emits electrons when decomposing organic matter, and because he considered that organic substances can be obtained a high voltage the more. It was subjected to ignition loss test to examine the organic content of the four samples used this time. Table 4.2 is the test results of this four samples.

Table 4.2 Result of the loss on ignition test

SAMPLE NAME	Loss on Ignition (LOI)
Soil	20.33%
Cow dung	87.24%
Chicken dropping	82.55%
Leaf mold	80.33%

Sample that contains the most organic matter of 87.24% is cow dung. Those values that contains the lowest organic matter of 20.33% is the soil.

4.3 Results and Discussion

4.3.1 Experimental results of a single sample

Sample obtained the highest values as seen in Figure 4.2 illustrates the variation of voltage with duration of time by using some samples are 138.8 mV, 89.8 mV, 62.8 mV and 45.4 mV obtained by sample of chicken droppings, leaf mold, cow dung and the soil, respectively. In the case of chicken dropping show as the highest voltage.

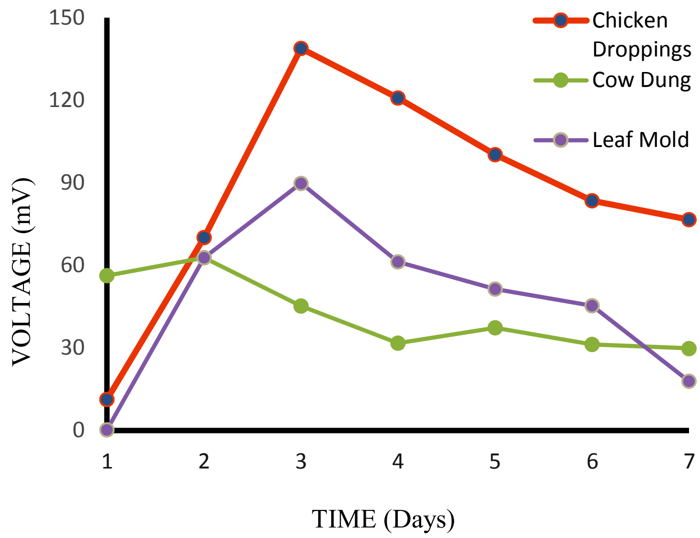

Figure 4.2 Variation of voltage with time obtained by single sample

Sample obtained the second highest value was microbial fuel cell using the leaf mold. Then the lowest value was a microbial fuel cell of the mulch only. In the case of chicken droppings, the voltage (*V*) increased sharply during the initial time (3 days); after that, it decreased gradually after that. During the initial stage, the bacteria got ample food and their activities increased very rapidly (Moqsud et al., 2011). For that reason, the voltage increased sharply. The voltage decreased gradually with time as the supply of food was used up by the bacteria (Moqsud et al, 2014).

4.3.2 Experimental results in the mixed sample.

Some result of using the mixed sample is illustrated in Figure 4.3. It shows a difference of initial value of the power generation as compared to the graph of a single sample.

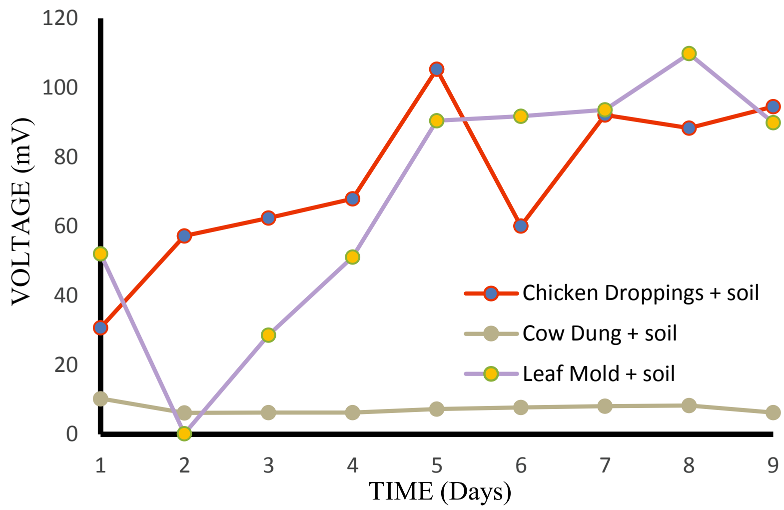

Figure 4.3 Variation of voltage with time obtained by mixed sample

Maximum value of the voltage obtained by using a mixed sample of chicken droppings and the soil was 105.3mV. Maximum value of the voltage obtained by using a mixed sample of cow dung and soil was 44.4mV. Maximum value of the voltage obtained by using a mixed sample of leaf mold and soil are 109.8mV. It is the highest among the three mixed samples. The possible reason why leaf mold and soil showed a higher value of voltage than the other samples is that leaf mold as a form of compost, were rich in nutrients and organic matter which support the growth of microorganisms (Jati SH, 2001; Hamzah, 1983)

4.3.3 Polarization curve for MFCs

The polarization curve of the MFC by using mixed sample of leaf mold and soil and also chicken droppings and soil in this experiment illustrated in Figure 4. A polarization curve is used to characterize current as a function of voltage. The polarization curve shows how well the MFC maintains voltage as a function of the current production. This polarization curve in Figure 4.4 was created at day of 5th and 8th after starting the experiment from each sample respectively. The polarization curve for all samples displayed similar trends. The trend of the polarization curve was very much similar with the polarization curve which was stated in other literature concerning MFCs (Logan and Regan, 2006; Moqsud et al., 2014; Moqsud et al., 2013). Figure 4.4 shows the maximum power density of around 0.07988 W/m^2 for sample of leaf mold and soil and around 0.07176 W/m^2 for sample of chicken droppings and soil. The power densities showed an incremental trend with decreasing external resistance and reaches to peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behaviour. (M.A. Moqsud et al, 2015)

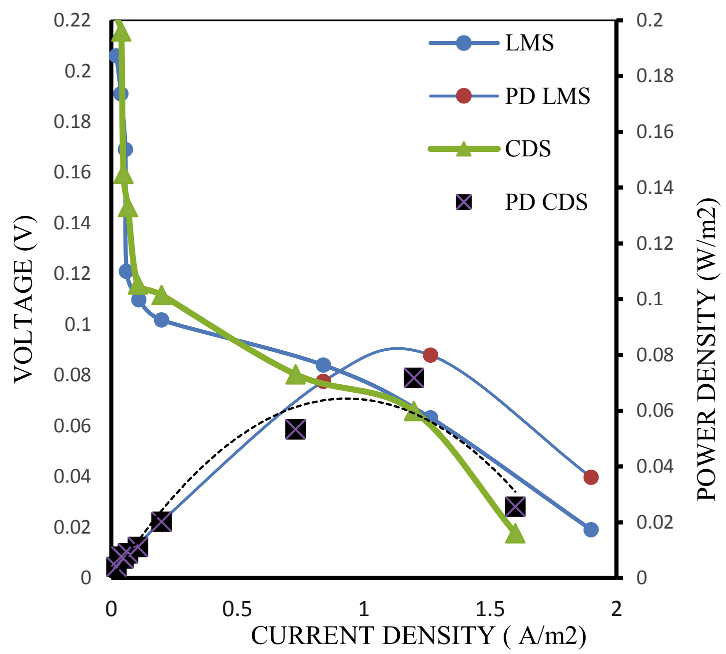

Figure 4.4 Polarization curve of the MFC at the 5th and 8th day after the experiment started

4.3.4. Relationship between voltage and current in the MFCs

Figure 4.5 shows the relationship between voltage and current in the MFCs for 5th and 8th day of elapsed time. It is found that the relationship was almost linear.

The intercept and inclination of the line represents electromotive force and internal resistance for the MFCs, respectively.

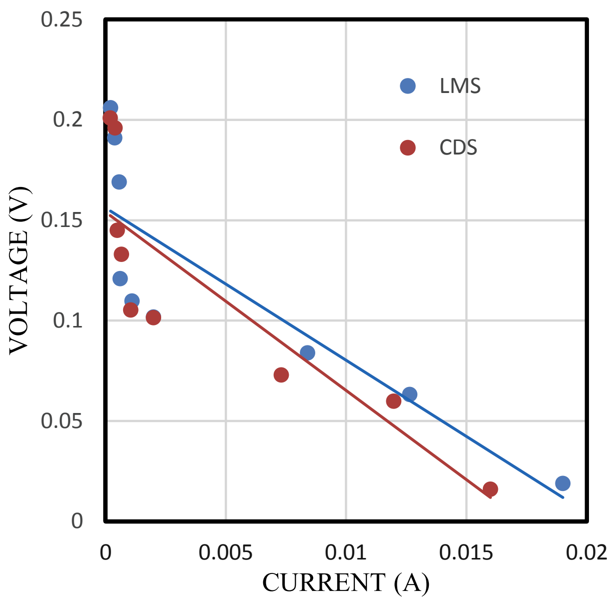

Fig. 4.5 Relationship between voltage and current in the MFCs

It represents that MFC with a good performance indicates high electromotive force and low internal resistance. The electromotive force of MFC was approximately 0.206 V and 0.201 V. The internal resistance of MFC was relatively low. On the other hand, the performance of MFC with chicken droppings and soil is lower than MFC with leafmold and soil. Maximum electric power is calculated from the linear relationship between voltage and current. The maximum power per anode area is 0.07988 W/m^2 for MFC of leaf mold and soil and 0.07176 W/m^2 for MFC of chicken droppings and soil.

4.4 Conclusion

In this study, it was observed that some of the planet's tiniest inhabitants might help address two of society's biggest environmental challenges: how to deal with the vast quantities of organic waste produced and where to find clean, renewable energy. MFCs using soil and organic wastes in this experiment, have proved to be a good way to get green electricity generation and to recycle organic waste in order to maintain healthy and pollution free environments, particularly in developing countries where solid waste management is a great concern.

The results towards the microbial fuel cell of a single sample has been obtained a higher value than the power generation amount of the microbial fuel cell using the mixed sample. A small amount of electricity is also necessary for electricity-scarce populations (25% of the world's population are deprived of electricity). Small amounts of electricity can be used for lighting light-emitting diode lamps or just to charge a mobile phone in a particular household using their own waste. Though the amount of electricity is still small enough in this MFCs work, it is still very much needed for the future green energy era, as it is an abundant source of biomass in many developing countries, furthermore this relative importance since the organic wastes in this case is actually a wastes that must be disposed of at a non negligible cost. Increasing the portion of biomass in the energy matrix will help to diminish the negative environmental impact of atmospheric CO_2 accumulation and to meet the targets predicted in the Kyoto protocol. So, by using organic waste, we can address some important problems currently faced by the world, it is the health and pollution of geo-environment problems due to unmanaged organic waste, as this organic waste would be used as raw material to generate electricity (people will reuse it carefully and the urgent need to reuse organic wastes is very much an important concern for the sustainable geo-environment in surrounding the world. Finally, it is clear that bioelectricity can be produced by organic wastes, which could provide some sort of 'light of hope' to the 1.6 billion people who still live in the dark at night all over the world.

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CHAPTER 5

The Effectiveness of Animal Dungs and Leaf mold for Bioelectricity Generation Using Microbial Fuel Cell with Soils

5.1 Introduction

For human life, the availability of sufficient and safe energy is the main requirement to achieve prosperity and increase the sustainability of the economic development of a society accompanied by the preservation of the environment. Depletion of conventional energy sources and also its negative effect on environment has led many researchers to look for alternative energy sources. Rapid growth and improving prosperity mean growth in energy demand is increasingly coming from developing economies, particularly within Asia, rather than from traditional markets in the OECD (Organisation for Economic Co-operation and Development). The relentless drive to improve energy efficiency is causing global energy consumption overall to decelerate. And, our society is facing a serious energy crisis and resource recovery from organic waste. It about 1.3 billion people in the world live without access to power. Table 5.1 illustrates some region in the world where still lie in no electricity. Providing electric power to these populations will cause a significant jump in demand in the coming decades. Meanwhile, depletion of conventional energy sources and its negative effect on environment has led many researchers to look for alternative energy sources. There are programs in many parts of the world to create “mini-grids” using renewables. But as electricity-generating capacity inevitably grows ever larger, we will not be able to avoid the increased use of fossil fuels as well — and especially coal. New coal-burning power plants will emit less carbon dioxide and other greenhouse gases than their predecessors, but the strain on the atmosphere will be substantial nonetheless (International Energy Agency, 2015). Moreover, we are currently depending upon fossil fuels such as coal, oil, natural gas for our energy requirements. Planet earth is facing an energy crisis owing to an escalation in global demand, continued dependence on fossil based fuels for energy generation and an increase in world population, exceeding seven billion people and rising steadily (Coyle and Simmons, 2014). Excessive burning of fossil fuels not only depletes natural non-renewable resource but also leads to carbon dioxide emission which give rise to life threatening conditions such as ozone layer depletion, climatic change and acid rains (Vernona et al, 2011). This persuades us to find a suitable alternative energy source. Many research works have been carrying out to find an energy source which is renewable in nature, one such thing is microbial fuel cells. Search of alternative energy such as organic waste resource recovery is an important topic. This include technologies consist of any waste treatment process that creates new energy in the form of electricity, heat or transport fuels (e.g. diesel) from a waste source. So, we can manage and control of its polluting effects on the environment and climate change to become a precious resource and fuel for the urban sustainable energy mix of tomorrow. However, an increasingly demanding set of environmental, economic and technical factors represents a challenge to the development of these organic waste technologies.

Table 5.1 Region in the world where still in no electricity.

REGION	POPULATION (in Billion)	POPULATION WITHOUT ELECTRICITY (in Billion)	% OF THE LACK OF ELECTRICITY
ASIA	3.6	0.622	17.2
AFRICA	1.1	0.6226	56.6
MIDDLE EAST	0.2148	0.0177	8.2
LATIN AMERICA	0.4661	0.0232	4.9
ARROUND THE WORLD	**7.5**	**1.3**	**17.3**

(Source : reprocessed from International Energy Agency's electricity database and methodology, 2015)

The world generates huge volumes of organic waste. Much of this waste has largely been left to rot in the fields, but several rapid advances in technology are creating opportunities to turn organic waste into valued commodities such as power, or into added-value products such as fertilizer and clean fuel. By way of example, South East Asia produces more than 50% of the total global coconut production. The coconut waste (consisting of coconut husk) is a feedstock for two distinct products that serve two large global markets: coco-fibre products including geo-textiles and coco-peat products, an organic substitute which can replace a large part of global substrate market, driven by new regulations to limit the use of environmentally-damaging traditional bogland peat.

Organic waste generation rates are affected by socio-economic development, degree of industrialization, and climate. Generally, the greater the economic prosperity and the higher percentage of urban population, the greater the amount of solid waste produced. Reduction in the volume and mass of solid waste is a crucial issue especially in the light of limited availability of final disposal sites in many parts of the world. Although numerous waste and by-product recovery processes have been introduced, anaerobic digestion has unique and integrative potential, simultaneously acting as a waste treatment and recovery process. The enormous increase in the quantum and diversity of organic waste materials generated by human activity and their potentially harmful effects on the general environment and public health, have led to an increasing awareness about an urgent need to adopt scientific methods for safe disposal of organic wastes.

While there is an obvious need to minimize the generation of wastes and to reuse and recycle them, the technologies for recovery of energy from wastes can play a vital role in mitigating the problems. Besides recovery of substantial energy, these technologies can lead to a substantial reduction in the overall organic waste quantities requiring final disposal, which can be better managed for safe disposal in a controlled manner while meeting the pollution control standards. The organic waste which generated has increased rapidly over the last few decades and a major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery such as investigated by Sujauddin (Sujauddin et al, 2008) that solid waste management (SWM) is a multidimensional challenge faced by urban authorities, especially in developing countries, while Moqsud (Moqsud, 2003) and Zurbrugg (Zurbrugg et al 2005) studied the organic waste can be effectively recycled by composting.

Data from reference cities show that although there is wide variation, generally as a nation's wealth increases, so does its per capita production of waste. Average figures are 225 kg per capita per year in low-income, 330 kg in middle-income, and 550 kg in high-income countries (Waste Management World, 2011). Where large quantities of waste are created, usually in the major cities, there are inadequate facilities for dealing with it, and much of this waste is either left to rot in the streets, or is collected and dumped on open land near the city limits. There are few environmental controls in these countries to prevent such practices. There are a variety of ways of using organic waste and in this technical brief we hope to outline a few of the principle methods used for putting it to good use. The three main ways of using organic waste that we will look at are for soil improvement, for animal raising and to provide a source of energy. According to FAO (Food and Agriculture Organization of The United Nations Organization), 15% of the estimated fruit and vegetable production will be a waste and roughly one-third of the edible parts of food produced for human consumption, gets lost or wasted globally, which is about 1.3 billion ton per year (FAO, 2011). So that, if about 15 % of the waste is abandoned in the environment without any treatment or it is not properly treated for resource recovery, they entail unique problems as shown in Table 5.2.

Other problems involved with the un-well management of organic wastes are:

- The possible contamination with environmental pollutants such as heavy metals and organic toxics: hygienic aspects: high contents of extraneous materials.

- Consequently, a comprehensive planning framework for the use of organic wastes must consider nutrient contain, the necessity to avoid the input of contaminants into the soil and the food-chain and the maintenance of quality control.
- An increasing problem in densely populated industrial countries is that lack of land area often does not allow for the proper application of organic waste fertilizers.

Table 5.2 Environmental Problems due to Livestock Farming in Japan (2010)

	Stink	Water	Pest	Others	Total
Dairy cattle	390	199	24	151	685
Cow cattle	220	114	22	70	394
Hog	466	246	8	50	663
Poultry	254	44	87	33	399
Others	27	11	4	7	44
Total	1,357	614	145	311	2,185
Percentage	62.1	28.1	6.6	14.2	100.0

(Source: MAFF, Department of Production, 2010).
Notes:1)The number of problems indicates the number of local residents'complaints on environmental problems to local government in the given year.
2)The percentage is the rate of livestock farmers in trouble out of the total number of livestock farmers
3)'Others' includes noise and inflow of animal waste.

Some various reasons for improving the recycling of municipal and industrial organic waste on agricultural land. These include:

- To recycling of organic matter and mineral nutrients, and possible suppression of soil-borne pathogens.
- Conservation of naturally available but limited supplies of nutrient resources.
- Avoidance of alternative disposal methods which are environmentally damaging, expensive, or limited by space.

Utilization of municipal organic waste principally to create clean energy through the development and operation in some itinial project activity to utilize municipal waste to energy ("MWE"). With increasing attention to a circular economy, "resource recovery and reuse" (RRR) holds a prominent position in several Sustainable Development Goals, inevitably linking the challenges of all human living sectors.

Whereas, the organic wastes contain large amounts of nutrients and various other minerals. Cristiani et al (Cristiani et al, 2013) considered the advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates to produce electrical energy or other high-value added products. Table 5.3 shows the nutritional values of organic wastes and soil used in this research.

Table 5.3. Nutritional Values of Organic Waste and Soil.

Parameter	SOIL	COW DUNG	CHICKEN DROPPING	LEAF MOLD
N (mg/kg)	5.1	2.04	1.72	4.3
P (mg/kg)	10.3	0.76	1.82	3.6
K (mg/kg)	124.2	0.82	2.18	5.0
EC (mS/cm)	0.395	18.7	19.74	1.5
C/N ratio	6.72	19.9	9.65	10.2

Mostafa et al (Mostafa et, 2011) considered one of the renewable energy sources to produce electricity is fuel cells (FC). Moqsud (Moqsud et al 2012a, 2013) investigated some previous studied for MFC use the available substrates from renewable sources and convert them into harmless by-products with the simultaneous production of electricity. Allen and Benneto (Allen and Benneto, 1993), Daniel et al (Daniel et al, 2009), Li et al (Li et al 2012), evaluated for electricity generation using waste water, Bennetto (1984), Logan et al (Logan et al, 2006 and 2007) studied using bacteria. Habermann and Pommer (Habermann and Pommer, 1991) were to develop a low maintenance fuel cell system with long-term stability with sulphide storage capacity, Hong (Hong et al, 2009) developed microbial fuel cell using sediment. Khalid (Khalid et al, 2011) developed organic waste for biogas and other energy-rich compounds. Microbial fuel cell using sewage sludge as fuel studied by Jiang (Jiang et al,2010). Spegel and Preston (Spiegel and Preston, 2003) demonstrated energy from anaerobic digester gas (ADG). Zhang (Zhang et al, 2009) analyzed of microbial communities in wheat straw biomass-powered microbial fuel cells. Moqsud (Moqsud et al,2015) investigated bioelectricity generation by using paddy plant microbial fuel cells (PMFCs) in soil mixed with compost, moreover Wang (Wang et al,2009) studied by corn stover biomass while Hassan et al (Hasan et al, 2014) evaluated rice straw for electricity. Velasquez (Velasquez et al, 2009) investigated algae in microbial fuel cells. Jauharah (Jauharah et al,2015) developed electricity from a mix of fruit and vegetable wastes. Brahmaiah (Brahmaiah et al,2016) investigated municipal solid waste generated electricity. Resch et al (Resch et al, 2008) considered the production of electricity or biofuels using innovative technologies and renewable sources is a global priority in terms of energy strategies. Microbial fuel cell is a bioreactor that converts chemical energy present in the organic matter into electrical energy by using microorganisms as a catalyst (Potte, 1991). This catalytic reaction takes place under anaerobic condition and the microorganisms used are termed as electricigens (Allen and Benneto, 1993). The advantages of using microbial fuel cell is that they can be used at room temperature itself, easy to handle, not toxic, it can extract 90% of electrons from organic compound, self-sustaining, renewing (Davis, 2007). The disadvantage is that they cannot produce much current and scale up process is the major problem (Rahimnejad et al, 2015). Applications are they can be used to produce hydrogen, used in wastewater treatment, used as biosensors, desalination process can be done using microbial fuel cells (Das, 2010). This research becomes very important and very interesting because of the increasing need for alternative energy while the amount of non-renewable fuel is decreasing. MFC has been well established for almost one hundred years.

However, Jessica Li (2013) investigated this capability did not exceed laboratory based experiment until the 20th century when research on this subject and the creation of MFCs received sporadic approach. The objective of this study is focus and prove the ability of some cheap and abundant-organic wastes such as cow dung, chicken dropping and leaf mold mixed with soil as a very prospective substrate for bioelectricity generation. Thus, it develops a microbial fuel cell that generates green and safe electricity using animal dungs and leaf mold mixing with soil as an efficient, renewable and an eco-friendly solution for organic waste management to produce clean energy and other sustainable resources.

5.2 Materials and methods

5.2.1 Materials preparation.

To conduct the experiments which was done in Department of Civil and Environmental Engineering of Yamaguchi University-Japan, some materials were prepared such as carbon felt, soil, cow dung, chicken droppings, leaf mold, effective microorganisms / EM (commercially available from EM Kenkyusho, Shizuoka, Japan), acrylic rectangular chambers, volt meter, resistors, iron wires, alligator clips, capacitor and some supporting test equipment. The EM which used in this work was for each case to start the bioelectricity generation and to reduce possible odour from organic wastes during the investigation. The Soil which used in whole experiments were sampled in the 10 cm layer of natural Tokiwa Park soil, located in the plant area of Tokiwa Park (33°57'02.9" N , 131°16'47.5" E) at Ube city, Yamaguchi Prefecture, Japan. The soil used in this work as they are thought to increase not only the physical volume of samples properties and the optimum content but it also to increase the nutrient ability supplying food for microorganism to generate electricity. A 16V 1000 μF capacitor was used in this research to store the electric energy, to reduce the voltage with less power wasted and to keep constant voltage. Carbon felt type of Kreca Felt X F 210-X was used. Some advantages that arise in using of carbon felt such as a large surface area that offers sufficient reaction sites for the electron-transfer re-actions, their suitability for mass production and good process ability, but their properties vary with the raw material used for their fabrication. The property of the electrodes shows at table 5.4.

Table 5.4 Properties of Carbon felt

PROPERTIES	**MEASURE VALUE**
Fiber grade	Carbonized
Ash content (%)	≤ 1.0
Thickness (mm)	10
Unit Mass (g/m^2)	500
Bulk density (kg/m^3)	50
Carbon Content (%)	≥ 97

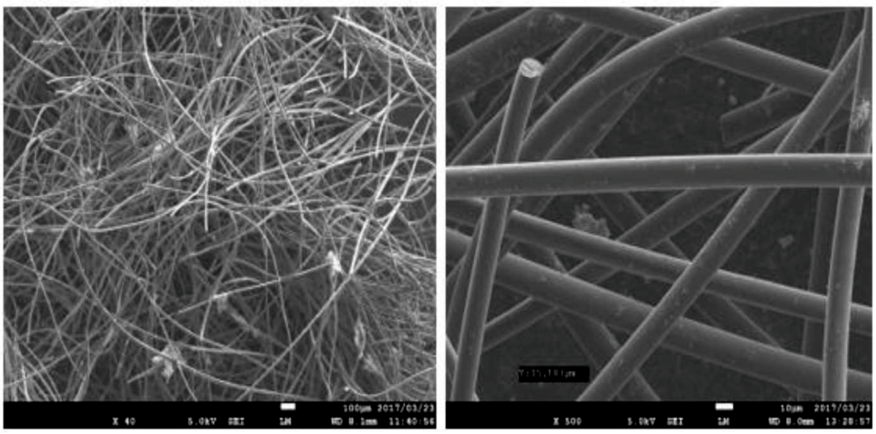


Figure 5.1 SEM Images of Carbon Felt as Electrode (in scale 40x and 500x)

Furthermore, figure 5.1 show the SEM images of carbon felt as electrodes. The Cow dung were taken from the Department of Agriculture, Yamaguchi University at Yoshida campus, Japan. The chicken droppings and leaf mold were collected from Japan Agricultural Office, Ube city branch.

5.2.2 MFC assembly

In this study, the MFCs employed a blend of some organic wastes and soil which over a testing time within 21 days. Figure 5.2 describes the schematic diagram for the MFC in this study. Then, an amount of each organic waste (400 g), 400 g of soil and add 4 g of EM were blended with added 150 ml of water until mixed completely.

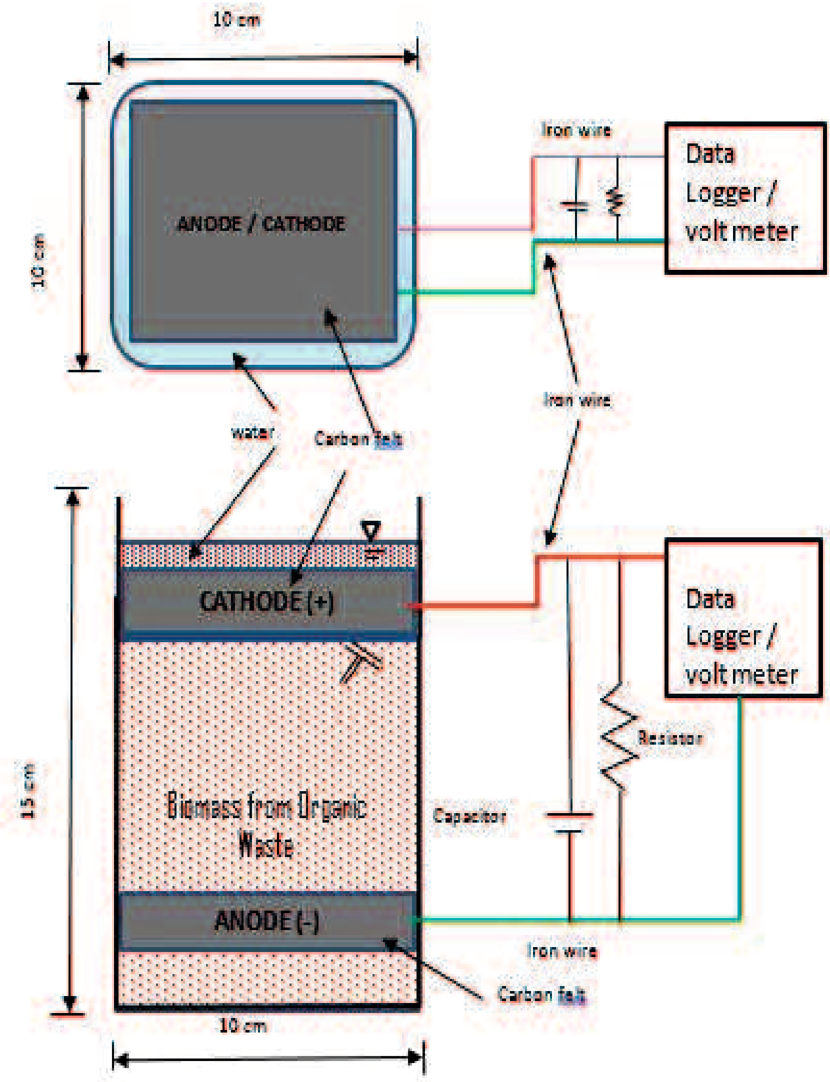


Figure 5.2 The schematic diagram of the MFC used in this study.

The blended sample was poured into the container. Carbon felt was used for both electrodes (anode and cathode). The anode was set approximately 5 cm below the surface of the compost, while the cathode was placed immediately above the compost surface, but under the water. The area of electrodes was kept the same as the cell areas (100 cm^2). Both the anode and cathode were connected by a single iron wires and had a fixed external capacitor and a resistance (100Ω) used as the load for the power being generated which measured by volt meter daily. The laboratory tests were conducted under a constant room temperature of 25^0 C. Experiments were conducted with pure samples and mixed samples.

In the anode compartment of MFC devices, microorganisms metabolize a substrate such as sugar in absence of oxygen, and they produce carbon dioxide, protons and electrons as describe below:

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^- \quad (1)$$

When oxygen is supplied from air to the cathode, following reaction is proposed:

$$6O_2 + 24H^+ + 24e- \rightarrow 12H_2O \quad (2)$$

5.2.3 Loss on ignition test (LOI)

Loss on ignition (LOI) has been widely used as a method to estimate the amount of organic matter (Walter and Dean, 1974). Evaluated LOI test is a common and widely used method to examine the organic compounds. We conducted LOI test of the four samples used in this research. The content of organic matter is to have greatly influence to the amount of power generation in this microbial fuel cell.

Table 5.5 shows the LOI test results of the four samples. The sample which contains the most organic matter of 87.24% is cow dung. The lowest value of 20.33% is for soil. It is considered that more organic substances in a mixture of organic waste with soil that can influence on more voltage generation than soil only.

Table 5.5 Result of the Loss On Ignition Tests

Sample name	**Loss on Ignition (LOI)**
Soil	20.33%
Cow dung	87.24%
Chicken dropping	82.55%
Leaf mold	80.33%

5.2.4. Experiments on pure samples

4 samples of 400 g of cow dung, chicken droppings, leaf mold, and soil were prepared and investigated separately. Then they were added in to the each acrylic rectangular after blended completely. All samples parameter condition was showed by table 5.6.

5.2.5. Experiments on mixed sample

Soil and organic wastes in this work were mixed with a ratio of the same volume to generate bioelectricity in a microbial fuel cell (MFC). Quangguo et al (Quangguo et al, 2016) and Fedorivics et al (Fedorovics et al , 2009) studied the bacterial communities in MFC known exoelectrogenic bacteria in an acetate-fed MFC. Electroactive microorganisms can generate electricity directly from organic compounds. Due to their specific ability to transfer electrons outside the cell to the anode of the MFC, these bacteria are renowned as exoelectrogens ("exo-" for extracellular and "electrogens" for the ability). In microbial fuel cells (MFCs), many microorganisms work in a consortium state, meaning they are not in the same pure colony, but many of them and some of which have been identified as geobacter metallireducens, and rhodoferrax ferrireducens.

Table 5.6 Parameter conditions for pure samples.

Parameter	**Test I *(Soil)***	**Test II (leaf mold)**	**Test III (Cow Dung)**	**Test IV (Chicken droppings)**
Soil (g)	400	0	0	0
Organic waste (g)	0	400	400	400
pH	6.32	5.48	6.72	6.22
Electrodes (carbon felt)	Yes	Yes	Yes	Yes
EM (g)	4	4	4	4
Water (ml)	150	150	150	150

While geobacter metallireducens is a class of bacteria from the genus geobacter unique because it can produce like filaments that act as nanowires to transfer electrons from outside the cell to the insoluble electron acceptor such as iron minerals and most likely to electrodes. It is considered that more voltages can be obtained by mixing soil with organic matter. Moreover, the blended soil and some of organic waste in this work as they are thought to increase the physical volume of samples properties and it increases the nutrient supply ability for microorganism. The type and number of microorganisms which survive are different by region in the distribution of the soil. The mixture of organic constituents in the waste and microorganisms in the soil are expected to lead the higher values of output voltage. Table 5.7 illustrates the parameter condition for mixed samples.

Table 5.7 The parameter condition for mixed samples.

Parameter	**Test V** *(Leaf mold + soil)*	**Test VI** **(Cow Dung + soil)**	**Mixed test VII** **(Chicken Droppings + soil)**
Soil (g)	400	400	400
Organic waste (g)	400	400	400
pH	6.83	6.48	7.2
Electrodes (carbon felt)	Yes	Yes	Yes
EM (g)	4	4	4
Water (ml)	150	150	150

5.2.6. Measurement

Since MFC is the source of direct current (DC), in this experiment we calculate the magnitude of the potential difference (voltage) between the anode and cathode poles. The voltage which generated across the resistor and capacitor was monitored every day at 1 pm. It is estimated that at that time is the most appropriate time for research measurement.

In this research, we present the MFC's electric potentials in volts per square meter because of the difference in electrical potential between the two electrodes in the MFC circuit as the main-focus and related to the advanced plan of this research that we want to know the potential of electricity generated when coupled series due to differences potential resulting by each MFC reactor. Polarization curve and power density–current curves were investigated as described to formulated polarization curve and power density–current curves by using different resistors and internal resistances and power densities. Electrode output was measured in volts (V) against time. The current I in amperes (A) was calculated using Ohm's law,

$$I = V / R \quad (3)$$

Where V is the measured voltage in volts (V) and R is the known value of the external load resistor in Ohms (100 Ω in this study). From this, it is possible to calculate the power output P in watts (W) of the MFCs by taking the product of the voltage and current i.e.

$$P = I \times V \quad (4)$$

The power density and current density was calculated using:

$$\text{Power density} = (I * V) / \alpha \quad (5)$$

$$\text{Current density} = (V / R) / \alpha \quad (6)$$

Where α is the electrode area. Normally, the anode area is taken as the electrode area. For example, if the electrode material is rectangular the area will be simply the length multiplied by width.

Furthermore, the root-mean-square deviation (RMSD) is used as a statistical analysis which is a good accuracy measurement. It serves to aggregate the magnitudes of various errors into a single measure. The RMSD is used to compare differences that may vary, neither of which is accepted as the result within the total period of the experiment.

5.3. Results and Discussion

5.3.1. Bioelectricity results in MFC

Figure 5.3 provides the variation of voltage with duration in microbial fuel cell using pure samples. The maximum value of electricity production were 10880 ± 4.784 mV/m^2, 8980 ± 3.265 mV/m^2, 6280 ± 5.887 mV/m^2, 6070 ± 7.048 mV/m^2 for pure samples of Test IV, Test II, Test III, and Test I, respectively.

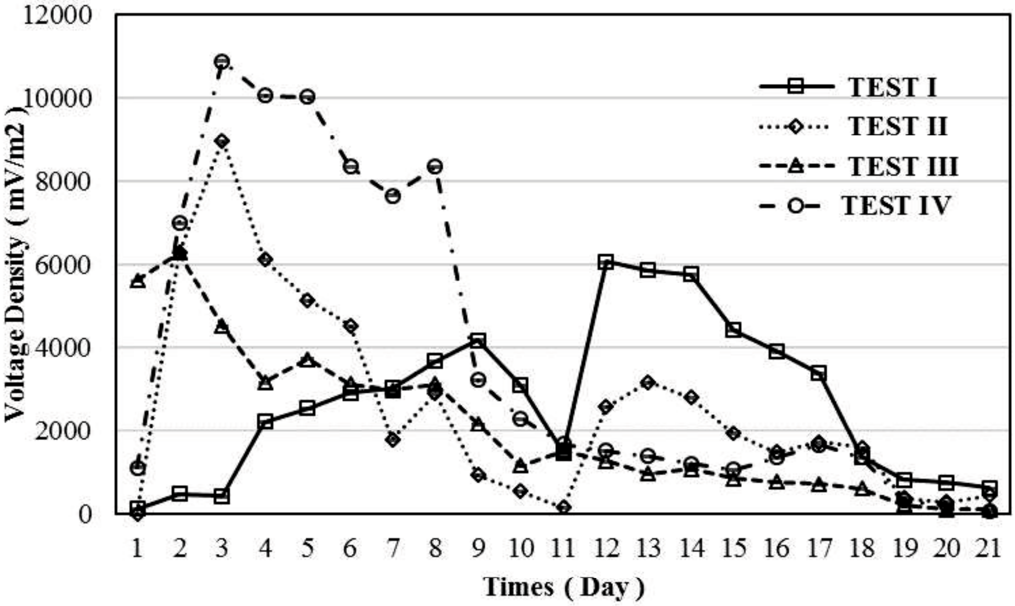


Figure 5.3. Variation of voltage with duration in microbial fuel cell using pure samples.

It is described that for the pure samples, until 21 days of monitoring an increasing –decreasing trend in between each 2-9 and 11-17 days of output voltage were observed in the MFCs, and most of increasing trend among 2-9 days in all the MFCs. However, among 2-5 days as initial stage were obtained the highest peaks of voltages in all experiments, then the electricity production of a MFC gradually decreases over period of 15 days. During the initial stage since the bacteria got ample food and their activities increased very rapidly and because the samples were used several hours after collection, the bacterial colony might have already grown exponentially. The bacteria naturally produce electricity through their ability to degrade organic compounds in the sample. The growth of microorganisms in general depends on the condition of foodstuffs and the environment. If food and environmental conditions are suitable for these microorganisms, then microorganisms will grow with a relatively short time and perfect. For that reason, the voltage increased sharply. Afterwards by the time the samples were used to power the MFC, the bacteria might have already begun depleting their resources and the supply of food was used up by the bacteria. then the electricity production decreased steadily over the period of 15 days.

5.3.2 Experimental results from mixed samples.

The comparison for changes in voltage among triplicate models of mixed samples is shown by figure 5.4. In this case, it shows the result of mixed samples within 3 days of initial time, the bacteria got ample food and their activities increased very rapidly, the voltage (V) increased sharply.

Afterwards, after 12 days the voltage decreasing trend gradually with time was observed as the sample still had high percentage of organic matter as supply of food for the bacteria. The maximum value of voltage was 10980 ± 11.32 mV/m^2, 10530 ± 4.921 mV/m^2 and 4440 ± 9.741 mV/m^2 for a mixed sample of Test V, Test VII, and Test VI, respectively.

A reason why the mixed sample of Test V showed a higher value of voltage than the other samples is that leaf mold, as a form of compost, as compost is rich in nutrients and organic matter which supports the growth of microorganisms.

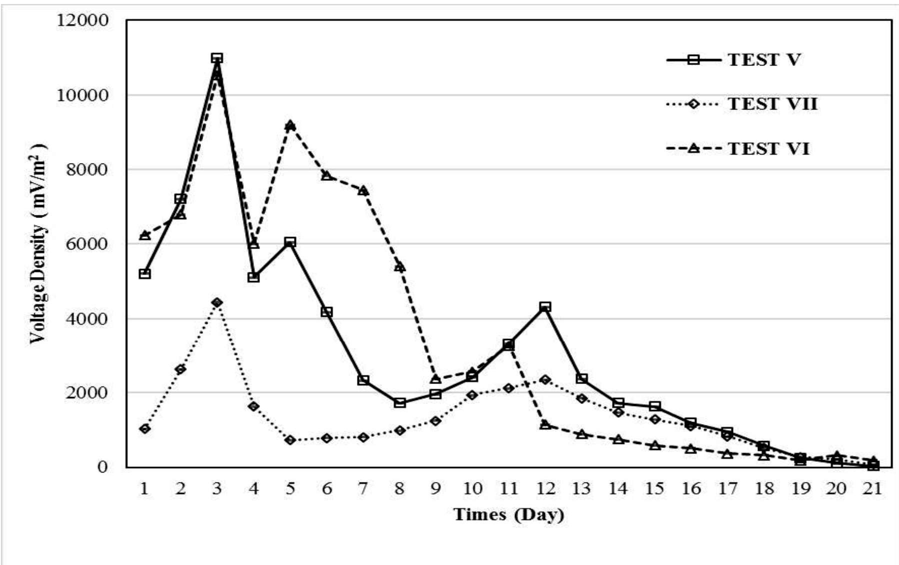


Figure 5.4 Variation of voltage with duration in microbial fuel cell among mixed samples

5.3.3 Polarization curve for MFCs

The polarization curves of the MFC using mixed sample are illustrated in figure 5.5. A polarization curve is used to characterize current as a function of voltage. They show how well the MFC maintains voltage as a function of the current production. The trend of the polarization curve was very much similar with the polarization curves which have been found in other literature concerning MFCs.

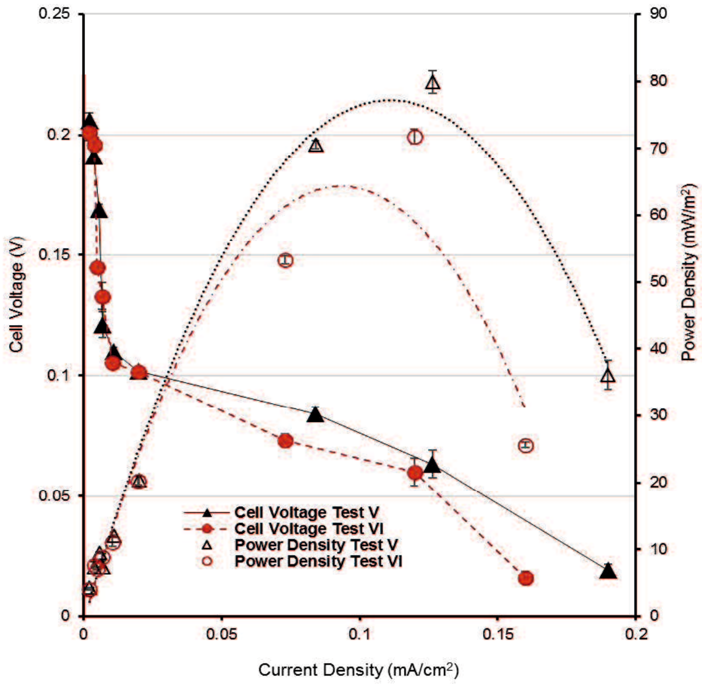


Figure 5.5 Polarization curve of the MFC

It shows that firstly, as no current flows for open circuit conditions, no power is produced. From this point onward, the power increases with current to a maximum power point (MPP of 79.885 ± 1.7 mW/m^2 for Test V and 71.76 ± 1.11 mW/m^2 for Test VI). Beyond this point, the power drops due to the increasing ohmic losses and electrode overpotentials to the point where no more power is produced (short circuit conditions).

Power densities showed an incremental trend with decreasing external resistance and reaches a peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behaviour.

5.3.4 Relationship between voltage and current in the MFCs

Figure 5.6 shows the relationship between voltage and current in the MFCs for 3rd day of elapsed time. It is found that the relationship was almost linear, Table 5.8 express the situation. We can understand that the maximum electric power which is calculated from the linear relationship between voltage and current and show the linear result between them.

The intercept and inclination of the line represents electromotive force and internal resistance for the MFCs, respectively. It represents that MFC with a good performance indicates high electromotive force and low internal resistance. The electromotive force of MFC of Test V was 206 ± 0.33 mV. On the other hand, the electromotive force of Test VI was 201 ± 0.53 mV. The maximum power density for Test V was 79.885 ± 1.7 mW/m^2 and 71.76 ± 1.11 mW/m^2 for Test VI. The consideration of this result, as described above, since leaf mold in Test V is rich in nutrients and organic matter which supports the growth of microorganisms.

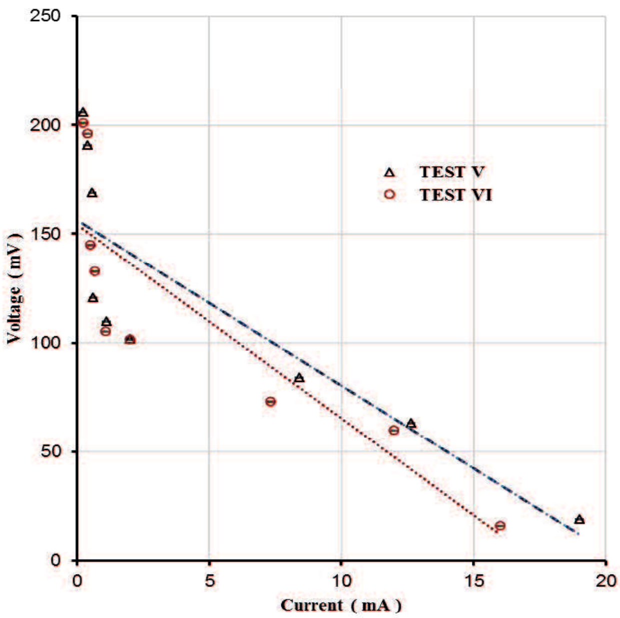


Figure 5.6 Relationship between voltage and current in the MFCs for 3rd day

Table 5.8 Test results of MFCs in case of Test V and Test VI

	Test V	Test VI
Electromotive force (mV)	206 ± 0.33	201 ± 0.53
Internal resistance (Ω)	1000	1000
Maximum power per area of cathode (mW/m^2)	79.885 ± 1.7	71.76 ± 1.11

5.3.5 Carbon felt as electrode materials

After the tests, to examine the performance of organic waste, anode and cathode, they were removed from the fuel cells and were checked by electronic microscopes. It was observed that on most parts of the anode or cathode, there were parts of organic waste that was still firmly bonded to the carbon felt. These findings indicate that the good bonding for each sample might have acted as bonding agent for the electron. The bonding area and number of bonding area of the organic wastes and the electrodes shows that they can catch and discharge the electrons and more number of them show that more electron can catches by or discharge by them. In another hand, power generation using MFC with low cost electrodes (carbon felt) and mixed culture was considered as cost-effective and environmentally sustainable process which will also provide a great potentiality for other applications like handy power supplies for remote sensors using native fuels. Carbon felt material has been chosen for these electrode characterization studies dues to its high surface area. So, the organic waste can work optimally with carbon felt as the electrode materials, as results shown in Figure 5.7a which shows the SEM images of organic waste as compost.

As well as Figure 5.7b shows of good bonding between organic waste and electrode. The energy dispersive X-ray spectroscopy (EDS) spectrum is presented in figure 5.8 a and 5.8b. EDS makes use of the X-ray spectrum emitted by a solid sample bombarded with a focused beam of electrons to obtain a localized chemical analysis.

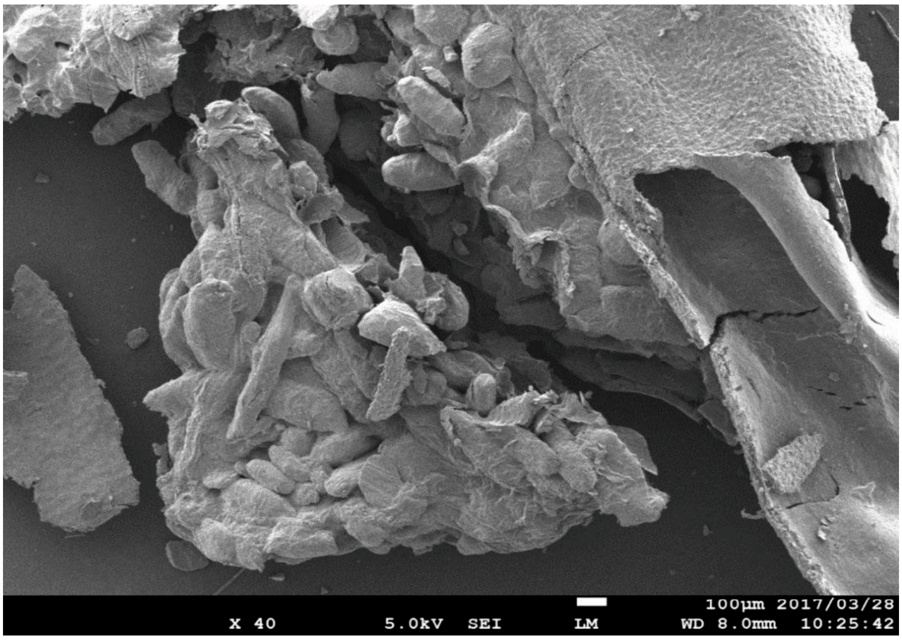


Figure 5.7a Images of organic waste and electrode by SEM (Scale 1:40)

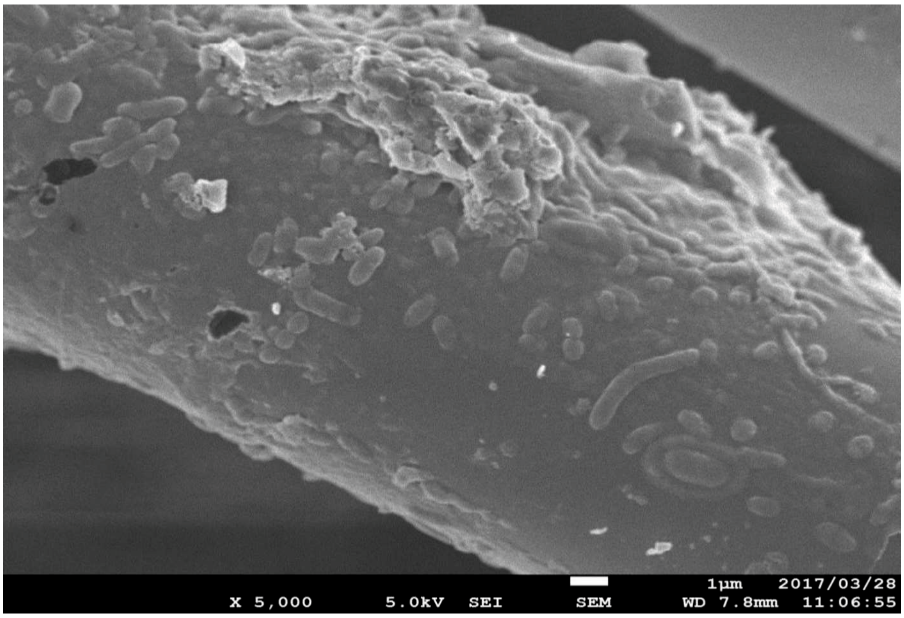
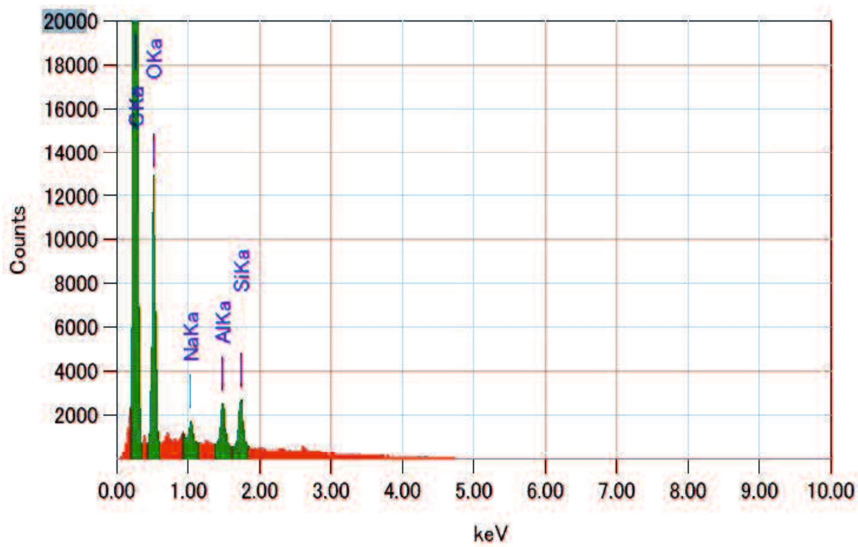


Figure 5.7b SEM image of good bonding between organic waste and electrode (Scale 1: 5000)

All elements from atomic number 4 (Be) to 92 (U) can be detected in principle, though not all instruments are equipped for 'light' elements ($Z < 10$). Qualitative analysis involves the identification of the lines in the spectrum and is straightforward owing to the simplicity of X-ray spectra. Quantitative analysis (determination of the concentrations of the elements present) entails measuring line intensities for each element in the sample and for the same elements in calibration Standards of known composition Energy dispersive spectroscopy was employed to identify the presence of element of carbon felt and persimmon waste. The EDS spectra show the presence of 86.25% carbon, 10.52% oxygen, 0.37% sodium, 1.16% aluminium and 1.69% silicon. The appearance of aluminium and silicon on EDS is due to the use of silicon as a sample coating and aluminium as a sample plate.



ELEMENT	(keV)	Quality (%)
C K	0.277	86.25
O K	0.525	10.52
Na K	1.041	0.37
Al K	1.486	1.16
Si K	1.739	1.69
TOTAL		100.00

Figure 5.8a EDS spectrum of electrode sample.

CONDITION	
Equipment name	7600 F
Voltage	5.0 kV
Current	1.00000 nA
PHA Mode	T3
Elapse Time	254.43 sec
Effective Time	245.63 sec
Dead Time	3%
Count Rate	4402 cps
Energy Range	0 – 20 keV

Figure 5.8 EDS spectrum of electrode sample.

5.4 Conclusion

1. Utilization of organic waste principally to create clean energy through the development and utilize organic waste to energy ("MWE") with any developed a propriety technology such as Microbial Fuel Cell (MFC).
2. MFC provides greater clean energy production and emission reductions.MFC is the source of direct current (DC), in this experiment we calculate the magnitude of the potential difference (voltage) between the anode and cathode poles. The maximum voltage density is10880 ± 4.784 mV/m^2 for pure samples of Test IV (chicken dropping) and 10980 ± 11.32 mV/m^2 for mixed sample of Test V (leaf mold and soil) . It is considered that the mixture of organic waste, soil and carbon felt as an electrode greatly supports the growth of microorganisms in working optimally to produce generate bioelectricity.

3. It proved that animal dungs and leaf mold as a variety of organic wastes contains large amounts of nutrients and various other minerals, it can improved to be more valuable as a microbial fuel cell to generates green and safe electricity moreover as an efficient, eco-friendly solution for organic waste management. This is a useful method of green and safe energy. Therefore, bioelectricity can be produced using mixed samples of organic waste and soil.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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CHAPTER 6

Bioelectricity Generation by Using Single Chamber Microbial Fuel Cells from Persimmon Fruit Waste Mixing With Soils

6.1 Introduction

6.1.1 World energy

Energy in any form plays the most important role in the modern world. Also, reduction and recycling of waste are very serious problems all over the world due to the limitation of final disposal sites and decreasing environmental loads (Khalid et al., 2011). A major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery (Moqsud, 2003; Sujauddin and Hoque, 2008; Zurbrugg et al., 2005). The scarcity of electricity is one of the major hindrances for the development of many countries all over the world.. Therefore, power shortage and load-shedding are very common phenomena that cause serious problems for the population of the developing countries, especially during the night time (Moqsud et al., 2014). With the rise in population and rise in the electricity demand on this planet, researchers are working towards increasing the electricity supply source. The future of energy sustainability and supply is likely to rely on renewable energy sources. The production of electricity or biofuels using innovative technologies and renewable sources is a global priority in terms of energy strategies (Resch et al., 2008). Some of the background's situation has resulted in great concern to finding alternate sources of electricity that are green and safe.

A plentiful and renewable carbon source that has been considered for MFC applications (mainly for electricity generation) is biomass (Moqsud et al., 2013). The MFC has emerged as an efficient and eco-friendly solution for organic waste management, especially in developing and technologically less sophisticated countries, and can provide green and safe electricity from organic waste (Moqsud et al., 2014). MFCs are so new that relatively little effort has been put into practical architectures using affordable materials (Logan., 2008). In recent years, advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Cristiani et al., 2013).

A microbial fuel cell (MFC) is an emerging renewable technology, which is designed to exploit the degradation of biological substrates to produce sustainable bioenergy in the presence of active microorganisms (Kan et al., 2011; Walter et al., 2015). There are already been investigated MFCs devices to produce bioelectricity form organic wastes and waste waters (Moqsud et al., 2013; Chakhtoura et al., 2014; Moqsud et al., 2010; Lu N et al., 2009; Feng C et al., 2013; Venkata Mohan et al., 2008); Prasad D et al., 2006; Sevda S et al., 2013).

Some researchers have used electricity generation in MFCs is favored by numerous substrates, extending from easily biodegradable pure substrates such as glucose (Rabaey et al., 2003), ethanol (Kim et al., 2007), phenol (Liu Y et al., 2008), chromium (Liu Y et al., 2008 ; Li Z et al., 2008), pentachlorophenol (Huang H et al., 2013) and acetate (Logan et al., 2007), to complex substances such as starch (Herrero-Hernandez et al., 2013), chitin (Rezaei et al., 2009b), and cellulose (Rismani-yazdi et al., 2007). In addition, microbial fuel cells have been tested for producing hydrogen (Call DF et al., 2009). However, utilization of these substrates in MFCs is not a cost effective option. Biomass being a carbon neutral has been attracted as one of the most promising future resources of electricity generation for addressing the rapidly growing energy needs (Mao et al., 2015). However, the use of persimmon waste as biomass to generate electricity in MFC has not previously attracted the attention of researchers.

6.1.2 Reduce environmental impact of organic waste

The bright chance's development of renewable energy on current trend is to use fruit waste to meet the demand. The global production of fruits and vegetables is in the increasing trend and having been recorded as 1.74 billion tons in 2013 (World Farmers Organization, 2014). Persimmon fruit production is very abundant in Japan. The waste that is considered trash by people actually still contain simple organic material (glucose), which could potentially be used as a food source for the bacteria in microbial fuel cell. While the persimmon fruit production in Japan is relatively abundant, such as in 2012 reached 244.8.5 thousand tons (Japan Fruit Growers Cooperative Association, 2012). From the characteristic analysis of the solid waste of many developing countries it is found that the major portion (more than 80%) of the total solid waste comprises of organic waste, which does not usually get much attention for recycling or resource recovery (Moqsud et al., 2008). The annual organic waste generated from the food industries and kitchen waste in Japan is about 20 million tons per year (Koike et al., 2009). Most of this waste is directly incinerated with other combustible waste, and the residual ash is disposed of in landfills. However, incineration of this water-containing waste is energy consuming. The wastes should be utilized, reuse and recycled as a valuable resource. These organic wastes contain large amounts of nutrients and various other minerals. Advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Cristiani et al., 2013). In order to get an efficient and eco-friendly solution for organic waste especially to provide green and safe electricity from organics waste, a blend of soil and persimmon fruit waste were tested as a solid waste management option by a MFC method.

6.1.3 Objectives of study

Therefore, the objective of this study was to explore and to evaluate bioelectricity generation by reusing persimmon waste as a low cost feasible potential substrate for bioelectricity generation so that this organic waste can be recycled and provide some sort of solution to populations experiencing electricity shortage (Moqsud et al., 2014). This resulting in environmentally friendly degradation of persimmon waste. This low cost and abundant by-product can alternatively be tested in MFCs for efficient and economical conversion to bioenergy (Waheed M. et al., 2016). The performance parameters using such as maximum power density, current density has done well.

6.2 Materials and methods

6.2.1 About sample collection

The persimmon waste were collected from Japan Agriculture Office, Ube city branch, and then crushed and kept in a frozen at -15 °C for further use in the MFC for some different experiments as a substrate for bioelectricity generation in the MFC. Persimmon is the name of a type of fruit of the genus Diospyros. This plant is also known as "KAKI", or in the English language named Oriental (Chinese / Japanese) persimmon. The scientific name is Diospyros feet. ('Kaki', Japanese, is the name of a substance produced by this fruit tannins). Waste persimmon that are inedible and also waste wasted skin and can be used as an additional income or a sideline.

On the other hand, the economic value of persimmon itself generally is now no longer expected by the farmers and while the persimmon fruit production in Japan is relatively abundant, such as in 2011 reached 207.5 thousand tons. (https://en.wikipedia.org/wiki/Persimmon). During the harvest and postharvest time, large amounts of fruit, especially their peels, about 10% of the whole fruit are generated as waste. It causes a waste disposal problem. Persimmon like most fruits have a lot of the nutrients, vitamins also minerals are very much. It can be consumed directly as fresh fruit or made of various types of grain, such as salad, juice, beverages, or preserves. The sweet taste of the flesh of this fruit is affected by sucrose levels. Sweet of fruit flesh showed low levels of sucrose. Sucrose can undergo hydrolysis in dilute acid solution or by the enzyme invertase into glucose and fructose (Ihsan and Wahyudi, 2010). The content of glycated in this fruit which will be utilized by the bacteria to produce electricity next.

6.2.2 Design of the one-chamber Microbial Fuel Cell (MFC)

Generally, microbial fuel cells are used under the conditions of an aerobic cathode with air and an anaerobic anode in waste water. The microbial fuel cell (MFC) technology has been widely developed in first countries, pursuing both outcomes: generation of electricity and treatment of wastes from different derivations (organic or inorganic). The MFC device uses electrochemically active microorganisms (EAM) to generate electricity (Logan B.,E, 2009), this technology for example, enables to supply the energy demands for small devices (Moqsud et al., 2013).

In this study, a one-chamber type of MFC with some blend of persimmon wastes are developed. Figure 6.1 illustrates the laboratory test device set up for the MFC's schematic diagram.

A rectangular (10x10x15 cm) acrylic container was used in the laboratory as a cell. Then some amount of crushed persimmon waste and some amount of soil mixed with in generally 100 g of water and 4 g of effective microorganisms were blended properly by a blender. That small amount of effective microorganism (commercially available from EM Kenkyusho, Shizuoka, Japan) was used for each case to start the bioelectricity generation (as microbial seed) and to reduce possible odour from the samples during the investigation. The blended sample was filled in the container. The anode was placed inside the biomass and the cathode was placed on the top. Both electrodes were connected to a data-logger (Midilogger GL200; Graphtec, Tokyo, Japan). According to Jessica Li (Jessica Li., 2013) bacteria in the anode chamber create protons and electrons during oxidation as part of their digestive process. The electrons are pulled out of the solution in the anode and placed onto an cathode's electrode. The electrons are then conducted through the external circuit and into the cathode chamber by way of the cathode's electrode. The external resistance was fixed at 100 Ω by assessing the polarization curve with different resistors and by comparing open circuit voltage. The data-logger was set to measure the voltage and temperature data.

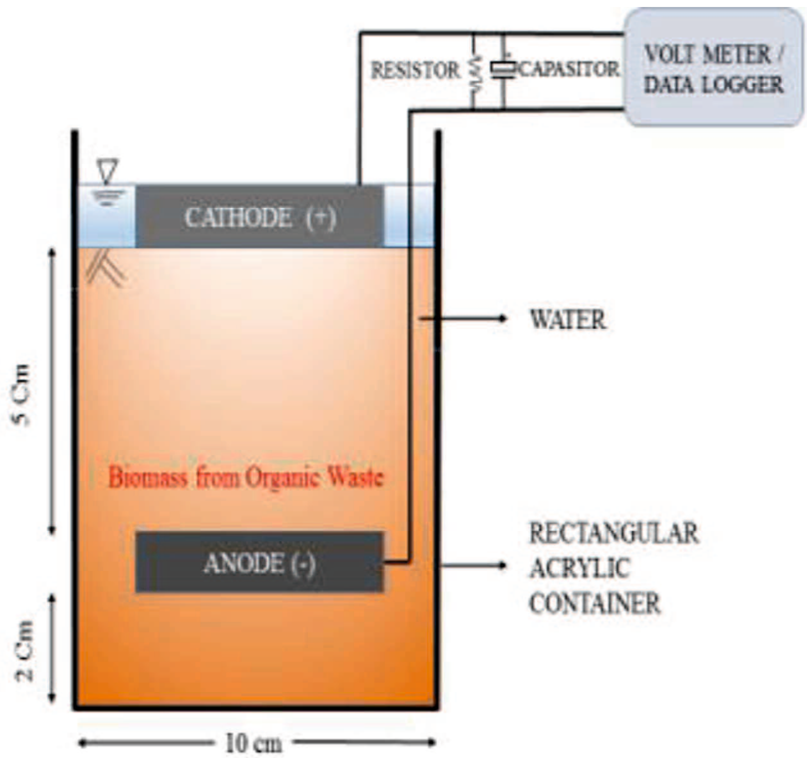

Fig.6.1 Schematic Diagram of Microbial Fuel Cell (MFC)

For ease of calculation, the voltage data at 1:00 pm was used for each day. The laboratory investigation was conducted in a constant room temperature of 25°C since bacteria grow and the metabolic process takes place with equal efficiency at all temperatures between the freezing point of water (0˚C) and the temperature at which protein or protoplasm coagulates (40˚C) (Microbiology. 2012).

Electrode output was measured in volts (*V*) against time. The current I in Amperes (*A*) was calculated using Ohm's law equation:

$$I = V / R \qquad (1)$$

where *V* is the measured voltage in volts (*V*) and R is the known value of the external load resistor in Ohms. From this, it is possible to calculate the power output *P* in watts (*W*) of the MFCs by taking the product of the voltage and current from equation:

$$P = I \times V \qquad (2)$$

More, electric current (I) was estimated by measuring the voltage (V) across the resistance (R) with the help of a data acquisition and it was connected to data logging multimeter. Polarization curves were obtained by changing the Resistor from 1Ω to 1KΩ during steady state, whereas the slope of this ohmic region in the V-I curve was considered to be R_{int} (Samsudeen et al., 2014). The maximum power density and corresponding current density was attained by using the power density curve method. The power density and current density were calculated as:

$$\text{Power density} = V^2/\alpha R \qquad (3)$$

$$Current\ density = V/\alpha R \qquad (4)$$

where α is the projected surface area of the anode (100 cm^2). In our study, the anode area was used for the electrode calculation area.

6.3 Results and Discussion

Figure 6.2 illustrates the variation of voltage with duration of time by using persimmon waste (PW) mixed with some type of soil (S), leafmold (LM), and ricebran (RB include for all single sample's replicates). It can be seen that the voltage of each MFC increased gradually with elapsed time and the peak value were reached in between 2 dan 9 days. In the case of persimmon waste mixed with soil (PWS) and persimmon waste mixed with leafmold (PWLM), the voltage (m*V*) increased sharply during the initial time (4 days); after that, it increased gradually and peaked after 8 days.

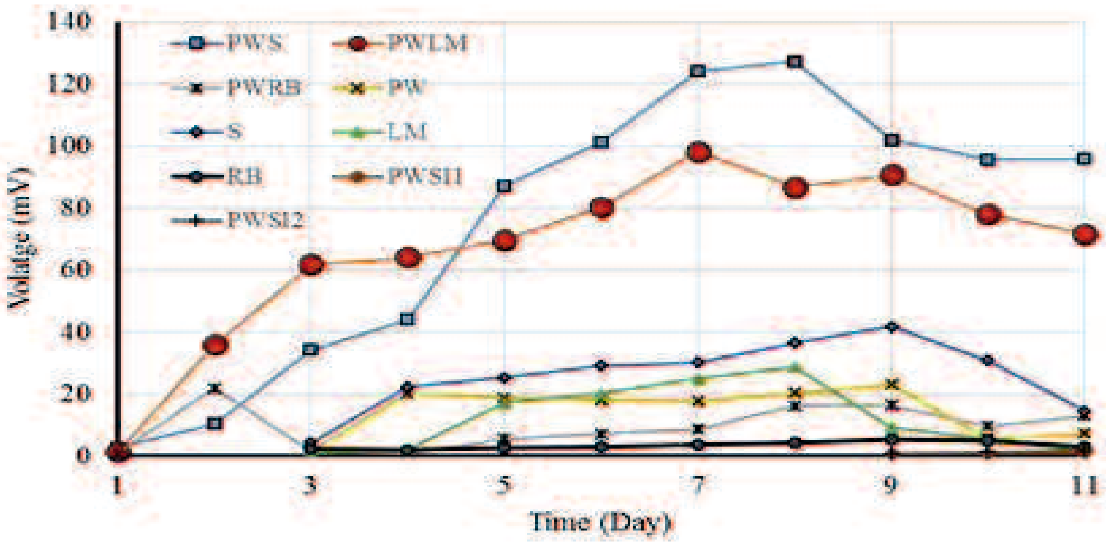

Figure 6.2 Variaton of Voltage with Time Duration of MFC

During the initial stage, the bacteria got ample food and their activities increased very rapidly (Moqsud et al., 2011). Mixed MFC of PWLM and PWS seems to generate a higher value of stable voltage when compared to effect of the microbes MFC else individually. The reason for enhanced stability would be the use of mediators of one microbe by the other to transfer electrons to the electrode (Rakesh et al., 2014). For that reason, the voltage increased sharply. The voltage decreased gradually with time as the supply of food was used up by the bacteria. Peak voltage was around 127.2 mV using persimmon waste mixed with soil. After the anaerobic condition prevailed, voltage increased sharply. The possible reason why the persimmon waste mixed with soil sample showed a higher value of voltage than the other is that in soil there were more mineral, glucose and nutrients which supplied the cell with a large amount of energy. In this figure also shows that over 8 days, the voltage gradually decreased. Over this period, bacteria reproduced and died out. It was expected that initially when there was enough food the bacterial colony would grow, and that after some period, as the food source depleted, and the remaining bacteria would die out leaving little or no bacteria to produce electricity (Jessica Li, 2013). However, the voltage generation for another samples were almost constant in all the stages. A small amount of voltage was generated due to the potential difference between the anode and cathode and also probably the phenomenon of organic matter decomposition in the soil (Moqsud et al., 2015). On all samples seen the voltage is still rising at a certain time. This is possible because the microbes are encouraged to metabolically more active than ever and the free electrons generated too much. This indicates that the MFC could recover his own electrical charge and this ability is a potential that can be developed. (Siti.L.A , 2012).

Figure 6.3 shows the polarization curve of the MFC using the persimmon waste. A polarization curve is used to characterize current as a function of voltage (Logan, 2007; Mohan et al., 2008). The polarization curve is a synthetic method to analyse the behaviour of a MFC (Logan et al., 2010): the curve represents the dependence of cell's voltage on the electrical current flowing in the circuit and allows to estimate the values of electrode overpotentials and the internal resistance of the cell, representing an overall measurement of cell's internal voltage losses and defined, geometrically, by the slope of the linear region of the polarization curve (Logan BE., 2008).

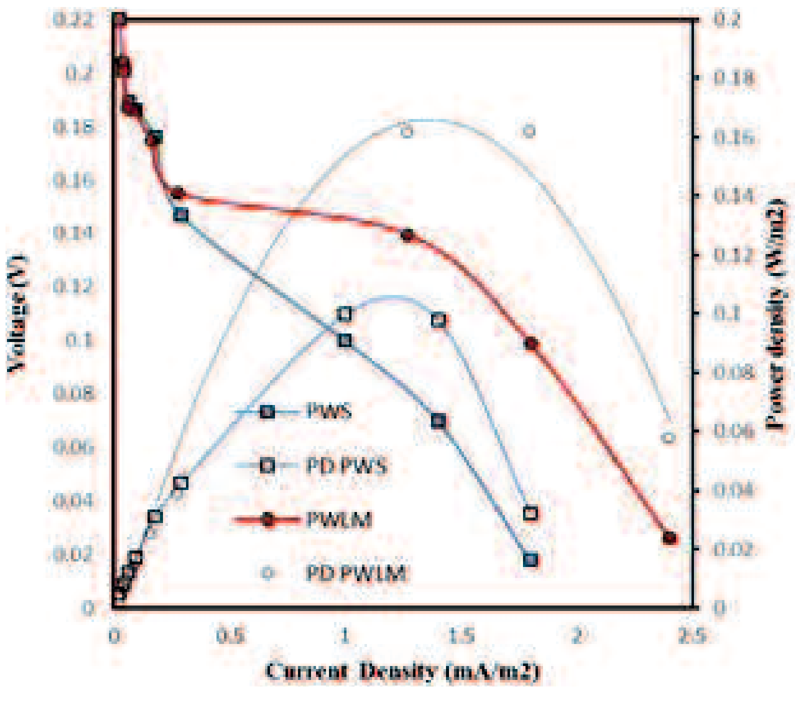

Fig.6.3 Polarization curve of MFC (Day 22)

The power curve is calculated from the polarization curve and describes the power output of the cell as a function of the current. Usually it has a parabolic shape with a single point of maximum (called Maximum Power Point or MPP), which occurs when the external resistance of the circuit equals internal resistance of the cell. According to Moqsud et al (Moqsud et al., 2015) : a polarization curve is used to characterize current as a function of voltage. The polarization curve shows how well the MFC maintains voltage as a function of the current production. Current was measured using Ohm's law, as stated in the 'Materials and method'. By changing the circuit`s external resistance (load) we obtain a new voltage, and hence a new current at that resistance. Therefore, to obtain a polarization curve, a series of different resistances on the circuit was used, measuring the voltage at each resistance as shown in Figure 3. Power density and current density were calculated as described in Logan et al, 2008.The polarization curve shows how well the MFC maintains a voltage as a function of the current production (Schamphelaire et al., 2008; Srikanth and Venkata Mohan, 2012). It was observed that the performance index, that is, maximum power density (W/m^2, normalized to the anode projection area), reached around 0.0098 W/m^2 and 0.162 W/m^2 using persimmon waste mixed with soil (PWS) and persimmon waste mixed with leafmold (PWLM), respectively.

The trend of the polarization curve was very much similar with the polarization curve which was stated in other literature concerning MFCs (Logan and Regan, 2006, Moqsud et al., 2014 and Moqsud et al., 2013). The power densities showed an incremental trend with decreasing external resistance and reaches to peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behaviour (Moqsud et al., 2015).

Figure 6.4 shows the relationship between voltage and current in the MFCs for 22 days of elapsed time. It is found that the relationship was almost linear.

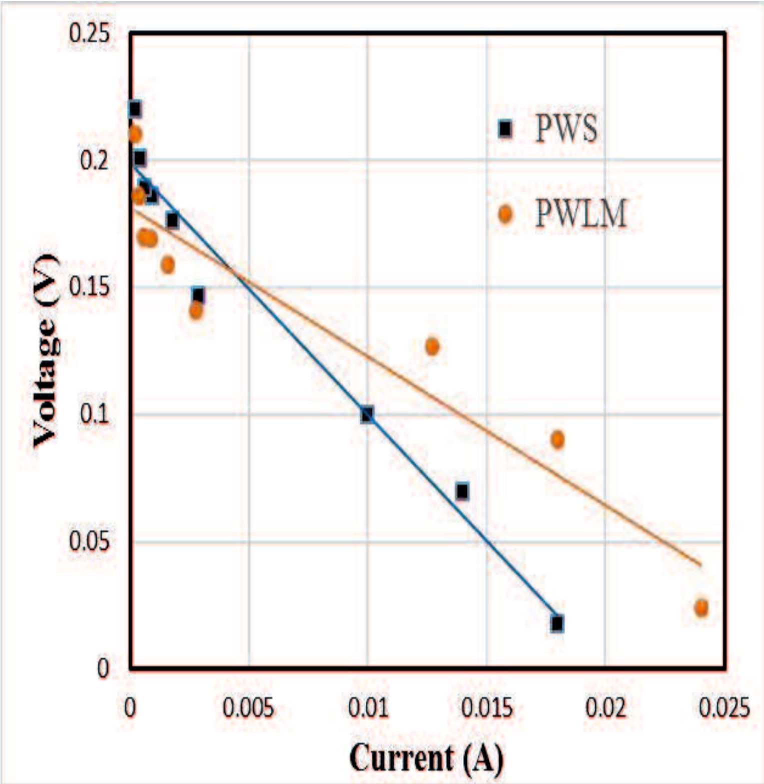

Fig. 6.4 Relationship between voltage and current in the MFCs (Day 22)

The intercept and inclination of the line represents electromotive force and internal resistance for the MFCs, respectively. It represents that MFC with a good performance indicates high electromotive force and low internal resistance. The electromotive force of MFC was approximately 0.22 V. The internal resistance of MFC was relatively low.

On the other hand, the performance of MFC with soil is lower than mixed with leafmold. But this result is still interesting to prove persimmon fruit waste as a good green waste for bioelectricity generation. As described above, it is considered that soil does not work well in dry conditions. Maximum electric power is calculated from the linear relationship between voltage and current. The maximum power per anode area is 0.162 W/m^2 for the MFC with persimmon waste mixed with leafmold and 0.0098 W/m^2 for the MFC with persimmon waste mixed with soil.

6.3 Conclusion

This investigation established the feasibility of producing electricity directly from persimmon waste using MFCs. It was observed that some of the planet's tiniest inhabitants might help address two of societies biggest environ mental challenges: how to deal with the vast quantities of organic waste produced and where to find clean, renewable energy. MFCs using persimmon fruit waste have proved to be a good way to get green electricity generation and to recycle organic waste to maintain healthy and pollution free environments, particularly in developing countries where solid waste management is a great concern. A small amount of electricity is also necessary for electricity-scarce populations (25% of the world's population are deprived of electricity). Small amounts of electricity can be used for lighting light-emitting diode lamps or just to charge a mobile phone in a household using their own waste. Though the amount of electricity is smaller in MFCs when using persimmon waste mixed with soil (0.0098 W/m^2) compared with persimmon fruit waste mixed with leafmold (0.162 W/m^2), it is still very much needed for the future green energy era, as it is an abundant source of biomass in many developing countries. Increasing the portion of biomass in the energy matrix will help to diminish the negative environmental impact of atmospheric CO_2 accumulation and to meet the targets predicted in the Kyoto protocol.

So, by using persimmon waste we can address some important problems currently faced by the world: first, the health and pollution of geo-environment problems due to unmanaged organic waste, as this organic waste would be used as raw material to generate electricity (people will reuse it carefully); second, we need not use our valuable food products (corn and soybean) to obtain transportation fuel, while at the same time millions of people, including children, cannot get food regularly; third, the urgent need to reuse bamboo is very much an important concern for the sustainable geo-environment in Japan, as well as other countries in the world—if we consider a 200 kW rated bioelectricity generator by MFC, then an average of huge amounts of persimmon waste will be required to conceptually extrapolate our findings; finally, it is clear that bioelectricity can be produced by persimmon waste, which could provide some sort of 'light of hope' to the 1.6 billion people who still live in the dark at night all.

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CHAPTER 7

Bioelectricity Generation In Microbial Fuel Cell Using Persimmon Fruit Wastes

7.1. Introduction

The world's energy crisis encouraged us to searching way and developing for renewable/alternative energy sources and technologies as well as environment protection. In the same time, a major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery (Moqsud, 2003; Sujauddin and Hoque, 2008; Zurbrugg et al., 2005). The wastes should be utilized as a valuable resource since they contain large amounts of nutrients and various other minerals. Advancements in environmentally friendly technologies have expanded a variety of organic wastes and renewable biomass types that could act as potential substrates to produce electrical energy or other high value products (Cristiani et al., 2013). One of organic waste which interesting to be utilized is persimmon fruit wastes (herewith call as PW). This fruit is popular in Japan and in other parts of the world. Persimmon is Japan's national fruit. Persimmon has traditionally grown and cultivated many fruits for ages and during its season, persimmon becomes quite big a topic. It considers about 15% of the whole fruit will generated as abundant fruit without any properly waste management, it will cause a very serious problem around the world due to the limitation of final disposal sites and decreasing environmental loads (Khalid et al., 2011).

Among the various choices of substituent energy generation, microbial fuel cell (herewith call as MFC) is one example of alternative technology that has potential to be developed. MFC is bio-electrochemical transducers that convert microbial reducing power (generated by the metabolism of organic substrates), into electrical energy. The MFC technology has been widely developed in first countries, pursuing both outcomes: generation of electricity and treatment of wastes from different derivations (organic or inorganic) (Washington, L. et al., 2015). Therefore, the main aim of this study was to develop and explore the PW as a low cost feasible MFC bioreactors which set up with organic waste mixing with soil to generate bioelectricity as an efficient and eco-friendly solution for organic waste management.

7.2. Materials and methods

7.2.1 About Sample collection

The PW was collected from Japan Agriculture Office, Ube city branch. Figure 7.1a and Figure 7.1b show the production of persimmons which relatively abundant. As in 2014 was 5.2 million tonnes for the world's persimmon production, while in Japan accounting for 0.24 million tonnes.

On the other hand, the economic value of persimmon itself generally is now no longer expected by the farmers. Persimmons like most fruits have a lot of the nutrients, vitamins and minerals. Some of the research studies showed that persimmon also contributes in calcium and potassium availability. Among sugars, sucrose and its monomers (glucose & fructose) are bountiful (Zheng and Sugiura, 1990; Ittah, 1993). The nutritional value of persimmons (value per 100 grams) is elucidated in Table 7.1. Sucrose, which contain in the persimmon, can undergo hydrolysis in dilute acid solution or by the enzyme inverse into glucose and fructose (Ihsan and Wahyudi, 2010). The content of glycated in this fruit which will be utilized by the bacteria to produce electricity next.

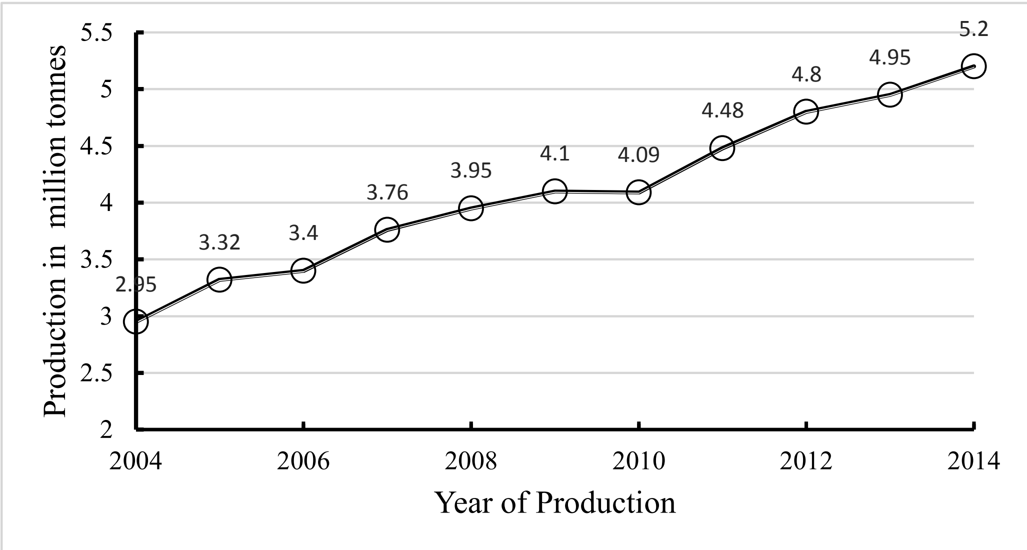

Figure 7.1a. Production of persimmons in the world (Source : FAO, 2015)

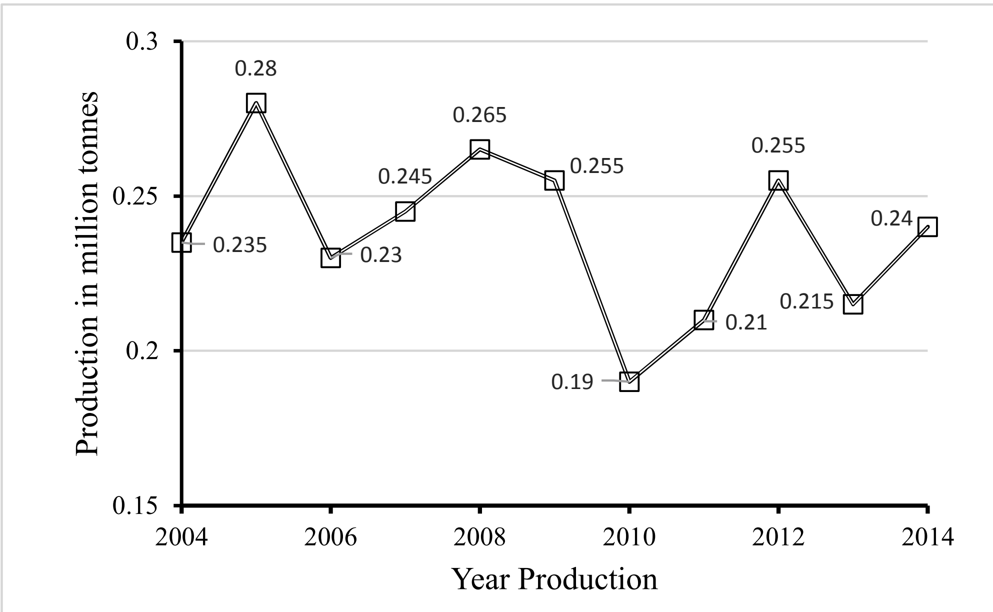

Figure 7.1b. Production of Persimmons in Japan (Source : FAO, 2015)

Table 7.1. Nutritional value of persimmons (value per 100 grams)

Parameter	Unit	Value
Moisture content	%	68.9 ± 1.27
Ash	%	0.32 ± 0.02
Reducing sugars	%	2.87 ± 0.10
Total sugars	%	7.40 ± 0.31
TSS	%	10 ± 0.42
pH		5.96 ± 0.21
Water	g	80.32
Energy	kJ	293
Sodium	mg	1
Potassium	mg	161
Kalsium	mg	8
Sucrose	mg/g	68.6 ± 30.29

Soil which used in whole experiments were sampled in the 10 cm layer of natural Tokiwa Park soil, located in the plant area of Tokiwa Park (33°57'02.9" N , 131°16'47.5" E) at Ube city, Yamaguchi Prefecture, Japan. Table 7.2 shows the properties of the soils.

Table 7.2. Characteristics of soil used in this experiment

AVS	pH	Water Content	LOI	EC	Amount
0.0051 mg/g	6.27	86.91%	10.24%	0.395 mS/cm	400 g

7.2.2 *MFC assembly*

The MFC used electrochemically active microorganisms (EAM) to generate electricity (Logan BE, 2009), this technology for example, enables to supply the energy demands for small devices (Moqsud et al., 2013). In this study some materials were prepared, such as carbon felt, PW, soils, leafmold, ricebran, acrylic rectangular chambers, data loggers, volt meter, resistors, capacitor, pH meter, cables, alligator clips, capacitor and some supporting test equipment. Figure 7.2 illustrates the laboratory test device set up for the MFC's schematic diagram.

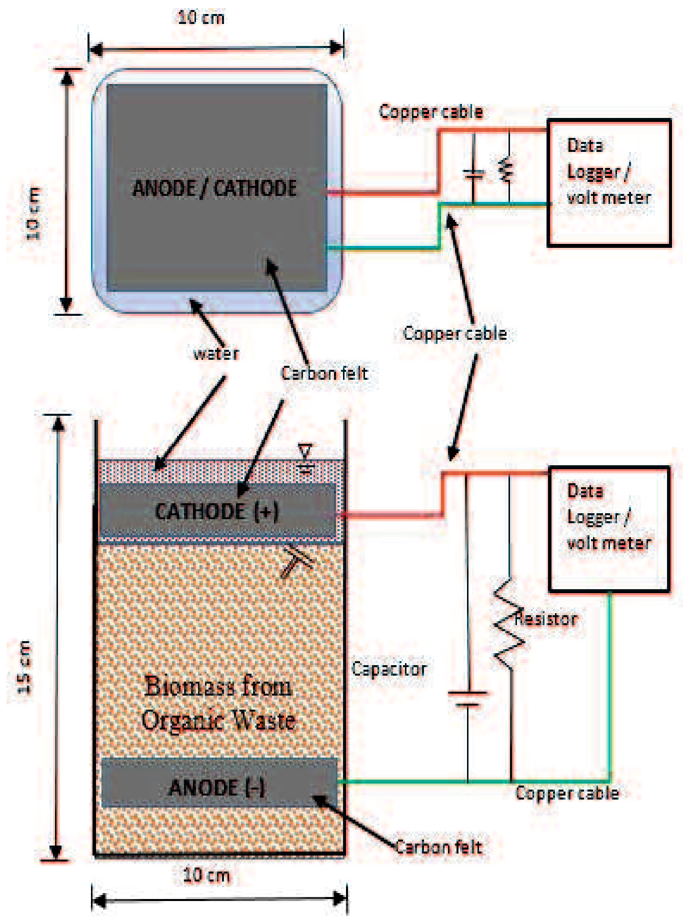

Figure 7.2. Schematic diagram of MFC cell set up

The MFC were constructed by using a rectangular acrylic container with chamber's dimensions of 150 mm of height, 100 mm of length and 100 mm of wide. Then crushed PW and soil each of 400 g mixed with 100 g of water and 4 g of effective micro-organisms (EM) were blended properly. The EM (commercially available from EM Kenkyusho, Shizuoka, Japan) used for each case to start the bioelectricity generation (as microbial seed) was reduced to possible odour from the samples during the investigation. Whereas the soil used in this work as they are thought to increase not only the physical volume of samples properties and the optimum content but it also to increase the nutrient ability supplying food for microorganism and generate the highest voltage. The sample then placed in the container. Carbon felt was used for both anode and cathode. The anode was placed inside the sample and cathode was placed on the top. Both the anode and cathode related to a data-logger (Midilogger GL200; Graphtec, Tokyo, Japan) and a fix resistance (100 Ω). The main advantages and purpose to use this kind of electrodes has derives from the fact that it can provide a more compact reactor for a given duty, together with a high fractional conversion. Both electrodes having dimension of 10 cm x 10 cm x 1 cm respectively. Table 7.3 shows the property of carbon felt as electrode. The data-logger was set to measure the voltage and temperature data. All experiments were performed in a controlled constant room temperature of 25°C since bacteria grows and the metabolic process takes place with equal efficiency at all temperatures between the freezing point of water (0˚C) and the temperature at which protein or protoplasm coagulates (40˚C) (Microbiology. 2012).

Table 7.3. Properties of Carbon felt

Properties	Fiber Grade	Ash (%)	Thickness (mm)	Unit Mass (g/m2)	Density (kg/m3)	Carbon Content (%)
Measure Value	Carbonized	≤ 1.0	10	500	50	≥ 97

According to Jessica Li (2013) bacteria in the anode chamber create protons and electrons during oxidation as part of their digestive process. The electrons are pulled out of the solution in the anode and placed onto a cathode's electrode. The electrons are then conducted through the external circuit and into the cathode chamber by way of the cathode's electrode.

The maximum power density (mW m^{-2}) and current density (mA m^{-2}) were calculated as:

Power density = $(I * V) / \alpha$

(3)

Current density = $(V / R) / \alpha$

(4)

where V (mV) is the voltage, R (Ω) is the resistance, and α is the projected surface area of the anode (0.01 m^2). In our study, the anode area was used for the electrode calculation area.

7.3 Result and Discussion

The cell power data across the external resistor R (100 Ω) was measured at every 1:00 pm for each day. It is estimated that at that time is the most appropriate effective time for research measurement as well as at that hour is estimated to be the peak activity of microorganisms and the peak sun exposure. In this study, 4 samples of 400 g of PW, soil (herewith call as S), leafmold (herewith call as LM), and ricebran (herewith call as RB), as pure sample under some condition as shown at Table 7.4. While for another mixed samples of persimmon waste with some type of soil (herewith call as PWS), persimmon waste and leafmold (herewith call as PWLM), and persimmon waste and ricebran (herewith call as PWRB) as mixed sample under some condition as shown at Table 7.5.

Figure 7.3 illustrates the variation of power density with duration. It is found that power density increased sharply during initial days and reached the peak between 2 and 12 days.

Table 7.4 Parameter conditions for each pure samples.

Coding of Sample / Parameter	**PW** *(Persimmon)*	**S** (Soil)	**LM** (Leafmold)	**RB** (Ricebran)
Soil (g)	0	400	0	0
Organic waste (g)	400	0	400	400
pH	6.32	5.48	6.72	6.22
Electrodes (carbon felt)	Yes	Yes	Yes	Yes
EM (g)	4	4	4	4
Water (g)	100	100	100	100

Table 7.5. Parameters for organic wastes mixed sample conditions

Coding of sample / Parameter	PWS (Persimmon + soil)	PWLM (Persimmon + leafmold)	PWRB (Persimmon + ricebran)
Persimmon waste	400	400	400
Organic waste or soil (g)	400	200	200
pH	6.83	6.48	7.2
Electrodes (carbon felt)	Yes	Yes	Yes
EM (g)	4	4	4
Water (g)	100	100	100

It shows, during the initial stage since the bacteria got ample food and their activities increased very rapidly (Moqsud et al., 2011). In the case of PWS and PWLM, the power density (mW/m^2) increased sharply during the initial time; then it increased gradually and peaked of around 16.180 mW/m^2 and 9.663 mW/m^2.

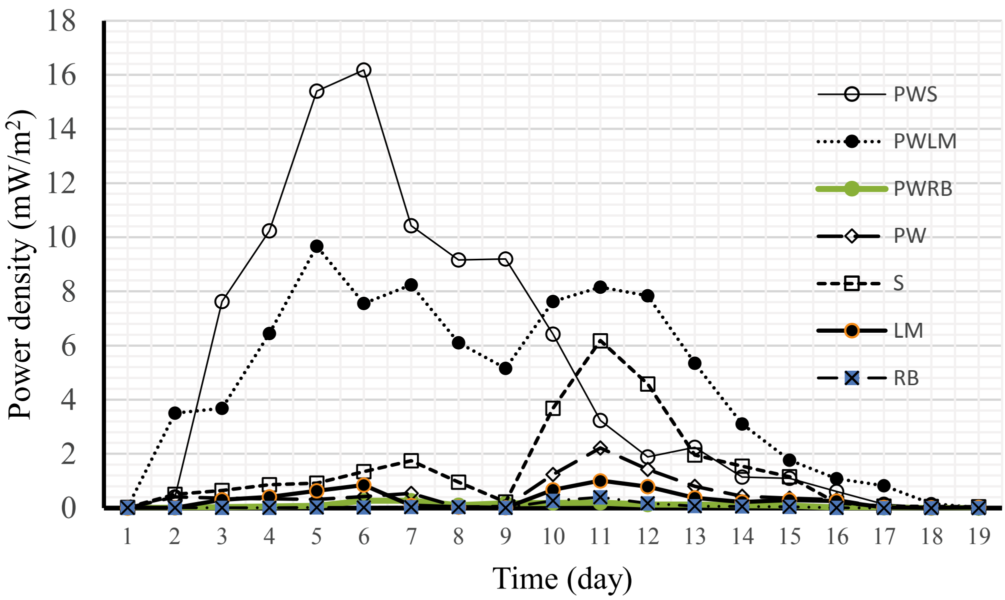

Figure 7.3. The variation of power density with duration

The mixed sample of PWS showed a higher value of voltage than the other since in the mixture consist more mineral and nutrients which supplied the cell with a large amount of energy. Another reason is the ample food, in which the amount of glucose inside the persimmon made the bacteria active and hence generated a higher voltage, more over the microbial activities influenced the generation of higher quantity of electricity in the initial stage. After the depletion of foods for the micro-organisms their activities also reduced and the generation of electricity reduced significantly. The reason for enhanced stability would be the use of mediators of one microbe by the other to transfer electrons to the electrode (Rakesh et al., 2014). Then, the power decreased gradually with time as the supply of food was used up by the bacteria. In the figure, it also shows that over 12 days, the power gradually decreased. Over this period, bacteria reproduced and died out. It was expected that initially when there was enough food the bacterial colony would grow, and that after some period of time, as the food source depleted, and the remaining bacteria would die out leaving little or no bacteria to produce electricity (Jessica Li, 2013). However, the power generation for another samples were almost constant in all the stages. A small amount of voltage was generated due to the potential difference between the anode and cathode and also probably the phenomenon of organic matter decomposition in the soil (Moqsud et al., 2015). On some samples seen the power is still rising at a certain time. This indicates that the MFC could recover his own electrical charge and this ability is a potential that can be developed. (Siti.L.A , 2012). The values showed in the figure 3 were quite satisfactory to proof that PW is the high potential material to utilize as power generation with comparing the various parameters in other MFC in different methods.

Consider to the renewable bio-energy as one of the ways to alleviate fuel needs of the future and to overcome the crisis of global warming. In this direction bioelectricity production utilizing PW in MFC has generated considerable interest in both basic and applied research in recent years. However, by using the PW to generate electricity in MFC has not attracted the researchers before.

Scale-up experiment with same treatment as laboratories scale has done to analyse the feasibility and to improve the resulting voltage generated on larger designs with the same quality results as on a laboratory scale. As illustrated at figure 7.4 that 2109.9 $mW/m^{2,}$ 2319.88 mW/m^2, 4384.06 mW/m^2 and 10317.19 mW/m^2 of power density are generated for 100 cm^2, 150 cm^2, 300 cm^2 and 500 cm^2 of size scale-up respectively. It shows that increasing scale-up of the electrode size will lead to increases power generated.

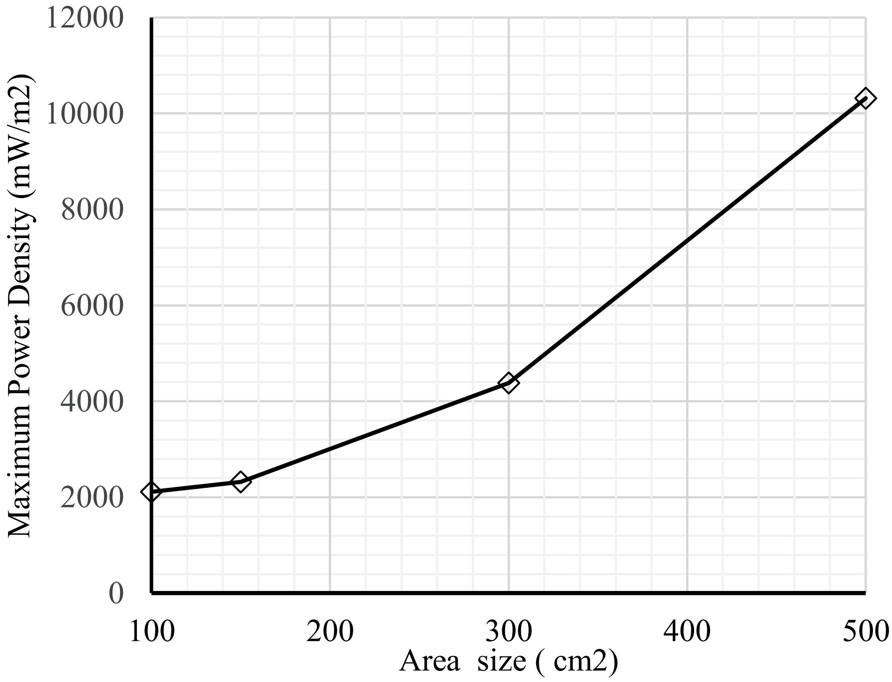

Figure 4**.** Power density of the scale-up area

7.4 Conclusion

The persimmon fruit waste can be recycled as bio-electricity generation. Though the power generates of 16.180 mW/m^2 and 9.663 mW/m^2 for PWS and PWLM. The power output in MFCs can be improved in the future by scale-up the electrode surface area, and volume of the samples The MFC by using PW is proved to be a good way to green electricity generation as well as the recycle of organic waste to maintain the healthy and free pollution environment in developing countries where solid waste management is a great concern and faced to the health and pollution of geo-environment problems due to unmanaged organic waste.

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Conflicts of interest

None

7.5 Reference

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CHAPTER 8

Evaluation of Scale-Up and Environmental Factors On Microbial Fuel Cell

8.1 Introduction

Recently, humanity is facing on their energy challenge and most countries in the world are on their way searching for new renewable energy resources thus technologies for environment protection. The incidence of power outages in various regions of the world is not a new problem and it is still happening today. The variety of fuels used to generate electricity all have some impact on the environment. Fossil fuel power plants generate significant amounts of CO2 emissions into the atmosphere, which are believed to be the main cause of climate change. Currently existing fleet of fossil fuel combustion power plants generate significant amounts of carbon dioxide emissions into the atmosphere (more than 12 billion tons of CO2 per year. The amount of CO2 emissions generated from a fossil fuel power plant will mainly depend on the type of fuel used, the type of power generation technology, the size of the plant, and the efficiency. Nuclear power plants are generating and accumulating copious quantities of radioactive waste that currently lack any repository. Even renewable energy facilities can affect wildlife (fish and birds), involve hazardous wastes, or require cooling water. An estimated 1.3 billon people – 17.3% of the global population – did not have access to electricity. Many more suffer from supply that is of poor quality.

Organic waste is interesting to develop as a renewable energy source. One of them is persimmon fruit wastes. This fruit is popular in Japan and in other parts of the world. In 2005, it production also still high and if it considers about 15% of the whole fruit will generated as waste, it causes a waste disposal problem. It should be utilized, as a valuable resource to produce electrical energy or other high value products (Cristiani et al., 2013).

MFCs are an alternative to conventional methods of generating electricity and treatment of organic wastes from different derivations. In the past 10–15 years, the microbial fuel cell (MFC) technology has captured the attention of the scientific community for the possibility of transforming organic waste directly into electricity through microbially catalyzed anodic, and microbial/enzymatic/abiotic cathodic electrochemical reactions.The aim of this study was to evaluate a scale-up and environmental factors of low cost feasible MFC reactor by using organic wastes (especially by using persimmon fruit wastes) as an efficient and eco-friendly solution for organic waste to generate bioelectricity.

8.2 Materials and methods

8.2.1 Sample Collection

In this study, I used the organic wastes as the feed. Organic waste is material that is biodegradable and comes from either a plant or animal. Organic waste is usually broken down by other organisms over time and may also be referred to as wet waste. Most of the time, it is made up of vegetable and fruit debris, paper, bones and human waste which quickly disintegrate. The persimmon fruit waste, rice bran and leaf mold as organic waste, was collected from Japan Agriculture Office, Ube city branch. Figure 8.1 and Figure 8.2 show the production of persimmons which relatively abundant. The economic value of persimmon fruit itself generally is now no longer expected by the farmers, but they contain a lot of nutrients, vitamins and minerals which will be utilized by the bacteria to produce electricity next.

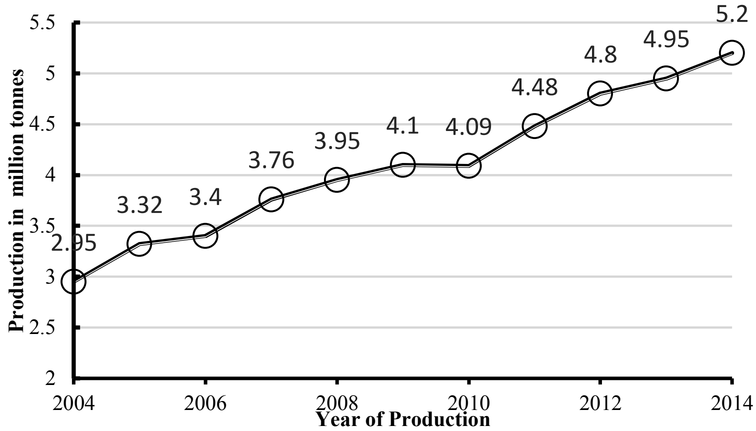


Figure 8.1. Production of persimmons in the world (Source : FAO, 2015)

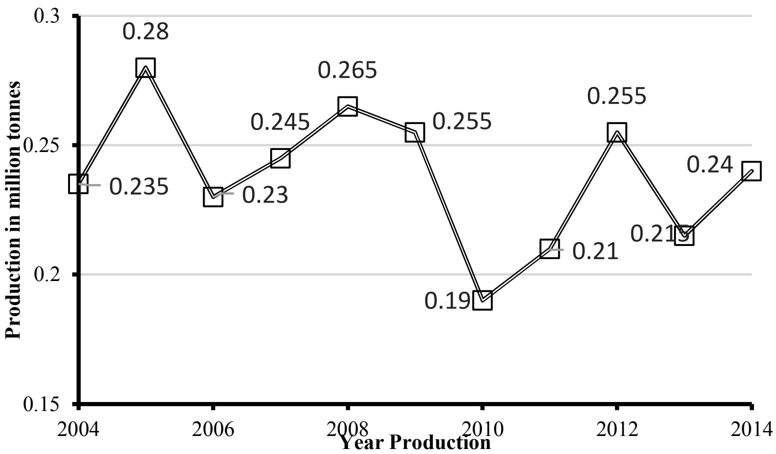


Figure 8.2. Production of persimmons in Japan (Source : FAO, 2015)

Consider also the average production of rice husk in Japan from 2004-2014 which reaches 1.078 million tons per year, if not handled properly will be an environmental problem. The nutritional value of persimmons, rice bran and leaf mold (value per 100 grams) is elucidated in Table 8.1.

Soil which used in whole experiments were sampled in the 10-cm layer of natural Tokiwa Park soil, located in the plant area of Tokiwa Park (33°57'02.9" N, 131°16'47.5" E) at Ube city, Yamaguchi Prefecture, Japan. Table 8.2 shows the properties of the soils.

Table 8.1. Nutritional value of persimmon fruit and organic waste (value per 100 grams)

Organic waste	pH	Moisture content (%)	Total Sugar (g)	C/N Ratio	Water (g)	Sodium (mg/kg)	Pottasium (mg/kg)	Kalsium (mg/kg)
Persimmon Fruit	5.96 ± 0.21	68.9 ± 1.27	21 ± 0.31	14.84	135	1.7	310	27
Leaf mold	7.5± 0.21	77.4 ± 2.25	0.5± 0.017	17.6	95.64	25	187	33.0
Rice bran	6.85 ± 0.1	12.12 ± 0.25	0.9± 0.01	12	6.13	5.0	1485	57.3

Table 8.2. Characteristics of soil used in this experiment

AVS	pH	Water Content	LOI	EC	Amount
0.0051 mg/g	6.27	86.91%	10.24%	0.395 mS/cm	400 g

8.2.2 Microbial Fuel Cell (MFC) Scale-up Assembly and Field Work Preparation.

First, we assemble a basic prototype of one-chamber type of MFC. Microbial fuel cells (MFCs) represent a completely new method of renewable energy recovery: the direct conversion of organic matter to electricity using bacteria. While this sounds more like science fiction than science, it has been known for many years that bacteria could be used to generate electricity. However, expensive and toxic chemicals were needed to shuttle electrons from the bacteria to the electrode and purified chemicals (such as glucose) were needed for the bacteria to grow on. We now know that we can make electricity using any biodegradable material-- even wastewater-- and that we don't have to add any special chemicals if we use bacteria already present in the wastewater. While some iron-reducing bacteria, can be used to make electricity, there are many other bacteria already present in wastewater that can do this.One of the great things about microbial fuel cells is the wide range of "fuels" it can use to create electricity. Almost any organic material can work, and not only is energy created in the process, but also the fuel is consumed in the process: an advantage when we look at some of the applications. It shares a lot in common with a standard hydrogen fuel cell in terms of setup, with an anode and cathode chamber and a proton exchange membrane between the two.

The process moves along these steps:

1. The microbial (normally a bacteria) consumes (oxidizes) fuel that passes into the anode, liberating electrons which it transfers into an electrode wire linking the anode with the cathode.

2. Hydrogen proton charges pass from the anode to the cathode via the proton exchange membrane.
3. The cathode chamber contains oxygen or an oxidizing agent, and the hydrogen combines with the oxygen in electron charges for form water and completes the circuit, producing power.

Figure 8.3 is a schematic view of the microbial fuel cell. Electrons are generated when the microorganisms to oxidative decomposition of the organic matter. And a mechanism that the current flows by a potential difference between the positive electrode negative electrode receives the electrons. Carbon dioxide is released in the negative electrode at that time. Water oxygen is used in the chemical reaction resulting from the positive electrode. Expression that are noted below is a reaction formula when the electrons in the positive electrode and the negative electrode occurs.

In Anode :

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$$

In Cathode :

$$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$$

We used carbon felt (as electrodes), organic wastes (persimmon fruit waste, leafmold, ricebran), soils, the 10x10x15 cm of acrylic rectangular chambers and some supporting test equipment. Setting the both electrodes (which have a basic size of 10 cm x 10 cm x 1 cm respectively) related to a coper wire, external resistance and capacitor to a data-logger.

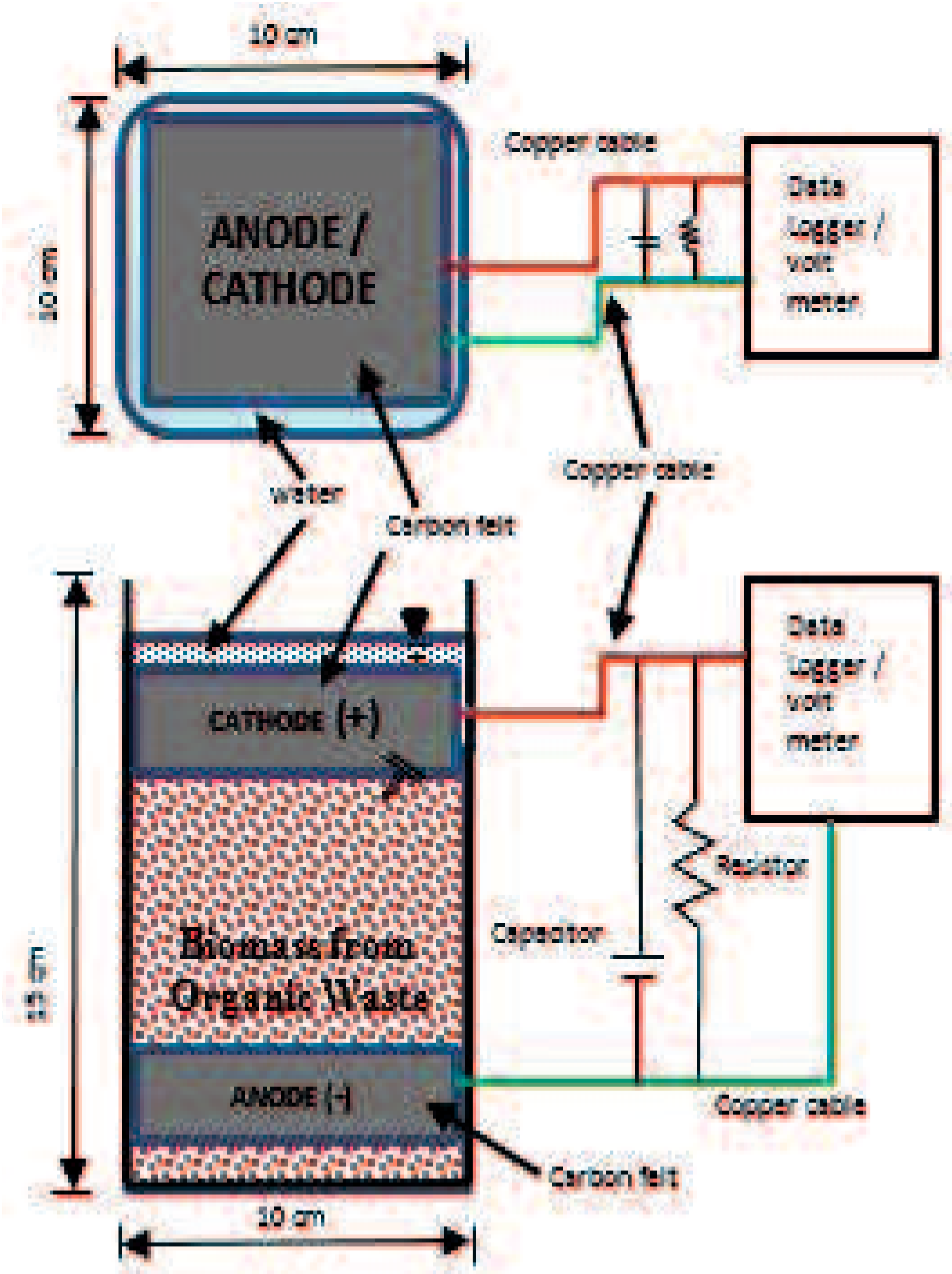


Figure 8.3 Schematic Diagram of MFC

All experiments were performed in a controlled constant room temperature of 25 °C. Then all each sample were added in to a rectangular acrylic container after they blended until mixed completely. For scale-up work, we prepared 4 buckets in diameter of 10 cm, 15 cm, 30 cm and 50 cm as shown by Figure 8.4.

Then for determine the effect of environmental condition for voltage generation, we did fieldwork as showed at Figure 8.5. For field research, in addition to equipment that is essentially the same as the equipment on the basic prototype, we also use carbon and charcoal fiber as electrodes as the same size and treatment for 12 samples in the fieldwork.

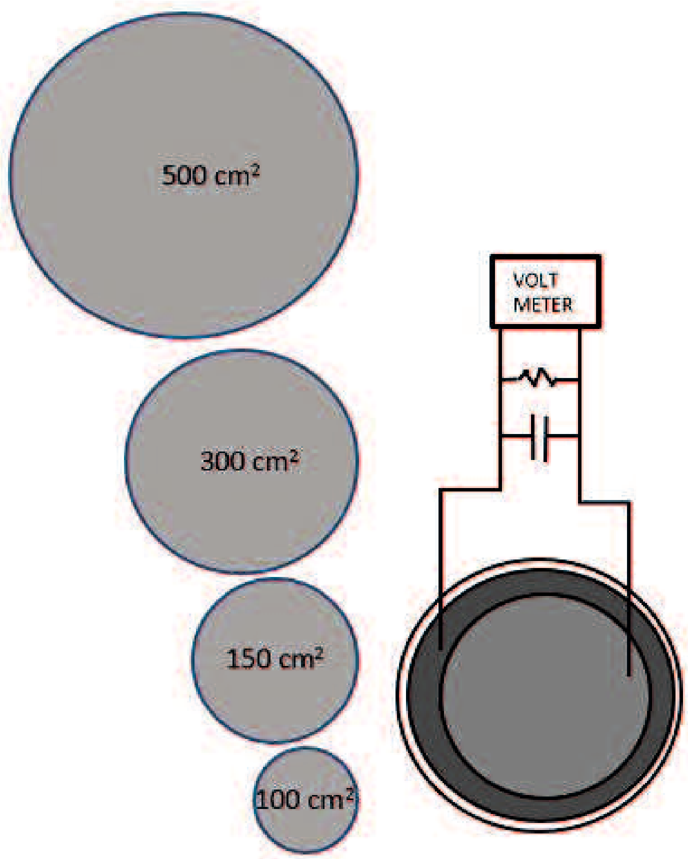


Figure 8.4. Schematic diagram MFC cell set up

Figure 8.5 Image of Fieldwork of MFC Scale-up

Next, we prefer to use carbon felt as electrodes because they commercially available, easy to manufacture as compact reactor, fiber diameter is good match to bacteria and they has high surface area, per volume up to 15,000 m2/m3. The properties of carbon felt as illustrated at Table 8.3.

Table 8.3. Properties of Carbon felt

PROPERTIES	MEASURE VALUE
Fiber grade	Carbonized
Ash content (%)	≤ 1.0
Thickness (mm)	10
Unit Mass (g/m^2)	500
Bulk density (kg/m^3)	50
Carbon Content (%)	≥ 97

Then, 4 samples of 400 g of persimmon waste (herewith call as PW), soil (herewith call as S), leafmold (herewith call as LM), and ricebran (herewith call as RB), as pure sample under some condition as shown at Table 8.4. While for another mixed samples of persimmon waste with some type of soil ((herewith call as PWS), persimmon waste and leafmold (herewith call as PWLM), and persimmon waste and ricebran (herewith call as PWRB) as mixed sample under some condition as shown at Table 8.5.

Just like with traditional fuel cells, there are many variations on microbial fuel cells, so we'll focus on the most widely established MFC in terms of research and use, known simply as the mediator-free microbial fuel cell.

Table 8.4. Parameter conditions for each pure sample.

	Soil (g)	**Organic Waste (g)**	**pH**	**Electrodes**	**EM (g)**	**Water (g)**
PW (Persimmon Waste)	0	400	6.32	Yes	4	100
S (Soil)	400	0	5.48	Yes	4	100
LM (Leafmold)	0	400	6.72	Yes	4	100
RB (Ricebran)	0	400	6.22	Yes	4	100

Table 8. 5. Parameters for organic wastes mixed sample conditions

	PW (g)	**Organic Waste or Soil (g)**	**pH**	**Electrodes**	**EM (g)**	**Water (g)**
PWS	400	400	6.83	Yes	4	100
PWLM	400	200	6.48	Yes	4	100
PWRB	400	200	7.2	Yes	4	100

8.3 Results and Discussion

8.3.1 Variation of Voltage Generation with Time, Polarization Curve and Relationship between Voltage and Current in the MFCs.

Conventionally in an MFC, bacteria catalyse the oxidation of reduced substrates, releasing some of the electrons produced from cell respiration to the anode in the anaerobic compartment, where they flow to transferred through an external wiring circuit to the counter electrode (cathode) and create current.

The cell voltage (V) current (I) and power (P) were measured at every 1:00 pm for each day as the most appropriate time for research measurement. And it calculated using Ohm' s law equation as well as the root-mean-square deviation (RMSD) is used as a statistical analysis which is a good accuracy measurement.

Figure 8.6 illustrates the variation of the voltage of each MFC that was increased gradually with elapsed time and the peak value were reached in between 2 and 12 days. It shows, during the initial stage since the bacteria got ample food and their activities increased very rapidly (Moqsud et al., 2011). After that, it increased gradually and peaked after 4-11 as the supply of food was used up by the bacteria. For some samples the voltage increased after days 7, this indicates that the MFC could recover his own electrical charge and this ability is a potential of MFC that can be developed. (Siti.L.A , 2012). The maximum values for pure sample were 4710 ± 122.84 mV/m^2, 7860 ± 100.78 mV/m^2, 3170 ± 126.58 mV/m^2 and 1980 ± 124.72 mV/m^2 for pure sample of PW, S, LM and RB respectively, while the maximum values for mixed sample were 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for mixed sample of PWS and PWLM and PWRB respectively.

It showed that the voltage value result for mixed sample of PWS is the highest one than the other because in the soil there were more mineral and nutrients which supplied the cell with a large amount of energy.

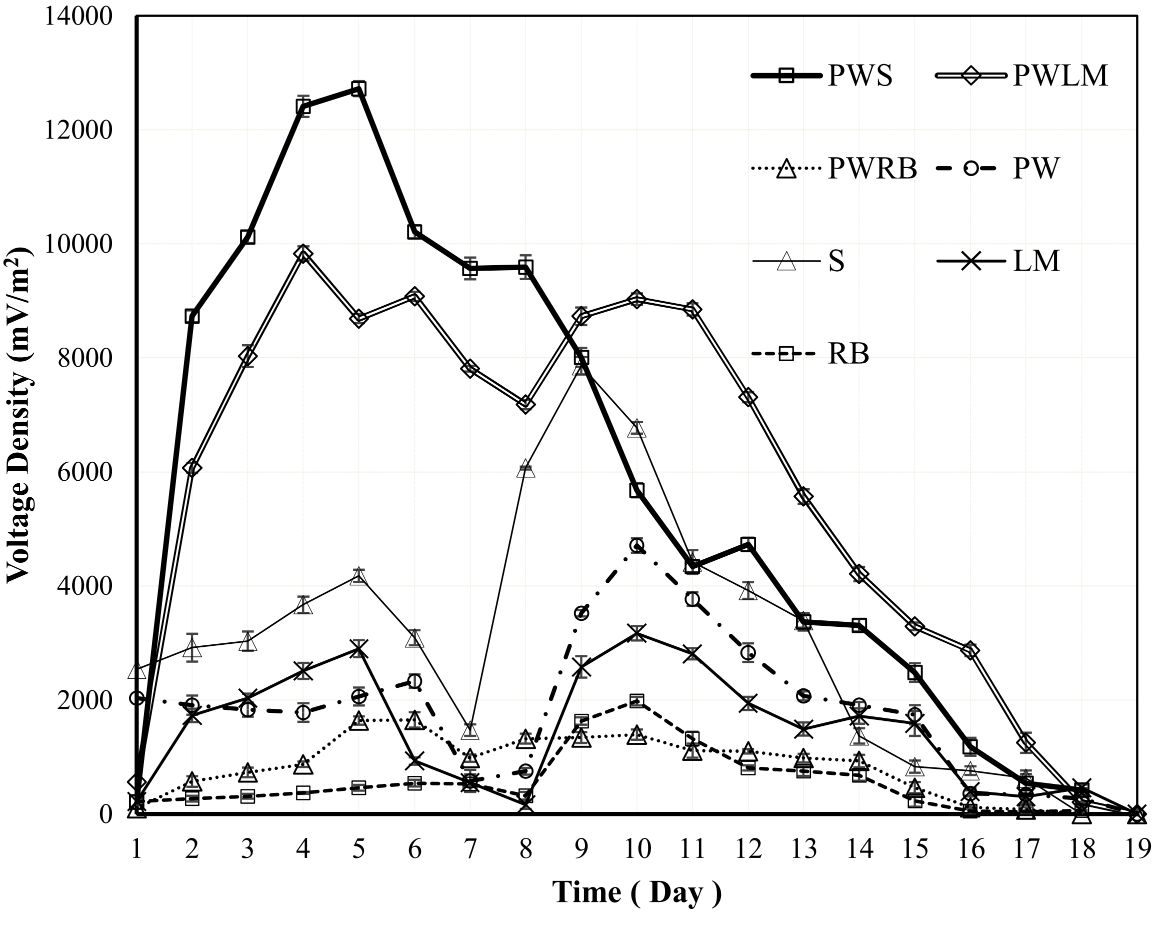


Figure 8.6. Variation of Voltage With Duration of Time in MFC

Figure 8.7 shows the polarization curve of the MFC using the persimmon waste which used to characterize current as a function of voltage (Logan, 2007; Mohan et al., 2008). It shows how well the MFC maintains voltage as a function of the current production. at each different resistance.

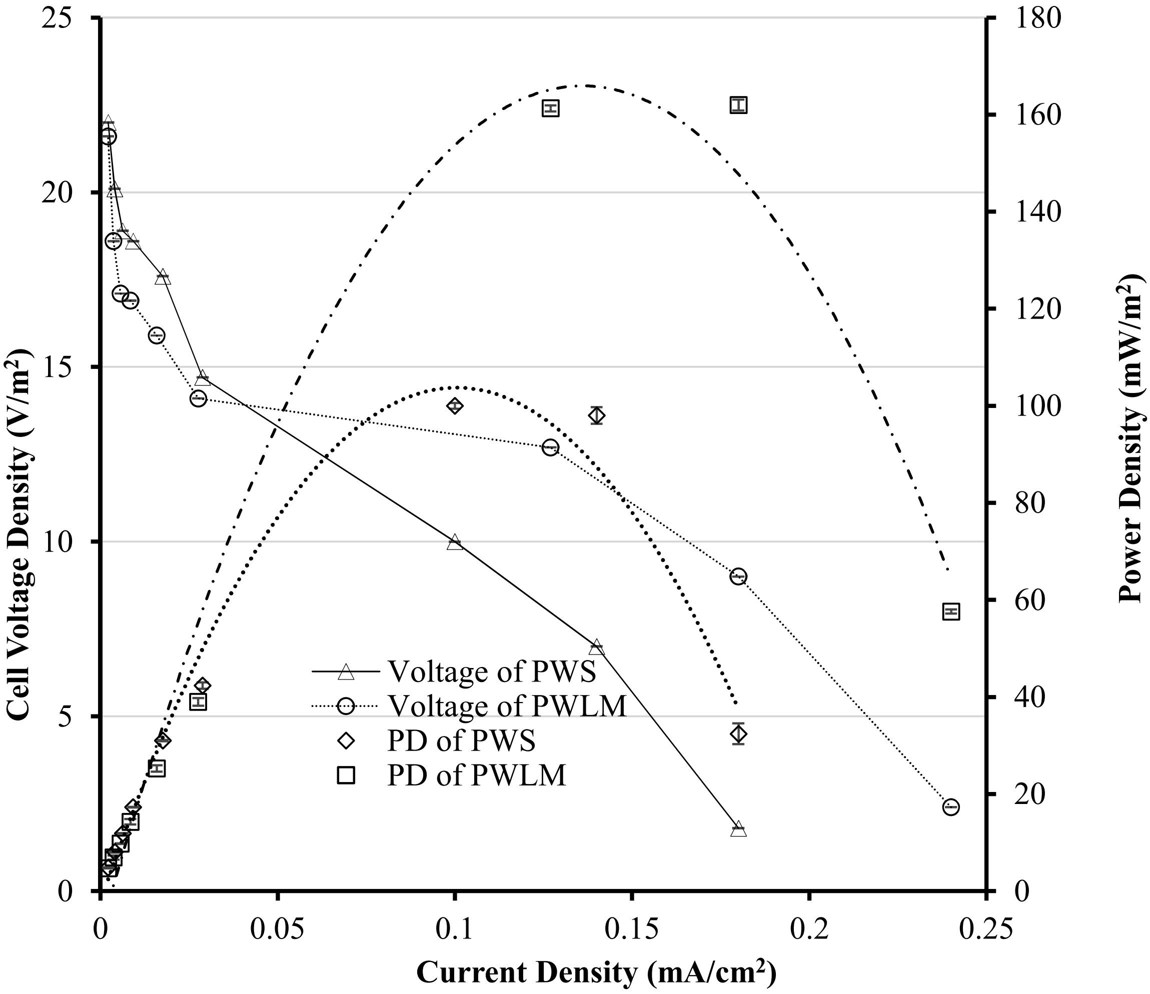


Figure 8.7. Polarization curve of the MFC using persimmon waste

It was observed that the maximum power density reached around 100 ± 0.01 mW/m2 and 161.29 ± 0.74 mW/m2 for mixed sample of PWS and PWLM, respectively. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behavior (Moqsud et al., 2015).

While Figure 8.8 shows the relationship between voltage and current in the MFCs for 12 day of elapsed time. As well as figure 6 that MFC has a good performance indicates high electromotive force and low internal resistance which was almost linear. The electromotive force of PWS was 22 ± 0.01 V/m^2, as well as 21.6 ± 0.6 V/m^2 for PWLM.

The internal resistance of MFC was relatively low. This approve persimmon fruit waste as a good green waste for bioelectricity generation.

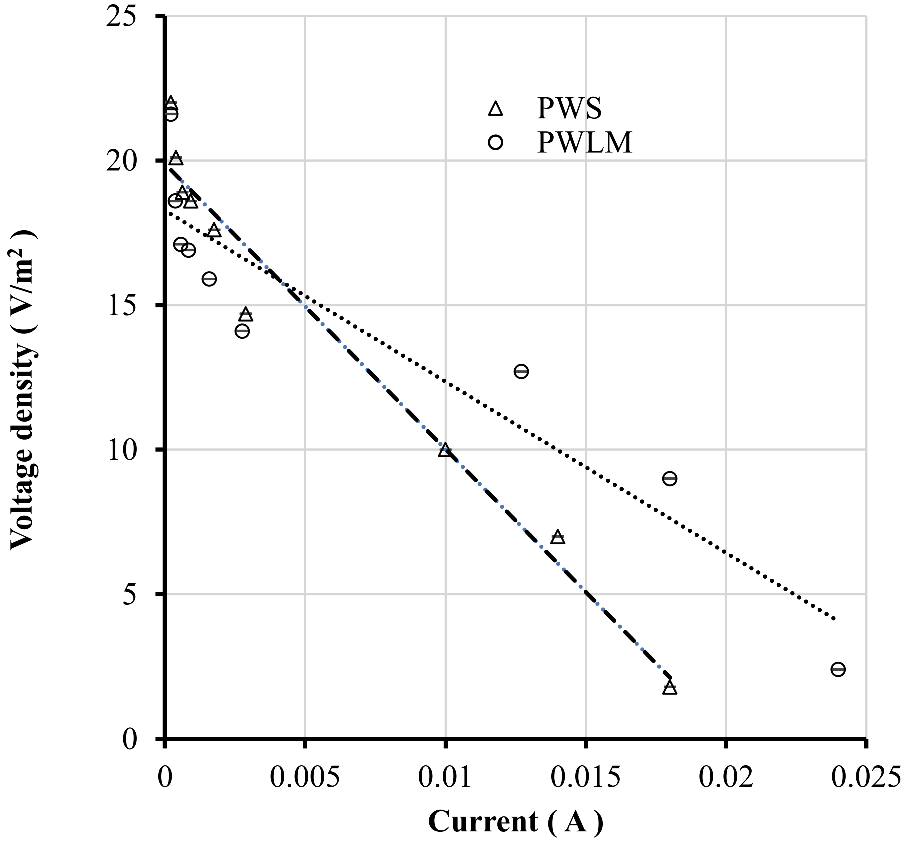


Figure 8.8 Relationship voltage and current in the MFCs (Day 12)

8.3.2 Influence of Scale-up

Scale-up experiment with same treatment as laboratories scale has done to analyze the feasibility and to improve the resulting voltage generated on larger designs with the same quality results as on a laboratory scale. As illustrated at Figure 8.9 and 8.10 that 2109.9 $mW/m^{2,}$ 2319.88 mW/m^2, 4384.06 mW/m^2 and 10317.19 mW/m^2 of power density are generated for 100 cm^2, 150 cm^2, 300 cm^2 and 500 cm^2 of size scale-up respectively. Both figures show that increasing scale-up of the electrode size will lead to increases voltage generated as well as the power density.

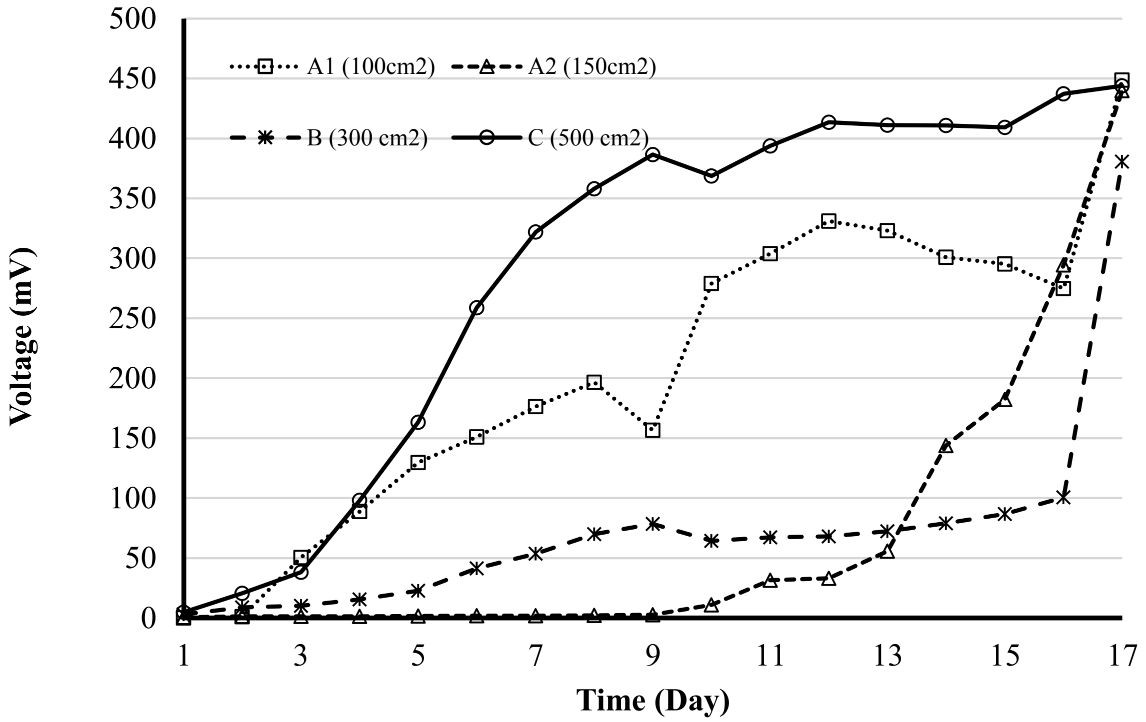


Figure 8.9 Voltage with duration of time in scale-up work

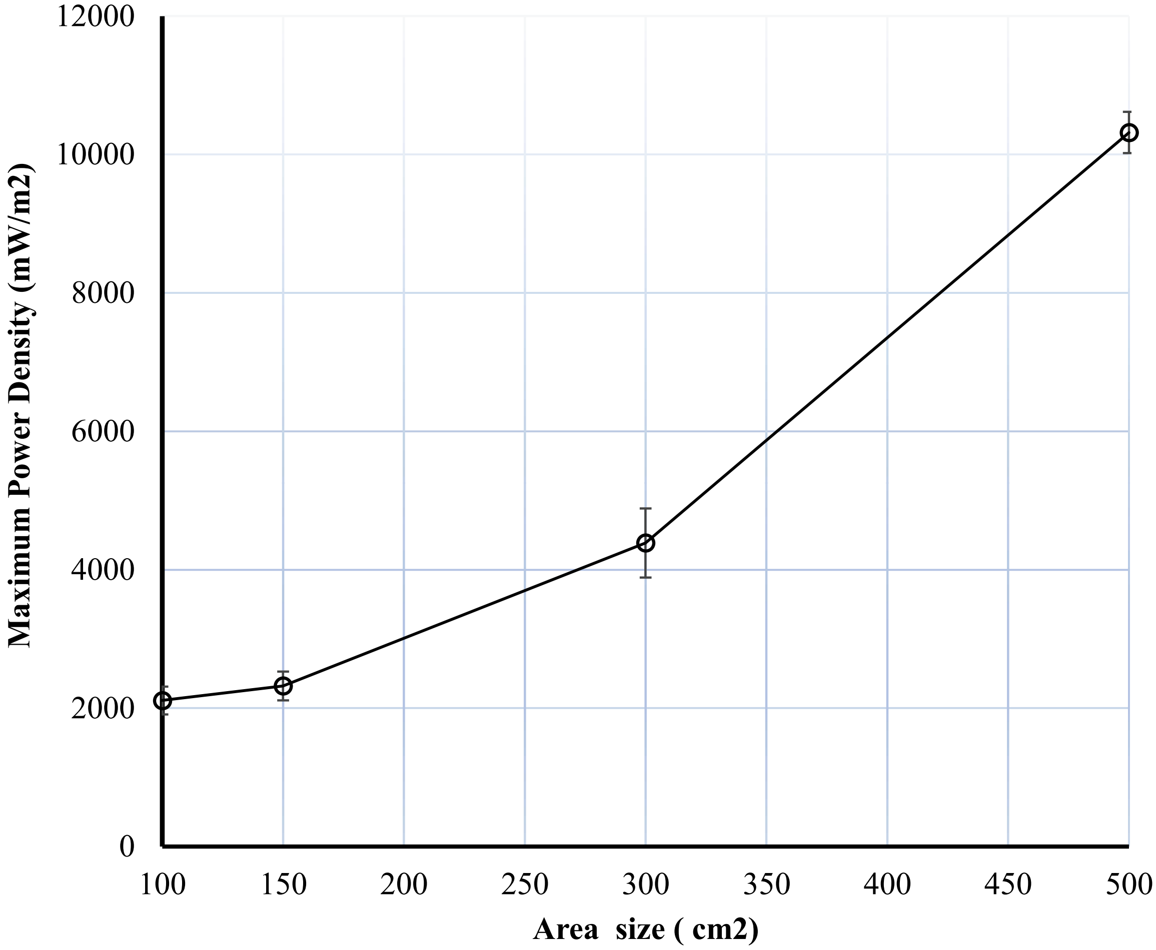
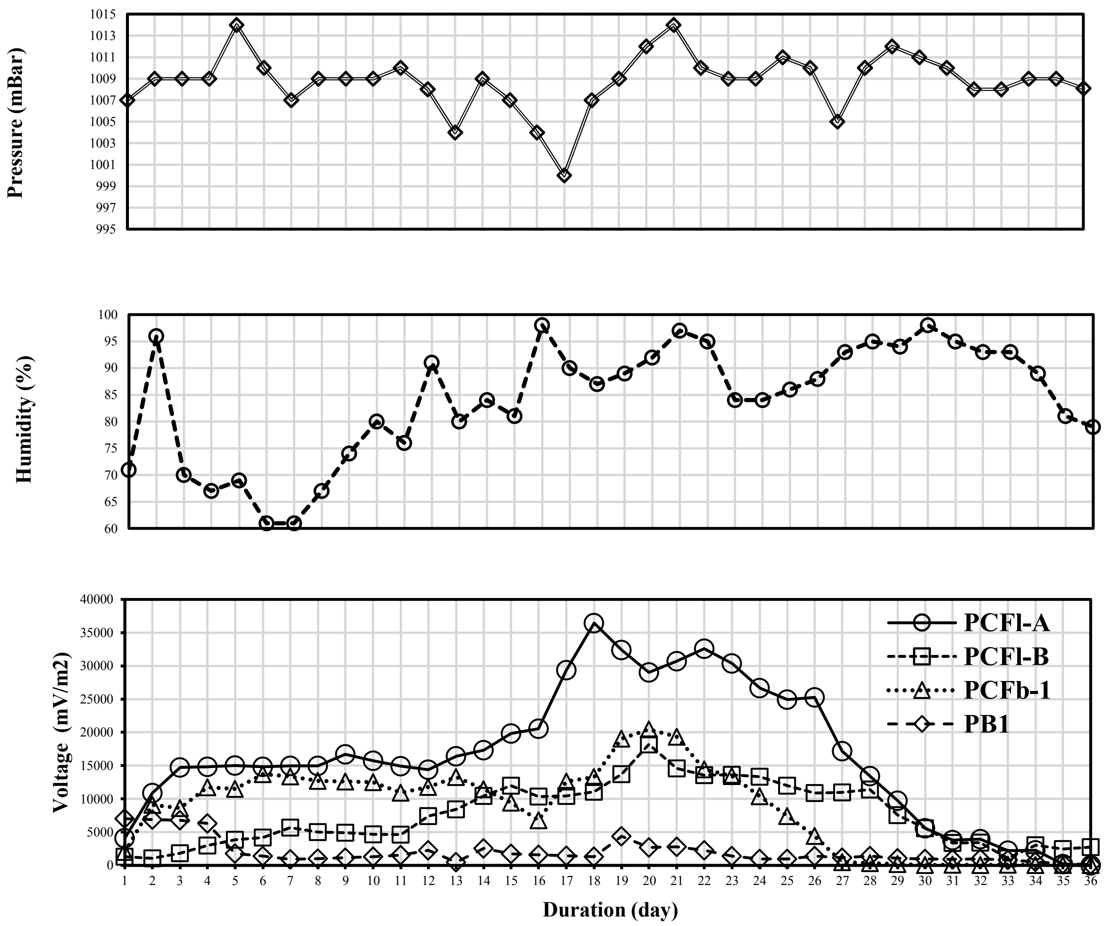


Figure 8.10 Power density of the scale-up the area

8.3.3 Effect of Environmental Factors

To obtain the result of the effect of the surrounding environmental factors which may influent to the research work and to create a condition as the natural environments/conditions to be applied, we did a field research using 12 MFC samples. We examined their voltage generated with considering their surrounding environmental factors such as pH, humidity, air pressure, solar radiation and temperature conditions and it illustrated in Figure 8.11.

It is observed that at day of 18, the higher values of voltage with higher amounts of humidity as well as pH, while solar radiation, as well as pressure and temperature sufficiently affects the voltage, although at the end of the experiment tends to be incompatible because at that time it is predicted that many dead bacteria and nutrient content in the sample has been considerably reduced. Totally, it found that the environmental factors did not have any substantial effects on the MFC operation work. Thus, MFC is applicable at any kind of environmental situations and conditions to get bioelectricity.



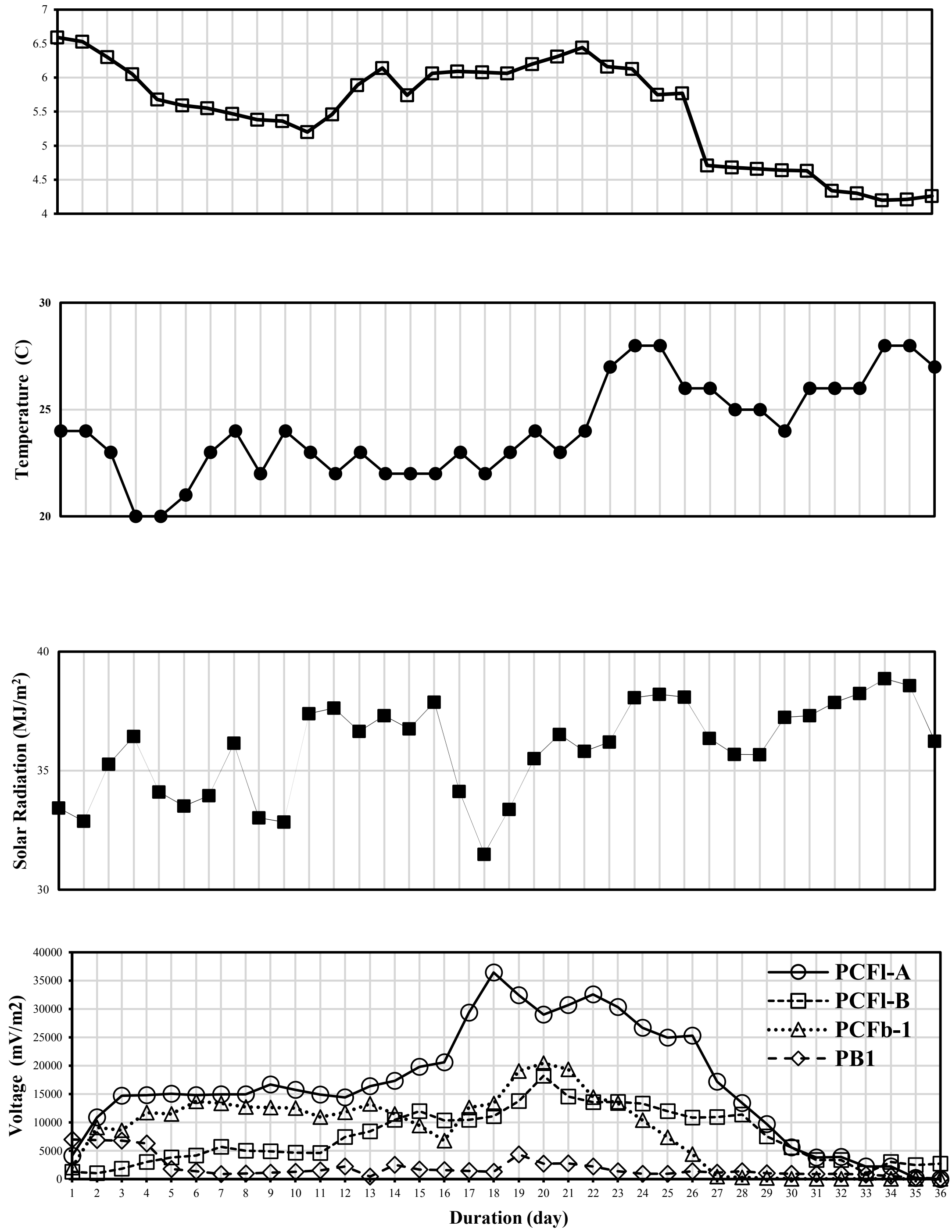


Figure 8.11 Some environmental factor effects to the voltage generation on MFC

8.3.4 Digital Microscope images, SEM image of MFC

In purpose for helps in studying surface detail structures of samples, The VHX-1000 Digital Microscope from Keyence was used. While to analyse the surface morphology and the elemental, we use SEM and EDS. Figure 8.12 and 8.13 illustrated the how well the bonding between persimmon fruit waste and in the surface of electrodes. That is the good point to show how well the performance of persimmon fruit waste and the existence of microorganism.

Figure 8.12 Digital Microscope Image of MFC

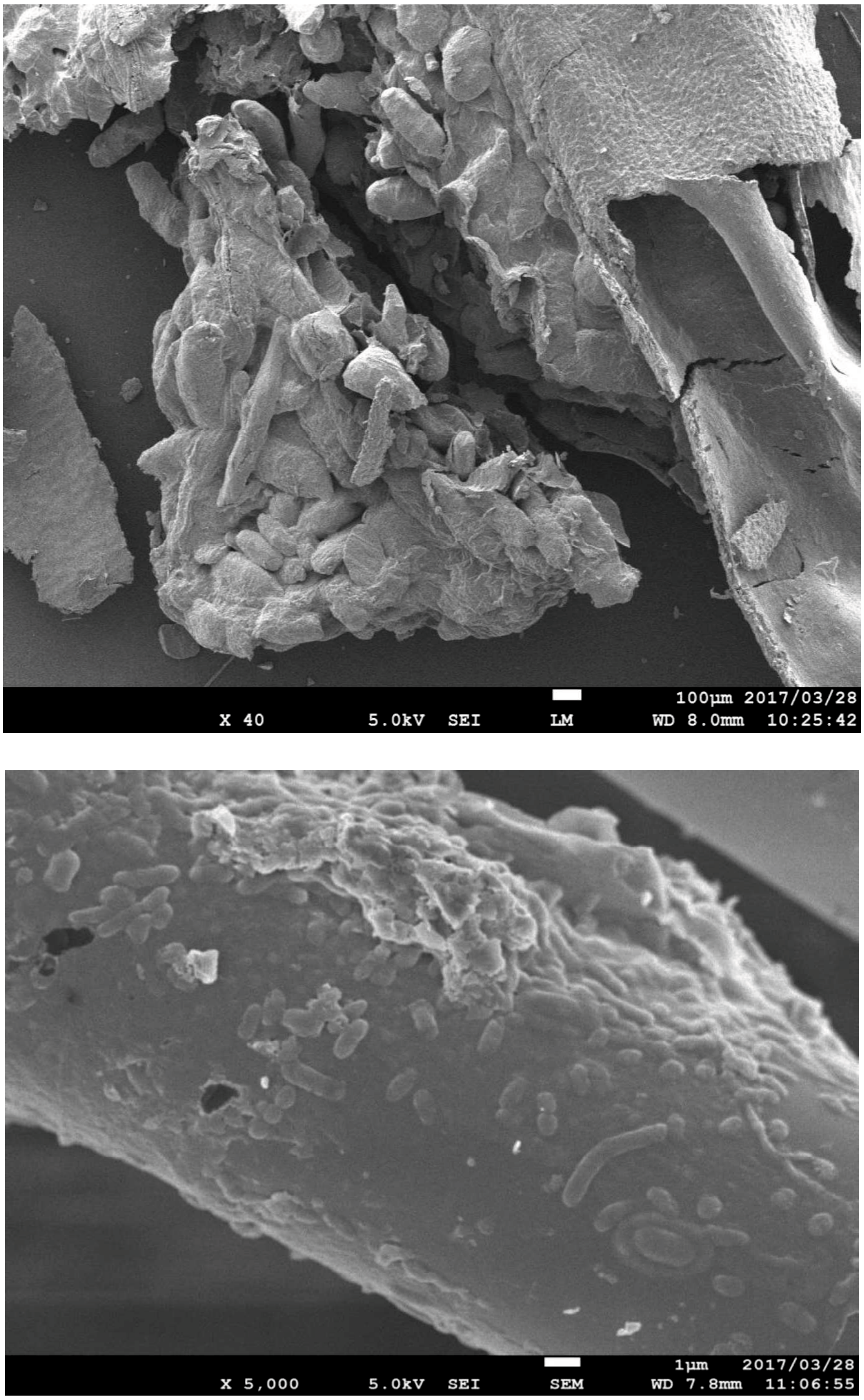


Figure 8.13 SEM image and EDS of MFC

8.4 Conclusion

Consider:

- The voltage values generate were 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for mixed sample of PWS and PWLM and PWRB respectively,
- The electromotive force of mixed sample of PWS was approximately 22 ± 0.01 V/m^2,
- The scale up voltage generate and environmental factor effects,

it proved that:

a. Persimmon waste have a potential impact as a low cost feasible material of MFC to generate bioelectricity. It is an efficient and applied eco-friendly solution by utilized the organic waste particularly in developing countries.
b. The power output in MFCs can be improved in the future by scale-up the electrode surface area, and volume of the samples.
c. It was seen that the environmental factors did not have any substantial effects on the MFC operation work. In summary, MFC is applicable at any kind of environmental situations and conditions to get bioelectricity.

Acknowledgements

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CHAPTER 9

Green Electricity by Water Plants in Organic Soil and Marine Sediment through Microbial Fuel Cell

9.1 Introduction

Microbial fuel cells (MFCs) are bio-electrochemical cells that convert microbial reducing power, into electrical energy which is green (Logan and Regan 2006, Moqsud et al. 2014, Moqsud et al. 2015). Plant MFC (PMFC) with living plants is also a way to get green energy (Wetser et al. 2015a, Moqsud et al. 2015, Strik et al. 2008). In PMFCs, plant roots directly fuel the electrochemically active bacteria at the anode by excreting rhizodeposits (Wetser et al. 2015a, Strik et al. 2008, DeSchamphelaire, et al. 2008, Kaku et al. 2008; Helder et al. 2010). Recently, research related to PMFC has received great attention all over the world. Moqsud et al. 2015 conducted PMFCs with rice plant but rice plant PMFC are needed special care to grow and life time is short. So to find out the best plants to conduct the PMFC is still needed as the plants grow in different weathers are different and the ability of generating the bioelectricity are also different. In this study, water plants were used to generate bioelectricity with microbial fuel cell which are easily found in Japan to compare the bioelectricity generation of fresh and marine water plant MFCs and to observe the seasonal and environmental influences on bioelectricity generation.

9.2 Materials and Methods

Plastic buckets of 28 cm in length and 28 cm in diameter were used for the PMFCs during June to December to observe the seasonal variation two types of soils were used in this experiment called organic soil and sea sediment. No additional fertilizer or chemicals were added in the soil to observe the influence in a natural state. Figure 9.1 illustrates the cross-section and plan of the experimental method.

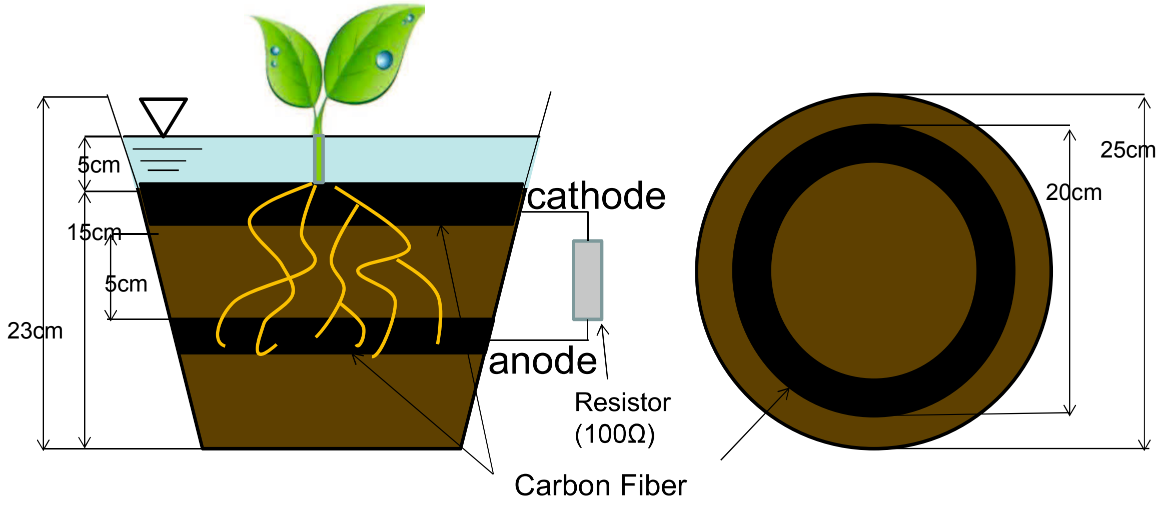

Figure 9.1: (a) Cross-section and (b) plan of the experimental set up

A circular shaped electrode made of carbon fiber (Toray industries, Tokyo) was used for both the electrodes (50 g each). The carbon fiber is not only good at conducting electricity with an electrical resistance of 5 ohm but also durable and favorable materials for soil environment (Moqsud et al. 2013). The anode area covers around 120 cm^2 in the soil of the MFCs. The anode was set approximately 5 cm below the surface of the soil, while the cathode was placed immediately above the soil surface, but under the water.

Table 9.1 summarizes the basic physicochemical properties of soil used in the experiment. Organic soil collected from local agricultural office was used for bucket no. 1, 2 and 3 (4 kg each) to prepare microbial fuel cell (MFC). Sea sediment was collected from Ube city sea shore areas and used the same amount (4kg each) to prepare MFC with sea plants in bucket 4, 5 and 6. Table 9.2 summarizes the condition of all 6 buckets. Bucket no. 1, 2 and 3 were used organic soil and fresh water of pH 7.1 and electrical conductivity 0.2 mS/cm. Similarly, for bucket 4, 5 and 6 used the same amount of sea sediment and carbon fiber as electrode materials.

Table 9.1 Basic physicochemical properties of soil used in the experiment

Parameters	Organic Soil Properties	Marine sediment Properties
pH	6.17	7.13
Electrical conductivity (mS/cm)	0.0876	31.9
Loss on ignition (%)	25.66	3.27
Oxidation reduction potential (mV)	163	151
Volumetric heat capacity (W/m$^{3\ 0}$C)	4.60	3.77
Thermal conductivity (W/m/^{0}C)	0.46	1.17
Thermal diffusivity (mm^2/S)	0.10	0.31

Table 9.2 Details of different bucket

	Bucket 1	Bucket 2	Bucket 3	Bucket 4	Bucket 5	Bucket 6
Plant	*Hydrocotyle verticillata*	*Rhynchospora colorata*	No Plant	*Artemisia fukudo*	*Phragmites australis*	No Plant
MFC	Yes	Yes	Yes	Yes	Yes	Yes
Soil (4 kg each)	Organic soil	Organic soil	Organic soil	Marine soil	Marine soil	Marine soil
Water	Water	Water	Water	Sea Water	Sea Water	Sea Water
Water pH	7.1	7.1	7.1	7.6	7.6	7.6
Water EC (mS/cm)	0.20	0.20	0.20	2.31	2.31	2.31

The fresh water plants called *Hydrocotyle verticillata, Rhynchospora colorata* and marine plants called *Artemisia fukudo*, *Phragmites australis* were planted in bucket no.1, 2, 4 and 5, respectively. For the case of bucket no. 3 and bucket no. 6, no plant was planted but prepared the MFC with organic soil and sea sediment, respectively. The voltage across the resister was monitored by the voltmeter every day at 11 am. Daily solar radiation, temperature, humidity and precipitation data are collected from the local weather office of Yamaguchi prefecture, Japan. Polarization curves and power density-current curves were made by using different resisters (Logan, 2006). In brief, electrode output was measured in volts (*V*) against time.

9.3 Results and discussion

9.3.1 Variation of voltage with time for fresh water plants

Figure 9.2 illustrates the variation of voltage with time for the case of bucket 1, bucket 2 and bucket 3.

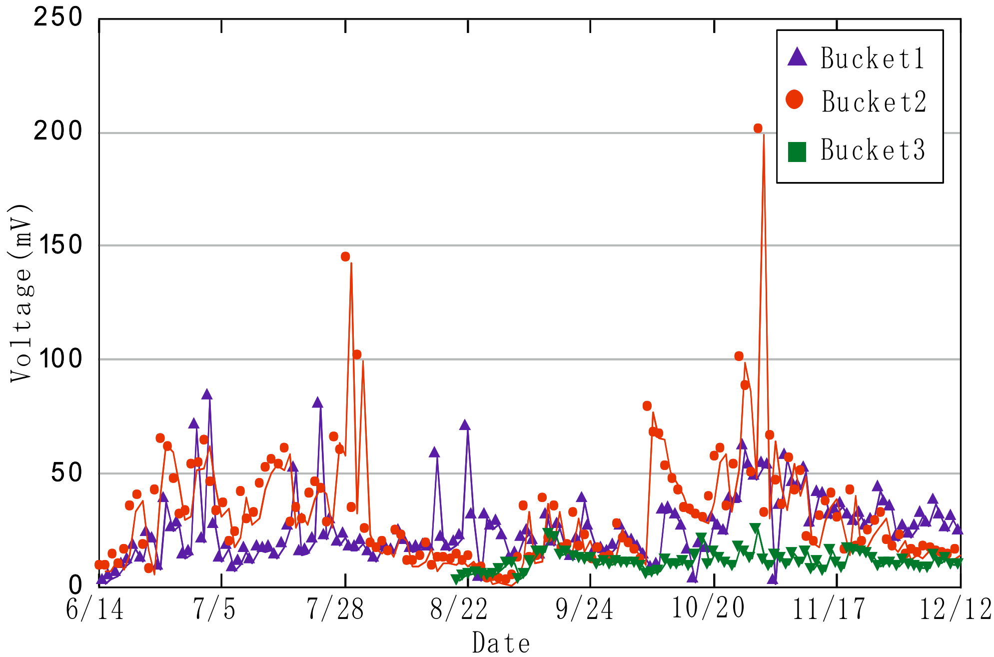

Figure 9.2 Variation of voltage with time for the fresh water plants and without water plants

It is observed that the bucket 3 (without plant) shows the lowest voltage. The peak voltage reached at around 200 mV in bucket 2. The average voltage was also higher in bucket 2 than bucket 1. This is due to the differences of the properties of the leaves and the roots of the two different types of plants. However, the voltage generated in bucket 3 (without plant) was always lower than the buckets with plants. This phenomenon proves that the plant played a significant role to generate electricity. The MFC without plant started later than the MFC with plants so the data are started later in the comparison. The duration of voltage generation is longer than the PMFC with rice plant (Moqsud et al. 2015). The cell voltage of bucket 1 and bucket 2 increased steadily from 7 days of plantation and reached at maximum of around 83 mV (at 30th Day) and 200 mV (day 120), respectively. The maximum achieved electrical power production was around 20 mW/m^2 anode surface area for bucket 2.

9.3.2 Variation of voltage with time for sea water plants

Figure 9.3 shows the variation of voltage with time for sea water plants and without plants.

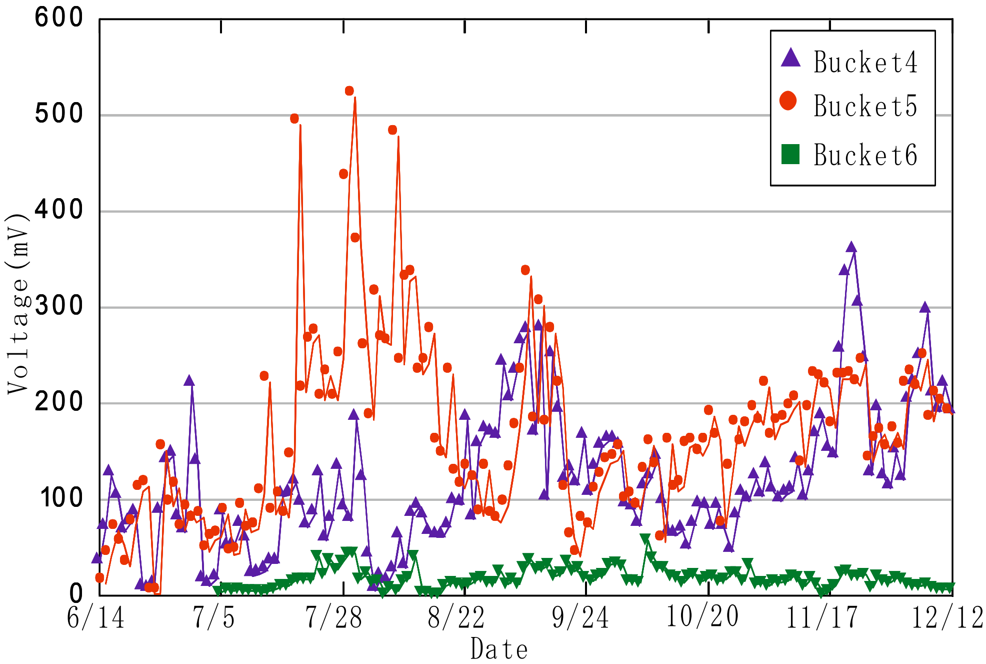

Figure 9.3 Variation of voltage with time for the sea water plants and without plants

It was observed that the voltage varied with time but the bucket 6 (without plant) showed the lowest voltage among the three MFCs. The voltage increased gradually with time and reached at peak after 30 days. Bucket 5 (*Phragmites australis*) showed the highest voltage among the three buckets. The cell voltage of bucket 4 and bucket 5 reached at maximum 357mV and 520mV, respectively. This corresponds to a current generation of 3.57 mA and 5.2 mA, respectively. The maximum achieved power production around 40 mW for bucket no. 5. The duration of voltage generation of all the PMFCs with sea plants were also longer than that of PMFCs with rice plants (Moqsud et al. 2015). The sea plants showed higher value of voltage than that of fresh water plants (bucket 1 and bucket 2) because the saline water and soil are more electrical conductive than the fresh water and soil

9.3.3 Variation of voltage with time and influence of solar radiation

Figure 9.4 illustrates the effects of solar radiation with time and voltage generation for all the buckets with plants.

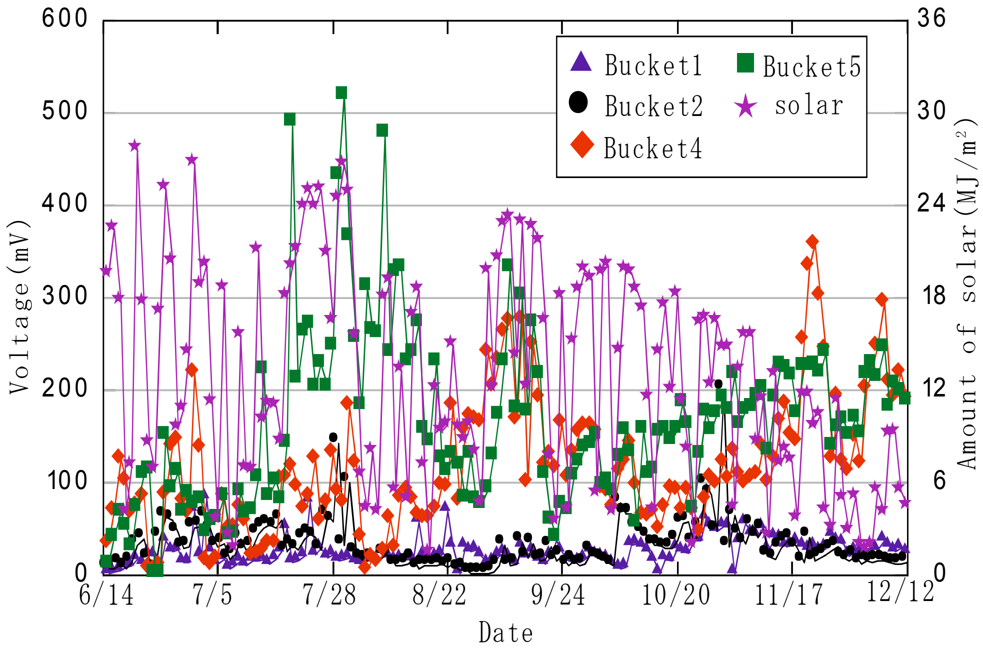

Figure 9.4 Variation of voltage with time for the water plants and solar radiation

It was observed that the voltage generation varies with time and after 30 days of planting the peak voltage was achieved on a day of higher solar radiation. At the middle of summer (July), the peak voltage showed with the higher solar radiation. However, during initial period the root and the plants did not grow enough to generate enough to act as an efficient cell. The Photosynthesis produced during the higher solar radiation day may have led to increase exudate production and substrate availability in the MFC thereby increasing the cell voltage.

9.3.4 Variation of voltage with time and influence of temperature

Figure 9.5 illustrates the variation of voltage with time and influence of ambient temperature.

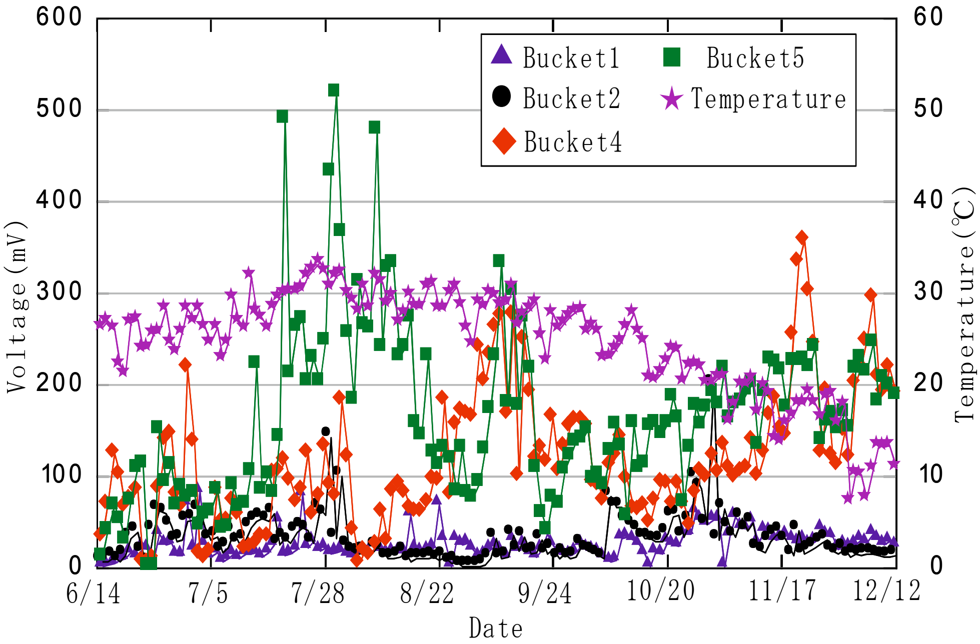

Figure 9.5 Variation of voltage with time for the water plants and temperature

It was observed that higher temperature also influences the higher voltage generation. However, during the winter season, temperature did not affect the cell voltage generation. This type of phenomenon was also similar findings by Strik et al. 2008. The temperature variation caused an effect to the microbial activities and consequently reduced the voltage generation during the winter as compared to summer voltage generation, however, the voltage value was still significant in this current research.

9.3.5 Polarization curve of the PMFs

Figure 9.6 illustrates the polarization curve for bucket 5 on day 90. The polarization curve for other buckets with plants were similar with bucket no. 5, so only bucket no. 5 is shown here. The polarization curve shows how well the MFC maintains voltage as a function of the current production. The trend of polarization curve which is illustrated in Fig.6 is almost similar with other polarization curves (Logan et al. 2006, Moqsud et al. 2015). Figure 9.6 shows the maximum power density is around 25 mW/m2.

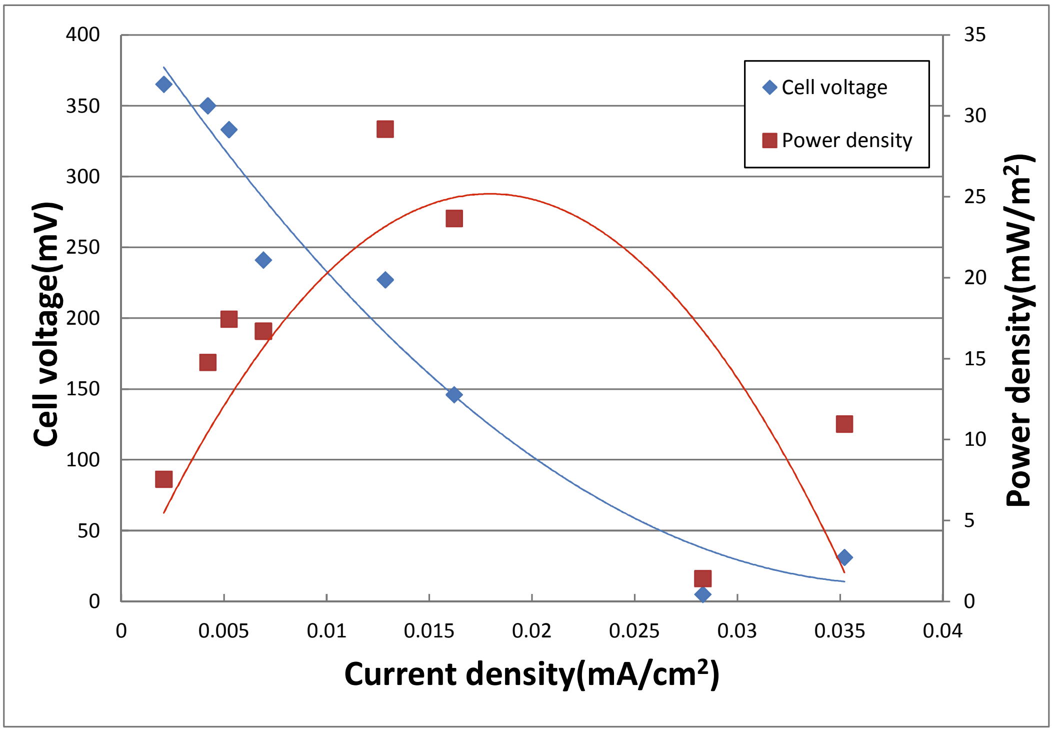

Figure 9.6 Polarization curve for sea water plants (Bucket 5) on 4th week

9.4 Conclusion

In this study, plant microbial fuel cells (PMFCs) were designed for bioelectricity generation by using water plants which grows abundantly in Japan. Peak voltage (around 520 mV) was obtained by *Phragmites australis*. MFCs prepared without plants derived the lowest voltage throughout the experiment. The seasonal variation was not so prominent for bioelectricity generation from PMFCs but weather factors such as solar radiation had a significant influence on the bioelectricity generation. It was found that sea water plants were more capable for bioelectricity generation. All water plants had extended duration of voltage generation and needed lesser efforts to nurture than rice PMFCs.

Acknowledgement:

The authors wish to acknowledge the financial support by Grant-in-Aid for Scientific Research (26630220) from Japan Society for the Promotion of Science.

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CHAPTER 10

Final Conclusions And Future Development

10.1 Final Conclusions

Today, relating to world's energy crisis problems, we need green energy for the future generation as well as a need the safe source of energy.

Microbial fuel cells (MFCs) are bio-electrochemical transducers that convert microbial reducing power, into electrical energy. Depletion of energy reserves, global warming and the concern of environmental pollution are inspiring the search for new environment-friendly and sustainable energy production methods all over the world. Both in developing countries and the industrialized countries people are trying to find a way how to collect energy from various renewable sources. So far, MFC is used for various purposes such as to clean waste water. Since we need green energy for the future generation. We also need the safe source of energy. Microbial fuel cell technology can be used for this purpose. In many countries in the world, the organic waste is not recycled properly. So by using this technology we can get green electricity from waste materials. We can design a method in which bio-electricity can be generated without destroying the crops with a sustainable source of bio-electricity by using unwanted materials. In this research study, we have proved to generate bio-electricity from different organic waste and to design an integrated hybrid system for multisource of resource recovery from the organic waste. Resource recovery and reuse of the organic waste is a much-needed task for the world. So it will be the challenge of this research to develop a new system for resource recovery from the organic waste which will be more sustainable. This is a useful and applicable potential-low cost method of green electrical energy.

Therefore, bioelectricity can be produced using mixed samples of organic waste and soil thus it reduce environmental impact of organic waste as well as low cost and safe bioelectricity generation system. As well as, MFC by using organic waste is applicable everywhere. Moreover, MFC can work well in any environmental situations and carbon felt is the most efficient as electrode for this work. Carbon felt characteristics are high porosity and high electrical conductivity, the large pores allow bacteria to penetrate through the structure and colonize the biofilm also internally. The cost is relatively low and the mechanical strength is high depending on the thickness of the material (N. Zhu et al, 2011).

Briefly, it proved that :

- The potential of green electrical energy can be developed by the utilization of organic wastes mixing with soil in MFC
- The overall voltage generated are proportional to the scale up of the MFC.
- Carbon felt is the most suitable of electrode material for electricity generation
- MFC can work well in any environmental factor / situations, the microorganism can run the life process to produce bioenergy independently.

Thus, this study will develop a bio-energy without using food product which reduce some environmental impact of organic waste , applicable everywhere as low cost and safe bioelectricity generation system.

10.2 Future Development

The generated power in MFC is still too low and researchers are working to improve it for commercial application. Eventough since this study has some future development such as :

1. The mixture of organic waste, soil and carbon felt as an electrode greatly supports the growth of microorganisms in working optimally to produce bioelectricity, so we can develop to more utilized organic waste in scale-up project and applicative project to support the green and safe energy development.
2. MFC is quite powerfull for turn on LED and to charge a mobile phone as well as USB charger in a household using their own waste, so the future application development in remote area is suitable.
3. MFC can work on any environmental situation, so we can apply and develop it at our real situation and sustainable.
4. To use the by-products of the electricity generation for bioremediation purposes.

Finally, The MFC system will have wider application potential in near future. Since MFC has major advantages of energy from organic waste such as the absence of pollutants and energy recovery with organic waste management.

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Green electricity by water plants in organic soil and marine sediment through microbial fuel cell

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ABSTRACT
In this research, water plants microbial fuel cells (MFCs) were designed for bioelectricity generation. Organic soil and marine sediment were used for fresh water and sea water plants, respectively. It was observed that sea plants were more efficient for bioelectricity generation than the fresh water plants. The peak voltage reached at 520 mV when *Phragmites australis* was used. The MFCs without plants always showed significantly lower (80% lower) voltage in both soils. Seasonal variation was not prominent; however, daily solar radiation had noteworthy influences on voltage generation for both plants.

KEYWORDS
Bioelectricity; green energy; organic soil; microbial fuel cell; sea sediment

1. Introduction

Microbial fuel cells (MFCs) are bio-electrochemical cells that convert microbial reducing power into electrical energy that is green (Logan and Regan, 2006; Moqsud et al., 2014; Moqsud et al., 2015). Plant MFC (PMFC) with living plants is also a way to get green energy (Strik et al., 2008; Wetser et al., 2015a; Moqsud et al., 2015). In PMFCs, plant roots directly fuel the electrochemically active bacteria at the anode by excreting rhizodeposits (Strik et al., 2008; Kaku et al., 2008; Helder, 2010; Wetser et al., 2015a). Recently, research related to PMFC has received great attention all over the world. Moqsud et al. (2015) conducted PMFCs with rice plant, but rice plant PMFCs need special care to grow and life time is short. So to find out the best plant to conduct the PMFC is still needed as the plants grown in different weathers are different and the ability of generating the bioelectricity is also different. In this study, water plants were used to generate bioelectricity with MFCs that are easily found in Japan to compare the bioelectricity generation of fresh and marine water plant MFCs and to observe the environmental factors those influence on bioelectricity generation.

2. Materials and methods

Plastic buckets of 28 cm in length and 28 cm in diameter were used for the PMFCs during June to December to observe the seasonal variation. Two types of soils were used in this experiment: organic soil and sea sediment. No additional fertilizer or chemicals were added in the soil to observe the influence of the bioelectricity generation in a natural condition. Figure 1 illustrates the cross-section and plan of the experimental method. A circular-shaped electrode made of carbon fiber (Toray industries, Tokyo) was used for both the anode and the cathode (50 g each). The carbon fiber is not only good at conducting electricity with an electrical resistance of 5 ohm but also durable and favorable material for soil environment (Moqsud et al., 2013; Moqsud et al., 2015). The anode area

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ueso.

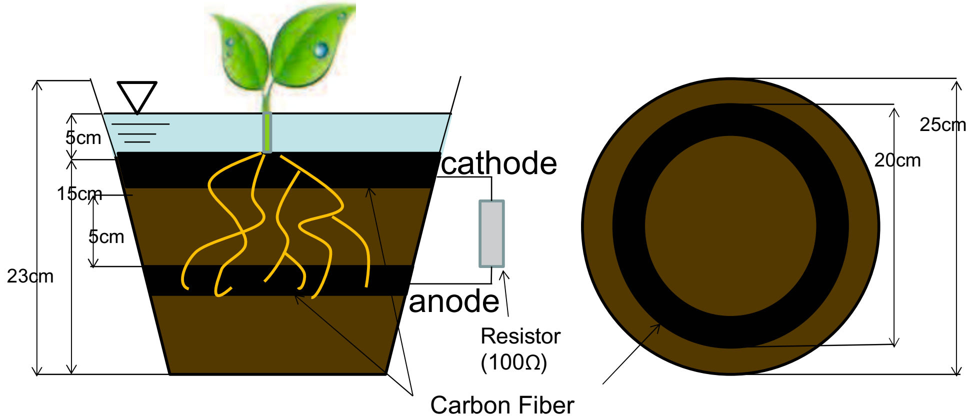

Figure 1. (a) Cross-section and (b) plan of the experimental setup.

Table 1. Basic physicochemical properties of soil used in the experiment.

Parameters	Organic Soil Properties	Marine Sediment Properties
pH	6.17	7.13
Electrical conductivity (mS/cm)	0.0876	31.9
Loss on ignition (%)	25.66	3.27
Oxidation reduction potential (mV)	163	151
Volumetric heat capacity (W/m^3 °C)	4.60	3.77
Thermal conductivity (W/m/°C)	0.46	1.17
Thermal diffusivity (mm^2/S)	0.10	0.31

covers around 120 cm^2 in the soil of the MFCs. The anode was set approximately 5 cm below the surface of the soil, while the cathode was placed immediately above the soil surface, but under the water. Table 1 summarizes the basic physicochemical properties of the soil used in the experiment. Organic soil collected from local agricultural office was used for buckets 1, 2, and 3 (4 kg each) to prepare MFC. Sea sediment was collected from Ube city sea shore areas and used the same amount (4 kg each) to prepare MFC with sea plants in buckets 4, 5, and 6. Table 2 summarizes the condition of all 6 buckets. Organic soil and fresh water of pH 7.1 and electrical conductivity 0.2 mS/cm in buckets 1, 2, and 3. Similarly, the same amount of sea sediment and carbon fiber as electrode materials were used for buckets 4, 5, and 6. Fresh water plants called *Hydrocotyle verticillata, Rhynchospora colorata* and marine plants called *Artemisia fukudo, Phragmites australis* were planted in bucket no. 1, 2, 4, and 5, respectively. For the case of bucket no. 3 and bucket no. 6, no plant was planted but the MFC was prepared with organic soil and sea sediment, respectively. The voltage across the resister was monitored by the voltmeter every day at 11 am. Daily solar radiation, temperature, humidity, and precipitation data were collected from the local weather office of

Table 2. Details of different buckets.

	Bucket 1	Bucket 2	Bucket 3	Bucket 4	Bucket 5	Bucket 6
Plant	*Hydrocotyle verticillata*	*Rhynchospora colorata*	No Plant	*Artemisia fukudo*	*Phragmites australis*	No Plant
MFC	Yes	Yes	Yes	Yes	Yes	Yes
Soil (4 kg each)	Organic soil	Organic soil	Organic soil	Marine soil	Marine soil	Marine soil
Water	Water	Water	Water	Sea Water	Sea Water	Sea Water
Water pH	7.1	7.1	7.1	7.6	7.6	7.6
Water EC (mS/cm)	0.20	0.20	0.20	2.31	2.31	2.31

Yamaguchi prefecture, Japan. Polarization curve was made by using different resisters. In brief, electrode output was measured in volts (*V*) against time.

3. Results and discussion

3.1. *Variation of voltage with time for fresh water plants*

Figure 2 illustrates the variation of voltage with time for the case of buckets 1, 2, and 3. It was observed that the bucket 3 (without plant) showed the lowest voltage. The peak voltage reached at around 200 mV in bucket 2. The average voltage was also higher in bucket 2 than that of bucket 1. This was probably due to the differences of the properties of the two different kinds of plants. However, the voltage generated in bucket 3 (without plant) was always lower than that of the buckets with plants. This phenomenon proves that the plant played a significant role to generate electricity. The MFC without plant started later than the MFC with plants so the data are started later in the comparison. The duration of voltage generation is longer than the PMFC with rice plant (Moqsud et al., 2015). The cell voltage of bucket 1 and bucket 2 increased steadily from 7 days of plantation and reached at maximum of around 83 mV (30th day) and 200 mV (at120th day), respectively. The maximum achieved electrical power production was around 20 mW/m^2 anode surface area for bucket 2.

3.2. *Variation of voltage with time for sea water plants*

Figure 3 shows the variation of voltage with time for sea water plants and without plants. It was observed that the voltage varied with time but the bucket 6 (without plant) showed the lowest voltage among the three MFCs. The voltage increased gradually with time and reached at peak after 30 days. Bucket 5 (*Phragmites australis*) showed the highest voltage among the three buckets. The cell voltage of bucket 4 and bucket 5 reached at maximum 357 and 520 mV, respectively. This corresponds to a current generation of 3.57 and 5.2 mA, respectively. The maximum achieved power production around 40 mW was found in bucket no. 5. The duration of voltage generation of all the PMFCs with sea plants was also longer than that of PMFCs with rice plants (Moqsud et al., 2015). The sea plants showed higher value of voltage than that of fresh water plants (bucket 1 and bucket 2) because the saline water and soil are more electrical conductive than the fresh water and soil.

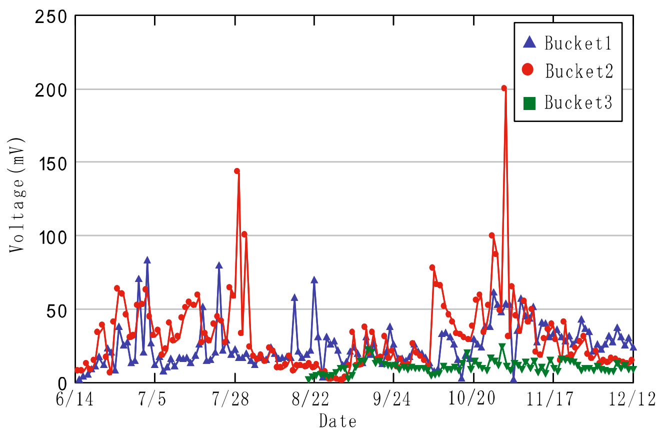

Figure 2. Variation of voltage with time for the water plants and without water plants.

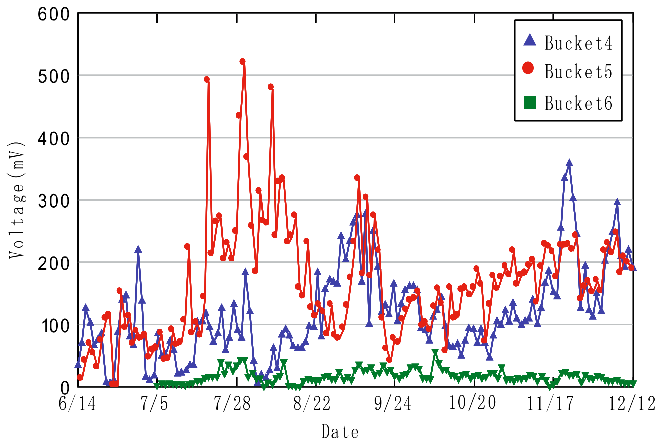

Figure 3. Variation of voltage with time for the sea water plants and without plants.

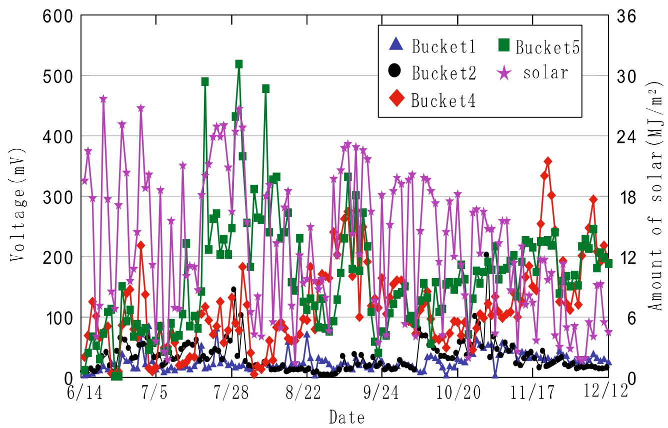

Figure 4. Variation of voltage with time for the water plants and solar radiation.

3.3. *Variation of voltage with time and influence of solar radiation*

Figure 4 illustrates the effects of solar radiation with time and voltage generation for all the buckets with plants. It was observed that the voltage generation varied with time, and after 30 days of planting, the peak voltage was achieved on a day of higher solar radiation. At the middle of summer (July), the peak voltage showed with the higher solar radiation. However, during the initial period, the root and the plants did not grow enough to generate enough to act as an efficient cell. The photosynthesis produced during the higher solar radiation day may have led to increase exudate production and substrate availability in the MFC, thereby increasing the cell voltage.

3.4. *Variation of voltage with time and influence of temperature*

The variation of voltage with time and influence of ambient temperature is illustrated in Figure 5. During summer, higher temperature influenced the higher voltage generation. However, during the winter season, temperature did not affect the cell voltage generation that much. This type of trend in voltage generation was also observed by Strik et al. (2008) in the Netherlands. The temperature variation caused an effect to the microbial activities and consequently reduced the voltage generation

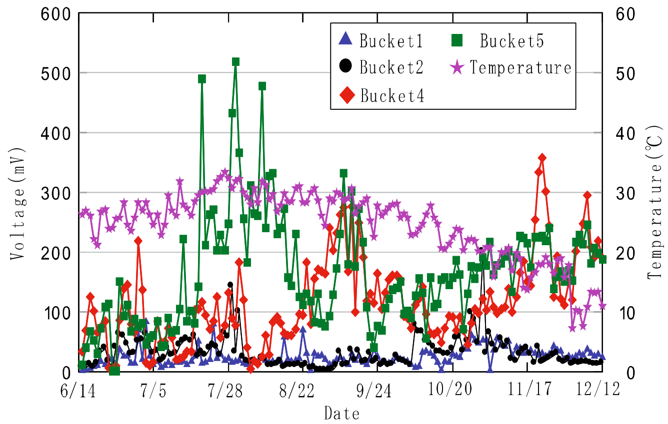

Figure 5. Variation of voltage with time for the water plants and temperature.

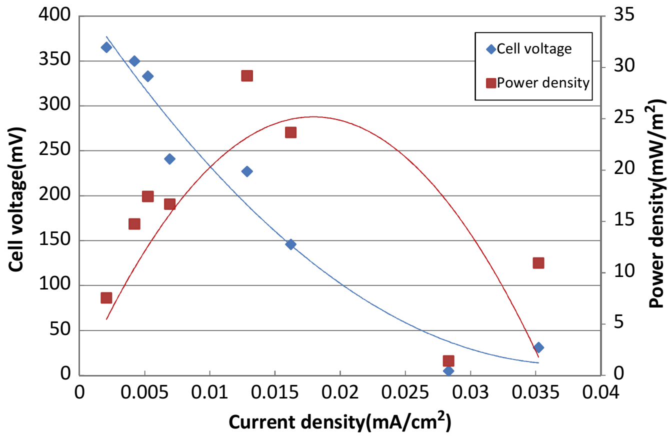

Figure 6. Polarization curve for sea water plants (Bucket 5) on 4th week.

during the cold winter as compared to hot summer voltage generation in Japan. However, the voltage value was still significant in this current research.

3.5. *Polarization curve of the PMFs*

Figure 6 illustrates the polarization curve for bucket 5 on day 90. The polarization curve for other buckets with plants was similar with bucket no. 5, so only bucket no. 5 is shown here. The polarization curve shows how well the MFC maintains voltage as a function of the current production. The trend of polarization curve,which is illustrated in Figure 6, is almost similar with other polarization curves (Moqsud et al., 2012, 2015), and it shows the maximum power density is around 25 mW/m2.

4. Conclusions

In this study, PMFCs were designed for bioelectricity generation by using water plants that grow abundantly in Japan. Peak voltage (around 520 mV) was obtained by *Phragmites australis*. MFCs prepared without plants derived the lowest voltage throughout the experiment. The seasonal variation was not so prominent for bioelectricity generation from PMFCs, but weather factors such as solar radiation had a significant influence on the bioelectricity generation. It was found that sea water plants were more capable for bioelectricity generation. All water plants had extended duration of voltage generation and needed lesser efforts to nurture than rice PMFCs.

Funding

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Strik, D., Hamalers, H., Snel, J., and Buisman, C. 2008. Green electricity production with living plants and bacteria in a fuel cell. *Int. J. Energy Res.* 32:870–876

Wetser, K., Sudirjo, E., Buisman, C., and Strik, D. 2015a. Electricity generation by a plant microbial fuel cell with an integrated oxygen reducing biocathode. *Appl. Energy* 137:151–157.

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The Effectiveness of Animal Dungs and Leaf Mold for Bioelectricity Generation Using Microbial Fuel Cell with Soils

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Abstract

A resource recovery from waste material is an important topic. Microbial fuel cell (MFC) is getting interest nowadays due to its superiority to generate electricity from a wide range of substrates by utilizing organic wastes. This study was aimed to investigate the potential electricity generation by utilizing animal dung and leafmold as a very prospective substrate for bioelectricity generation using MFC. MFC as a direct current source (DC), in this experiment we focus to prove the potential difference (voltage) generated by the material. The best result is 10980 ± 11.32 mV/m^2 for a mixed sample of Test V (leafmold and soil), while for the pure samples showed at 10880 ± 4.784 mV/m^2 for Test IV (chicken dropping). The advancements in this environmentally friendly study have expanded that cow dung, chicken droppings and leafmold as a variety of organic wastes which contains large amounts of nutrients and various other minerals, as a microbial fuel cell proved to generate sustainable green and safe electricity moreover as an efficient, eco-friendly solution for organic waste management.

Keywords

Eco-Friendly Solution, Environmental, Green and Safe Electricity, Microorganism, Microbial Fuel Cell, Organic Waste Management, Sustainable

1. Introduction

Our society is facing a serious energy crisis and resource recovery from organic waste. It about 1.3 billion people in the world live without access to power. **Table 1** illustrates some regions in the world where still lie in no electricity.

Table 1. Region in the world where still in no electricity.

Region	Population (In Billion)	Population without electricity (In Billion)	% of the lack of electricity
Asia	3.6	0.622	17.2
Africa	1.1	0.6226	56.6
Middle east	0.2148	0.0177	8.2
Latin America	0.4661	0.0232	4.9
Around the world	**7.5**	**1.3**	**17.3**

Source: reprocessed from https://www.washingtonpost.com/graphics/world/world-without-power/

Search of alternative energy such as organic waste resource recovery is an important topic. The organic waste which generated has increased rapidly over the last few decades and a major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery such as investigated by Sujauddin, Huda and Hoque (2008) [1] that solid waste management (SWM) is a multidimensional challenge faced by urban authorities, especially in developing countries, while Moqsud, M.A., 2003 [2] and Zurbrugg *et al.* (2005) [3] studied the organic waste can be effectively recycled by composting. If about 15% of the waste is abandoned in the environment without any treatment or it is not properly treated for resource recovery, they entail unique problems as shown in **Table 2**.

Whereas, the organic wastes contain large amounts of nutrients and various other minerals. Cristiani *et al.* (2013) [4] considered the advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates to produce electrical energy or other high-value added products. **Table 3** shows the nutritional values of organic wastes and soil used in this research.

Mostafa *et al.* (2011) [5] considered one of the renewable energy sources to produce electricity is fuel cells (FC). Moqsud, Omine and Yasufuku (2012a) [6], Moqsud *et al.* (2013) [7] investigated some previous studied for MFC use the available substrates from renewable sources and convert them into harmless by-products with the simultaneous production of electricity. Allen and Bennetto (1993) [8], Daniel *et al.* (2009) [9]and Li *et al.* (2012) [10] evaluated for electricity generation using waste water. Bennetto (1984) [11] and Logan *et al.* (2006) [12], Logan *et al.* (2007) [13] studied using bacteria. Habermann and Pommer (1991) [14] were to develop a low maintenance fuel cell system with long-term stability with sulphide storage capacity. Hong *et al.*(2009) [15] developed microbial fuel cell using sediment. Khalid *et al.* (2011) [16] developed organic waste for biogas and other energy-rich compounds. Microbial fuel cell using sewage sludge as fuel was studied by Jiang *et al.* (2010) [17]. Spiegel and Preston (2003) [18] demonstrated energy from anaerobic digester gas (ADG). Zang *et al.* (2009) [19] analyzed microbial communities in wheat straw biomass-powered microbial

Table 2. Environmental problems due to livestock farming in Japan (2010).

	Stink	Water pollution	Pest	Others	Total
Dairycattle	390	199	24	151	685
Beef cattle	220	114	22	70	394
Hog	466	246	8	50	663
Poultry	254	44	87	33	399
Others	27	11	4	7	44
Total	1,357	614	145	311	2185
Percentage	62.1	28.1	6.6	14.2	100.0

Source: MAFF, Department of Production (2010). Notes: 1) The number of problems indicates the number of local residents' complaints on environmental problems to local government in the given year, 2) The percentage is the rate of livestock farmers in trouble out of the total number of livestock farmers; 3) "Others" includes noise and inflow of animal waste.

Table 3. Nutritional values of organic waste and soil.

Parameter	Soil	Cow dung	Chicken dropping	Leaf mold
N (mg/kg)	5.1	2.04	1.72	4.3
P (mg/kg)	10.3	0.76	1.82	3.6
K (mg/kg)	124.2	0.82	2.18	5.0
EC (mS/cm)	0.395	18.7	19.74	1.5
C/N ratio	6.72	19.9	9.65	10.2

fuel cells. Moqsud, M., A. and Omine, K. (2010) [20] investigated bioelectricity generation by using organic waste moreover. Wang *et al.* (2009) [21] studied by corn stover biomass while Hassan *et al.* (2014) [22] evaluated rice straw for electricity. Velasquez-Orta, Curtis and Logan (2009) [23] investigated algae in microbial fuel cells. Jauharah, Boris and Raghavan (2015) [24] developed electricity from a mix of fruit and vegetable wastes. Brahmaiah, P. *et al.* (2016) [25] investigated municipal solid waste generated electricity. Resch, Hass and Faber (2008) [26] considered the production of electricity or biofuels using innovative technologies and renewable sources is a global priority in terms of energy strategies.

This research becomes very important and very interesting because of the increasing need for alternative energy while the amount of non-renewable fuel is decreasing. MFC has been well established for almost one hundred years. However, Jessica Li (2013) [27] investigated this capability did not exceed laboratory-based experiment until the 20th century when research on this subject and the creation of MFCs received sporadic approach. The objective of this study is to focus on and prove the ability of some cheap and abundant-organic wastes such as cow dung, chicken dropping and leafmold mixed with soil as a very prospective substrate for bioelectricity generation. Thus, it develops a microbial fuel cell that generates green and safe electricity using animal dungs and leafmold mixing with soil as an efficient, renewable and an eco-friendly solution for organic waste management.

2. Materials and Methods

2.1. Experimental Materials and Laboratory Instruments

To conduct the experiments which was done in Department of Civil and Environmental Engineering of Yamaguchi University-Japan, some materials were prepared such as carbon felt, soil, cow dung, chicken droppings, leafmold, effective microorganisms/EM (commercially available from EM Kenkyusho, Shizuoka, Japan), acrylic rectangular chambers, volt meter, resistors, iron wires, alligator clips, capacitor and some supporting test equipment.

The EM which used in this work was for each case to start the bioelectricity generation and to reduce possible odour from organic wastes during the investigation. The Soil which used in whole experiments were sampled in the 10 cm layer of natural Tokiwa Park soil, located in the plant area of Tokiwa Park (33˚57'02.9"N, 131˚16'47.5"E) at Ube city, Yamaguchi Prefecture, Japan. The soil used in this work as they are thought to increase not only the physical volume of samples properties and the optimum content but it also to increase the nutrient ability supplying food for microorganism to generate electricity. A 16 V 1000 μF capacitor was used in this research to store the electric energy, to reduce the voltage with less power wasted and to keep constant voltage. Carbon felt type of Kreca Felt X F 210-X was used. Some advantages that arise in using of carbon felt such as a large surface area that offers sufficient reaction sites for the electron-transfer re-actions, their suitability for mass production and good process ability, but their properties vary with the raw material used for their fabrication. The property of the electrodes shows at **Table 4**. Furthermore, **Figure 1** show the SEM images of carbon felt as electrodes. The cow dung were taken from the Department of Agriculture, Yamaguchi University at Yoshida campus, Japan. The chicken droppings and leafmold were collected from Japan Agricultural Office, Ube city branch.

2.2. MFC Assembly

In this study the MFCs employed a blend of some organic wastes and soil which over a testing time within 21 days. **Figure 2** describes the schematic diagram for the MFC in this study. Then, an amount of each organic waste (400 g), 400 g of soil and add 4 g of EM were blended with added 150 ml of water until mixed completely.

Table 4. Properties of carbon felt.

Properties	Measure value
Fiber grade	Carbonized
Ash content (%)	≤1.0
Thickness (mm)	10
Unit mass (g/m^2)	500
Bulk density (kg/m^3)	50
Carbon content (%)	≥97

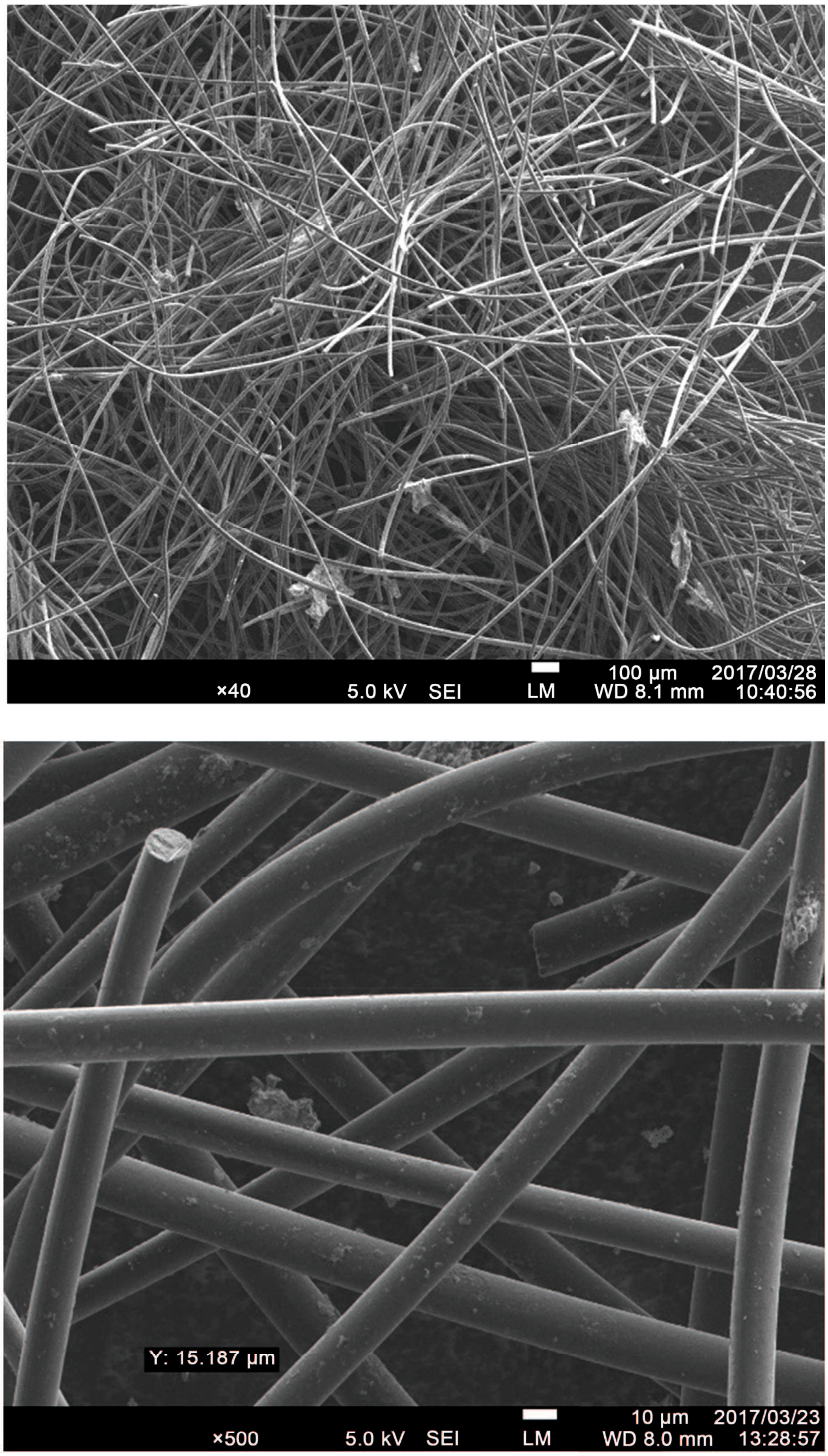

Figure 1. SEM image of carbon felt as electrode.

The blended sample was poured into the container. Carbon felt was used for both electrodes (anode and cathode).The anode was set approximately 5 cm below the surface of the compost, while the cathode was placed immediately above

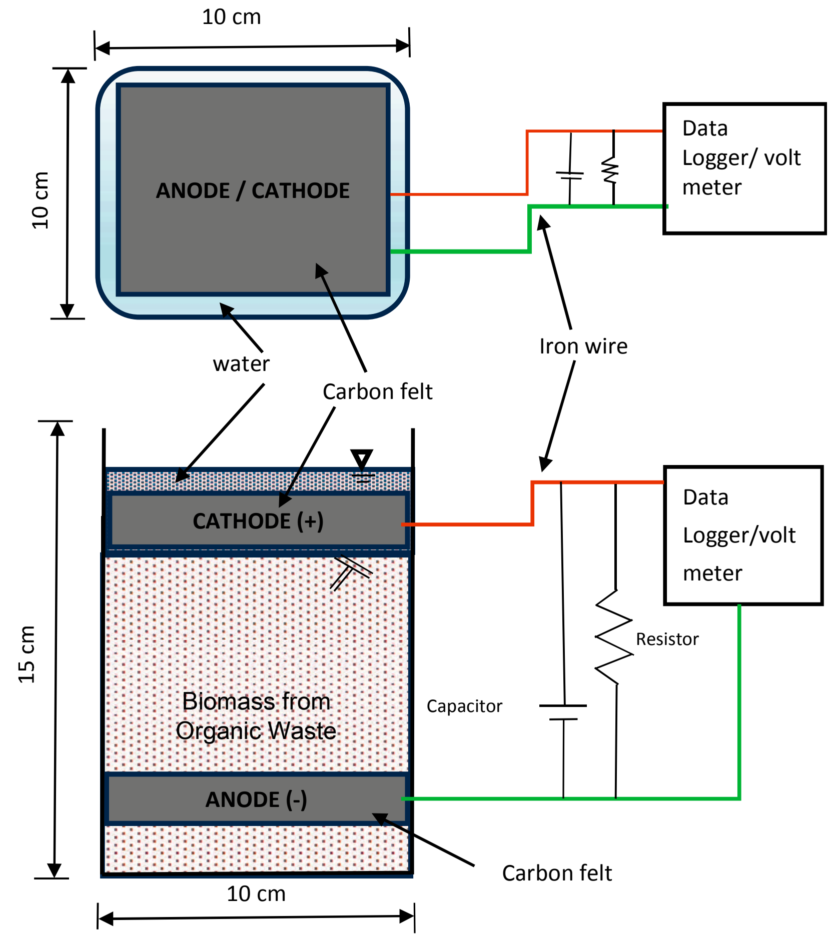

Figure 2. The schematic diagram of the microbial fuel cell used in this study.

the compost surface, but under the water. The area of electrodes was kept the same as the cell areas (100 cm^2). Both the anode and cathode were connected by a single iron wires and had a fixed external capacitor and a resistance (100 Ω) used as the load for the power being generated which measured by volt meter daily. The laboratory tests were conducted under a constant room temperature of 25˚C. Experiments were conducted with pure samples and mixed samples.

In the anode compartment of MFC devices, microorganisms metabolize a substrate such as sugar in absence of oxygen, and they produce carbon dioxide, protons and electrons as describe below:

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^- \quad (1)$$

When oxygen is supply from air to the cathode, following reaction is proposed:

$$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O \quad (2)$$

2.3. Loss on Ignition Test (LOI) of the Samples

Since the publication of the paper of Dean (1974), loss on ignition (LOI) has been widely used as a method to estimate the amount of organic matter.

Walter, E. and Dean, J. R. (1974) [28] evaluated LOI test is a common and widely used method to examine the organic compounds. We conducted LOI test of the four samples used in this research. The content of organic matter is to have greatly influence to the amount of power generation in this microbial fuel cell. **Table 5** shows the LOI test results of the four samples. The sample which contains the most organic matter of 87.24% is cow dung. The lowest value of 20.33% is for soil. It is considered that more organic substances in a mixture of organic waste with soil that can influence on more voltage generation than soil only.

2.4. Experiments on Pure Samples

4 samples of 400 g of cow dung, chicken droppings, leafmold, and soil were prepared and investigated separately. Then they were added in to the each acrylic rectangular after blended completely. All samples parameter condition was showed by **Table 6** as described below.

2.5. Experiments on Mixed Samples

Soil and organic wastes in this work were mixed with a ratio of the same volume to generate bioelectricity in a microbial fuel cell (MFC). Quanguo, Jianjun and Du (2016) [29] investigated MFC as a device that can convert chemical energy in influent substances to electricity via biological pathways. As there are many microorganisms in the soil. Fedorovich *et al.* (2009) [30] and Juang *et al.* (2011) [31] studied the bacterial communities in MFC known exoelectrogenic bacteria in an acetate-fed MFC. In microbial fuel cells (MFCs), many microorganisms work in a consortium state, meaning they are not in the same pure colony, but

Table 5. Result of the loss on ignition tests.

Sample name	Loss on ignition (LOI)
Soil	20.33%
Cow dung	87.24%
Chicken dropping	82.55%
Leaf mold	80.33%

Table 6. Parameter conditions for pure samples.

Parameter	Test I (Soil)	Test II (leaf mold)	Test III (Cow dung)	Test IV (Chicken droppings)
Soil (g)	400	0	0	0
Organic waste (g)	0	400	400	400
pH	6.32	5.48	6.72	6.22
Electrodes (carbon felt)	Yes	Yes	Yes	Yes
EM (g)	4	4	4	4
Water (ml)	150	150	150	150

many of them and some of which have been identified as *Geobacter metallireducens*, and *Rhodoferrax ferrireducens*. While *Geobacter metallireducens* is a class of bacteria from the genus geobacter unique because it can produce like filaments that act as nanowires to transfer electrons from outside the cell to the insoluble electron acceptor such as iron minerals and most likely to electrodes. It is considered that more voltages can be obtained by mixing soil with organic matter. Moreover, the blended soil and some of organic waste in this work as they are thought to increase the physical volume of samples properties and it increases the nutrient supply ability for microorganism. The type and number of microorganisms which survive are different by region in the distribution of the soil. The mixture of organic constituents in the waste and microorganisms in the soil are expected to lead the higher values of output voltage. **Table 7** illustrates the parameter condition for mixed samples.

2.6. Measurement

Since MFC is the source of direct current (DC), in this experiment we calculate the magnitude of the potential difference (voltage) between the anode and cathode poles. The voltage which generated across the resistor and capacitor was monitored every day at 1 pm. It is estimated that at that time is the most appropriate time for research measurement. In this research, we present the MFC's electric potentials in volts per square meter because of the difference in electrical potential between the two electrodes in the MFC circuit as the main-focus and related to the advanced plan of this research that we want to know the potential of electricity generated when coupled series due to differences potential resulting by each MFC reactor. Polarization curve and power density-current curves were investigated as described by Logan and Regan, 2006) [32] who formulated polarization curve and power density-current curves by using different resistors and internal resistances and power densities. Electrode output was measured in volts (V) against time. The current I in amperes (A) was calculated using Ohm's law,

$$I = V/R \tag{3}$$

where V is the measured voltage in volts (V) and R is the known value of the external load resistor in Ohms (100 Ω in this study). From this, it is possible to

Table 7. Parameter condition for mixed samples.

Parameter	Test V (Leaf mold + soil)	Test VI (Cow dung + soil)	Mixed test VII (Chicken droppings + soil)
Soil (g)	400	400	400
Organic waste (g)	400	400	400
pH	6.83	6.48	7.2
Electrodes (carbon felt)	Yes	Yes	Yes
EM (g)	4	4	4
Water (ml)	150	150	150

calculate the power output P in watts (W) of the MFCs by taking the product of the voltage and current *i.e.*

$$P = I \times V \tag{4}$$

The power density and current density was calculated using:

$$\text{Power density} = (I \times V)/\alpha \tag{5}$$

$$\text{Current density} = (V/R)/\alpha \tag{6}$$

where α is the electrode area. Normally, the anode area is taken as the electrode area. For example, if the electrode material is rectangular the area will be simply the length multiplied by width.

Furthermore, the root-mean-square deviation (RMSD) is used as a statistical analysis which is a good accuracy measurement. It serves to aggregate the magnitudes of various errors into a single measure. The RMSD is used to compare differences that may vary, neither of which is accepted as the result within the total period of the experiment.

3. Results and Discussion

3.1. Bioelectricity Results in MFC

Figure 3 provides the variation of voltage with duration in microbial fuel cell using pure samples. The maximum value of electricity production were 10880 ± 4.784 mV/m^2, 8980 ± 3.265 mV/m^2, 6280 ± 5.887 mV/m^2, 6070 ± 7.048 mV/m^2 for pure samples of Test IV, Test II, Test III, and Test I, respectively.

It is described that for the pure samples, until 21 days of monitoring an increasing-decreasing trend in between each 2 - 9 and 11 - 17 days of output voltage were observed in the MFCs, and most of increasing trend among 2 - 9 days in all the MFCs. However, among 2 - 5 days as initial stage were obtained the

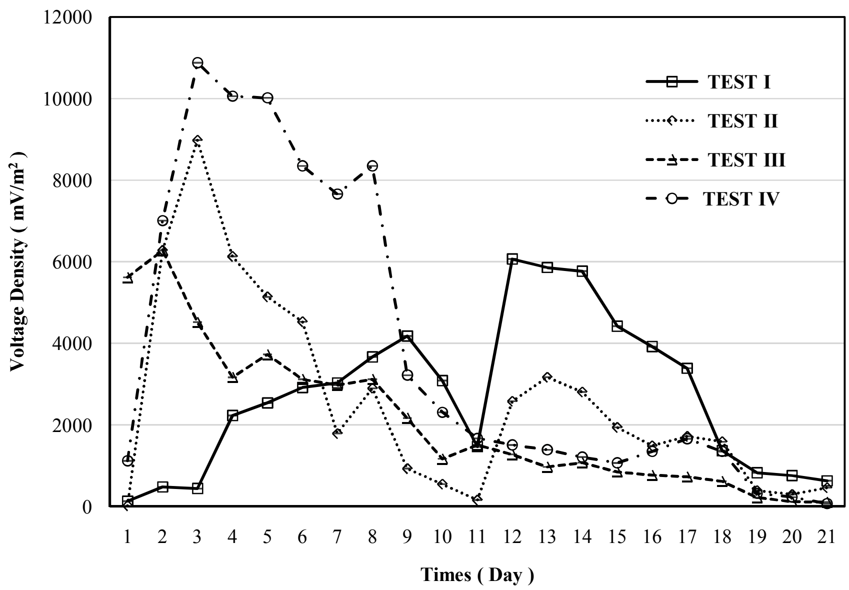

Figure 3. Variation of voltage with duration in microbial fuel cell using pure samples.

highest peaks of voltages in all experiments, then the electricity production of a MFC gradually decreases over period of 15 days. Moqsud, Bushra and Rahman (2011) [33] investigated during the initial stage since the bacteria got ample food and their activities increased very rapidly and because the samples were used several hours after collection, the bacterial colony might have already grown exponentially. The bacteria naturally produce electricity through their ability to degrade organic compounds in the sample. The growth of microorganisms in general depends on the condition of foodstuffs and the environment. If food and environmental conditions are suitable for these microorganisms, then microorganisms will grow with a relatively short time and perfect. For that reason, the voltage increased sharply. Afterwards by the time the samples were used to power the MFC, the bacteria might have already begun depleting their resources and the supply of food was used up by the bacteria as Moqsud *et al.* (2014) [34] stated in their study, then the electricity production decreased steadily over the period of 15 days.

3.2. Experimental Results from Mixed Samples

The comparison for changes in voltage among triplicate models of mixed samples is shown by **Figure 4**. In this case, it shows the result of mixed samples within 3 days of initial time, the bacteria got ample food and their activities increased very rapidly, the voltage (V) increased sharply. Afterwards, after 12 days the voltage decreasing trend gradually with time was observed as the sample still had high percentage of organic matter as supply of food for the bacteria. The maximum value of voltage was10980 ± 11.32 mV/m^2, 10530 ± 4.921 mV/m^2 and 4440 ± 9.741 mV/m^2 for a mixed sample of Test V, Test VII, and Test VI, respectively.

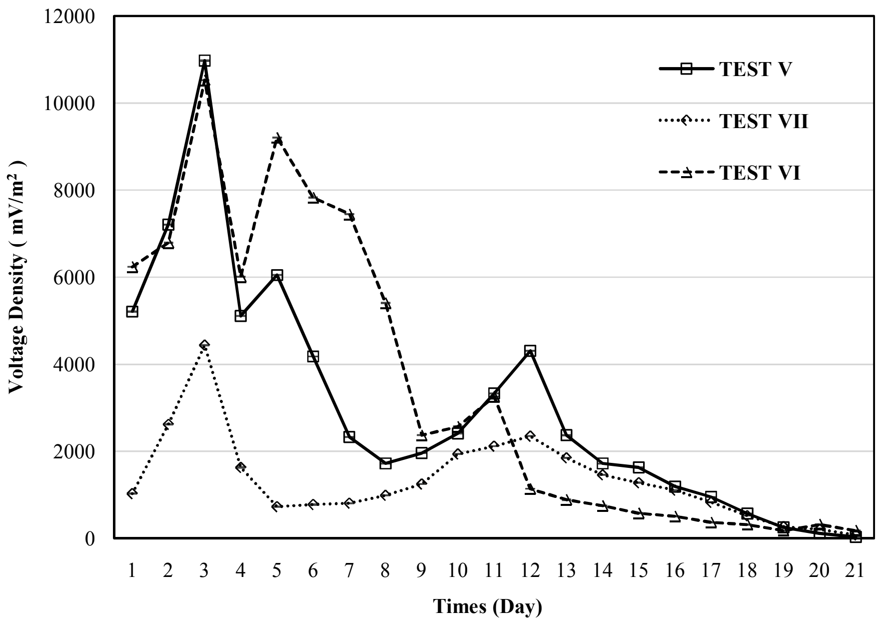

Figure 4. Variation of voltage with time obtained by mixed samples.

A reason why the mixed sample of Test V showed a higher value of voltage than the other samples is that leafmold, as a form of compost, as Jati SH. (2001) [35] and Hamzah (1983) [36] investigated compost is rich in nutrients and organic matter which supports the growth of microorganisms.

3.3. Polarization Curve for MFCs

The polarization curves of the MFC using mixed sample are illustrated in **Figure 5**. A polarization curve is used to characterize current as a function of voltage. They show how well the MFC maintains voltage as a function of the current production. The trend of the polarization curve was very much similar with the polarization curves which have been found in other literature concerning MFCs as studied by Logan and Regan (2006) [32].

It shows that the maximum power density of 79.885 ± 1.7 mW/m² for Test V and 71.76 ± 1.11 mW/m² for Test VI. The power densities showed an incremental trend with decreasing external resistance and reaches a peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behavior.

3.4. Relationship between Voltage and Current in the MFCs

Figure 6 shows the relationship between voltage and current in the MFCs for 3rd day of elapsed time. It is found that the relationship was almost linear. The intercept and inclination of the line represents electromotive force and internal resistance for the MFCs, respectively. It represents that MFC with a good per-

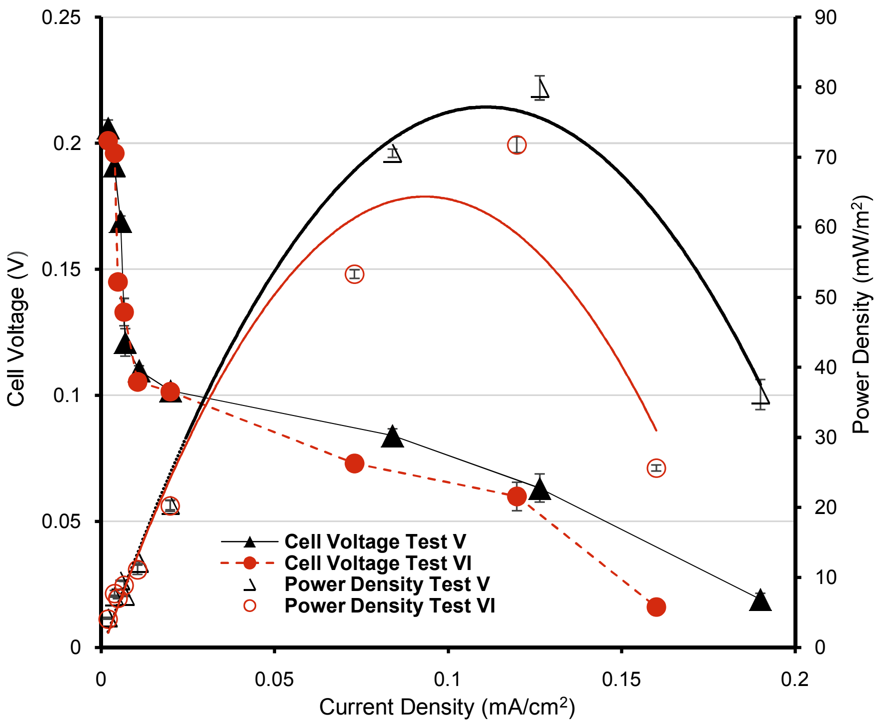

Figure 5. Polarization curve of the MFC.

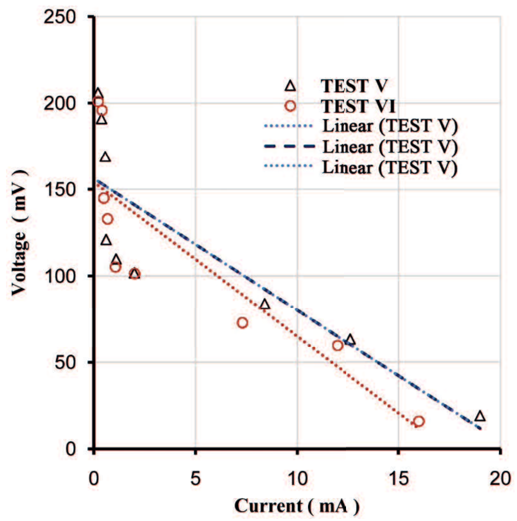

Figure 6. Relationship between voltage and current in the MFCs at 3rd day.

formance indicates high electromotive force and low internal resistance. The electromotive force of MFC of Test V was 206 ± 0.33 mV. On the other hand, the electromotive force of Test VI was 201 ± 0.53 mV. The maximum power density for Test V was 79.885 ± 1.7 mW/m^2 and 71.76 ± 1.11 mW/m^2 for Test VI. The consideration of this result, as described above, since leafmold in Test V is rich in nutrients and organic matter which supports the growth of microorganisms. The test results obtained from **Figure 6** are given in **Table 8**. Maximum electric power is calculated from the linear relationship between voltage and current.

3.5. Carbon Felt as Electrode Materials

After the tests, to examine the performance of organic waste, anode and cathode, they were removed from the fuel cells and were checked by electronic microscopes. It was observed that on most parts of the anode or cathode, there were parts of organic waste that was still firmly bonded to the carbon felt. These findings indicate that the good bonding for each sample might have acted as bonding agent for the electron. The bonding area and number of bonding area of the organic wastes and the electrodes shows that they can catch and discharge the electrons and more number of them show that more electron can catches by or discharge by them. So, the organic waste can work optimally with carbon felt as the electrode materials, as results shown in **Figure 7(a)** which shows the SEM images of organic waste as compost and **Figure 7(b)** shows of good bonding between organic waste and electrode.

The energy dispersive spectroscopy (EDS) spectrum is presented in **Figure 8**. Energy dispersive spectroscopy was employed to identify the presence of element of carbon felt and persimmon waste. The EDS spectra **Figure 4** show the presence of 86.25% carbon, 10.52% oxygen, 0.37% sodium, 1.16% aluminium and 1.69% silicon. The appearance of aluminium and silicon on EDS is due to the use of silicon as a sample coating and aluminium as a sample plate.

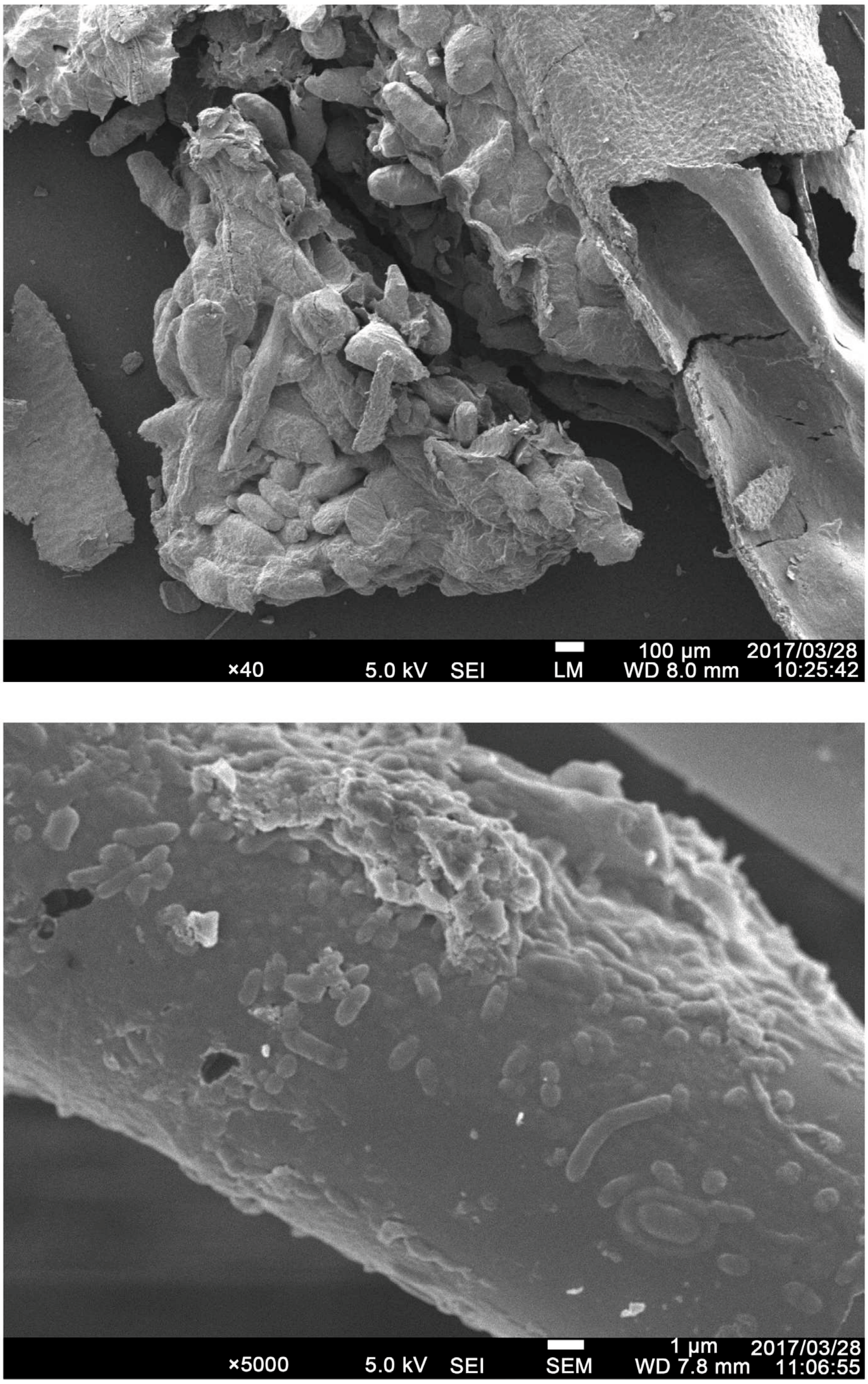

Figure 7. (a) Images of organic waste and electrode by SEM; (b) SEM image of good bonding between organic waste and electrode.

Table 8. Test results of MFCs in case of test V and test VI.

	Test V	Test VI
Electromotive force (mV)	206 ± 0.33	201 ± 0.53
Internal resistance (Ω)	1000	1000
Maximum power per area of cathode (mW/m^2)	79.885 ± 1.7	71.76 ± 1.11

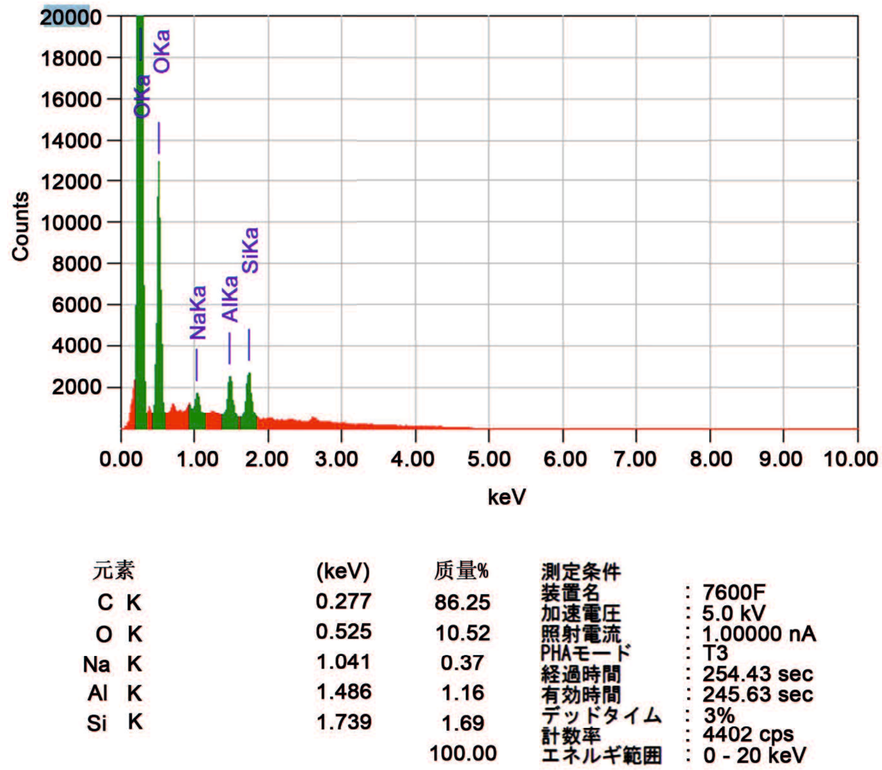

Figure 8. EDS spectrum of electrode sample.

4. Conclusions

1) MFC is the source of direct current (DC). In this experiment, we calculate the magnitude of the potential difference (voltage) between the anode and cathode poles. The maximum voltage density is 10880 ± 4.784 mV/m^2 for pure samples of Test IV (chicken dropping) and 10980 ± 11.32 mV/m^2 for mixed sample of Test V (leafmold and soil). It is considered that the mixture of organic waste, soil and carbon felt as an electrode greatly supports the growth of microorganisms in working optimally to generate bioelectricity.

2) It proved that animal dungs and leafmold as a variety of organic wastes contains large amounts of nutrients and various other minerals. It can improve to be more valuable as a microbial fuel cell to generate green and safe electricity, moreover, as an efficient, eco-friendly solution for organic waste management. This is a useful method of green and safe energy. Therefore, bioelectricity can be produced using mixed samples of organic waste and soil.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Bioelectricity Generation from Persimmon Fruit Waste by Using Single Chamber Microbial Fuel Cells Mixing With Soils

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Abstract

This study demonstrated a microbial fuel cells (MFCs) as bio-electrochemical devices which used to generate bioelectricity from a wide range of substrates by using bioelectrogenic microorganisms, and have special interest to supply the energy demands for small devices as a energy harvesting. While the persimmon fruit production in Japan is relatively abundant, such as in 2011 reached 207.5 thousand tons and during the harvest and post harvest time, about 10% large amounts of fruit, especially their peels, are generated as waste. It cause a waste disposal problem. In order to get an efficient and eco-friendly solution for organic waste especially to provide green and safe electricity from organics waste, a blend of soil and persimmon fruit waste were tested as a solid waste management option by a MFC method. The blend were tested in a membrane-less single chamber microbial fuel cells devices to generate bioelectricity along with biotransformation of persimmon wastes, over a testing time of 45 days and with some modification of resistor operation. The results in the experiments have shown good relationship among substrate and the performance of output voltage in the MFC, the highest value of output voltage in the MFC which contained a blend of 25:75 of persimmon and soil was 127.2 mV. While, for the MFC which contained a blend of 40:60 of persimmon wastes and leaf mold the highest value of output voltage was 98.3 mV. The proposed MFC can provide sustainable green and safe electricity from recycle and reuse of organic waste.

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Keywords: Bio-electricity; microorganism; microbial fuel cell; organic waste; persimmon waste; soil; sustainable

1. Introduction

1.1. World energy

Energy in any form plays the most important role in the modern world. Also, reduction and recycling of waste are very serious problems all over the world due to the limitation of final disposal sites and decreasing environmental loads (Khalid et l., 2011). Surrounding the world, resource recovery from waste material is an important topic in both developed countries and developing countries. A major portion of the total solid waste in developing countries is organic waste, and it is not properly treated for resource recovery (Moqsud, 2003; Sujauddin

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and Hoque, 2008; Zurbrugg et al., 2005). The scarcity of electricity is one of the major hindrances for the development of many countries all over the world. Many developing countries can produce electricity to supply only half of their demand. Therefore, power shortage and load-shedding are very common phenomena that cause serious problems for the population of the developing countries, especially during the night time (Moqsud et al., 2014). According to United Nation's statistics, around 1.6 billion people (25% of the total population) are living without electricity. With the rise in population and rise in the electricity demand on this planet, researchers are working towards increasing the electricity supply source. The future of energy sustainability and supply is likely to rely on renewable energy sources. The production of electricity or biofuels using innovative technologies and renewable sources is a global priority in terms of energy strategies (Resch et al., 2008). Some of the background's situation has resulted in great concern to finding alternate sources of electricity that are green and safe.

A plentiful and renewable carbon source that has been considered for MFC applications (mainly for electricity generation) is biomass (Moqsud et al., 2013). The MFC has emerged as an efficient and eco- friendly solution for organic waste management, especially in developing and technologically less sophisticated countries, and can provide green and safe electricity from organic waste (Moqsud et al., 2014). MFCs are so new that relatively little effort has been put into practical architectures using affordable materials (Logan., 2008). In recent years, advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Cristiani et al., 2013).

A microbial fuel cell (MFC) is an emerging renewable technology, which is designed to exploit the degradation of biological substrates for the production of sustainable bioenergy in the presence of active microorganisms (Kan et al., 2011; Walter et al., 2015). There are already been investigated MFCs devices to produce bioelectricity form organic wastes and waste waters (Moqsud et al., 2013; Chakhtoura et al., 2014; Moqsud et al., 2010; Lu N et al., 2009; Feng C et al., 2013; Venkata Mohan et al., 2008); Prasad D et al., 2006; Sevda S et al., 2013).

Some researchers have used electricity generation in MFCs is favored by numerous substrates, extending from easily biodegradable pure substrates such as glucose (Rabaey et al., 2003), ethanol (Kim et al., 2007), phenol (Liu Y et al., 2008), chromium (Liu Y et al., 2008 ; Li Z et al., 2008), pentachlorophenol (Huang H et al., 2013) and acetate (Logan et al., 2007), to complex substances such as starch (Herrero-Hernandez et al., 2013), chitin (Rezaei et al., 2009b), and cellulose (Rismani-yazdi et al., 2007).

In addition, microbial fuel cells have been tested for producing hydrogen (Call DF et al., 2009). However, utilization of these substrates in MFCs is not a cost effective option. Biomass being a carbon neutral has been attracted as one of the most promising future resources of electricity generation for addressing the rapidly growing energy needs (Mao et al., 2015). However, the use of persimmon waste as biomass to generate electricity in MFC has not previously attracted the attention of researchers.

1.2 Reduce environmental impact of organic waste

The bright chance's development of renewable energy on current trend is to use fruit waste to meet the demand. The global production of fruits and vegetables is in the increasing trend and having been recorded as 1.74 billion tons in 2013 (World Farmers Organization, 2014). Persimmon fruit production is very abundant in Japan. The waste that is considered trash by people actually still contain simple organic material (glucose), which could potentially be used as a food source for the bacteria in microbial fuel cell . While the persimmon fruit production in Japan is relatively abundant, such as in 2012 reached 244.8.5 thousand tons (Japan Fruit Growers Cooperative Association, 2012). From the characteristic analysis of the solid waste of many developing countries it is found that the major portion (more than 80%) of the total solid waste comprises of organic waste, which does not usually get much attention for recycling or resource recovery (Moqsud et al., 2008). The annual organic waste generated from the food industries and kitchen waste in Japan is about 20 million tons per year (Koike et al., 2009). Most of this waste is directly incinerated with other combustible waste, and the residual ash is disposed of in landfills. However, incineration of this water-containing waste is energy consuming. The wastes should be utilized, reuse and recycled as a valuable resource. These organic wastes contain large amounts of nutrients and various other minerals. Advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Christiani et al., 2013). In order to get an efficient and eco-friendly solution for organic waste especially to provide green and safe electricity from organics waste, a blend of soil and persimmon fruit waste were tested as a solid waste management option by a MFC method.

1.3 Objectives of study

Therefore, the objective of this study was to explore and to evaluate bioelectricity generation by reusing persimmon waste as a low cost feasible potential substrate for bioelectricity generation so that this organic waste can be recycled and provide some sort of solution to populations experiencing electricity shortage (Moqsud et al., 2014). This resulting in environmentally friendly degradation of persimmon waste. This low cost and abundant by-product can alternatively be tested in MFCs for efficient and economical conversion to bioenergy (Waheed M. et al., 2016). The performance parameters using such as maximum power density, current density has done well.

2. Materials and methods

2.1 About Sample collection

The persimmon waste were collected from Japan Agriculture Office, Ube city branch, and then crushed and kept in a frozen at -15 °C for further use in the MFC for some different experiments as a substrate for bioelectricity generation in the MFC.

Persimmon is the name of a type of fruit of the genus Diospyros. This plant is also known as"KAKI", or in the English language named Oriental (Chinese / Japanese) persimmon. The scientific name is Diospyros feet. ('Kaki', Japanese, is the name of a substance produced by this fruit tannins). Waste persimmon that are inedible and also waste wasted skin and can be used as an additional income or a sideline.

On the other hand, the economic value of persimmon itself generally is now no longer expected by the farmers and while the persimmon fruit production in Japan is relatively abundant, such as in 2011 reached 207.5 thousand tons. (https://en.wikipedia.org/wiki/Persimmon). During the harvest and postharvest time, large amounts of fruit, especially their peels, about 10% of the whole fruit are generated as waste. It cause a waste disposal problem. Persimmon like most fruits have a lot of the nutrients, vitamins also minerals are very much. It can be consumed directly as fresh fruit or made of various types of grain, such as salad, juice, beverages, or preserves. The sweet taste of the flesh of this fruit is affected by sucrose levels. Sweet of fruit flesh showed low levels of sucrose. Sucrose can undergo hydrolysis in dilute acid solution or by the enzyme invertase into glucose and fructose (Ihsan and Wahyudi, 2010). The content of glycated in this fruit which will be utilized by the bacteria to produce electricity next.

2.2 Design of the one-chamber Microbial Fuel Cell (MFC)

Generally, microbial fuel cells are used under the conditions of an aerobic cathode with air and an anaerobic anode in waste water. The microbial fuel cell (MFC) technology has been widely developed in first countries, pursuing both outcomes: generation of electricity and treatment of wastes from different derivations (organic or inorganic). The MFC device uses electrochemically active microorganisms (EAM) to generate electricity (Logan BE, 2009), this technology for example, enables to supply the energy demands for small devices (Moqsud et al., 2013).

In this study, a one-chamber type of MFC with some blend of persimmon wastes are developed. Figure 1 illustrates the laboratory test device set up for the MFC’s schematic diagram.

A rectangular (10x10x15 cm) acrylic container was used in the laboratory as a cell. Then some amount of crushed persimmon waste and some amount of soil mixed with in generally 100 g of water and 4 g of effective microorganisms were blended properly by a blender. That small amount of effective microorganism (commercially available from EM Kenkyusho, Shizuoka, Japan) was used for each case to start the bioelectricity generation (as microbial seed) and to reduce possible odour from the samples during the investigation. The blended sample was filled in the container. The anode was placed inside the biomass and the cathode was placed on the top. Both of the electrodes were connected to a data-logger (Midilogger GL200; Graphtec, Tokyo, Japan). According to Jessica Li (Jessica Li., 2013) bacteria in the anode chamber create protons and electrons during oxidation as part of their digestive process. The electrons are pulled out of the solution in the anode and placed onto an cathode's electrode. The electrons are then conducted through the external circuit and into the cathode chamber by way of the cathode's electrode. The external resistance was fixed at 100 Ω by assessing the polarization curve with different resistors and also by comparing open circuit voltage. The data-logger was set to measure the voltage and temperature data.

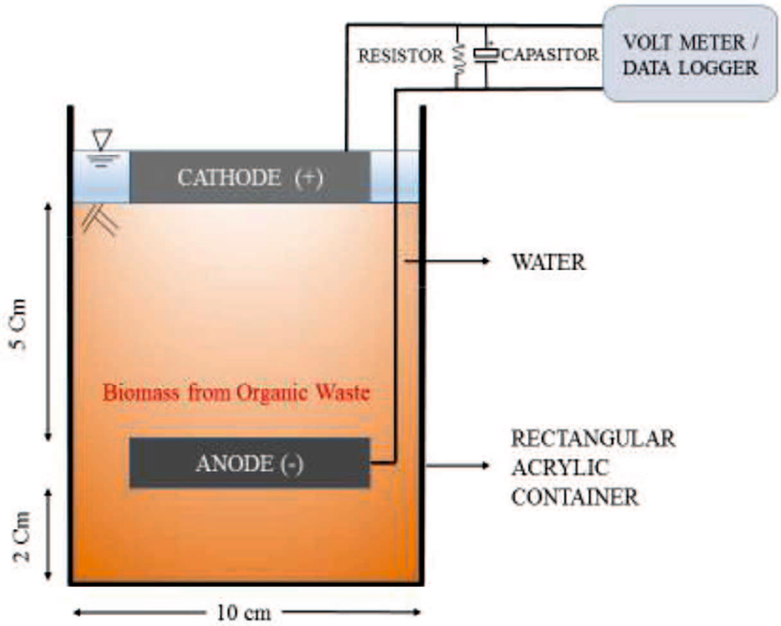

Fig.1. Schematic diagram of Microbial Fuel Cell (MFC)

For ease of calculation, the voltage data at 1:00 pm was used for each day. The laboratory investigation was conducted in a constant room temperature of 25°C since bacteria grow and the metabolic process takes place with equal efficiency at all temperatures between the freezing point of water (0˚C) and the temperature at which protein or protoplasm coagulates (40˚C) (Microbiology. 2012).

Electrode output was measured in volts (*V*) against time. The current I in Amperes (*A*) was calculated using Ohm's law equation:

$$I = V / R \quad (1)$$

where *V* is the measured voltage in volts (*V*) and R is the known value of the external load resistor in Ohms. From this, it is possible to calculate the power output *P* in watts (*W*) of the MFCs by taking the product of the voltage and current from equation:

$$P = I \times V \quad (2)$$

More, electric current (I) was estimated by measuring the voltage (V) across the resistance (R) with the help of a data acquisition and it was connected to data logging multimeter. Polarization curves were obtained by changing the Resistor from 1Ω to 1KΩ during steady state, whereas the slope of this ohmic region in the V-I curve was considered to be R_{int} (Samsudeen et al., 2014). The maximum power density and corresponding current density was attained by using the power density curve method. The power density and current density were calculated as:

$$Power\ density = V^2/\alpha R \quad (3)$$

$$Current\ density = V/\alpha R \quad (4)$$

where α is the projected surface area of the anode (100 cm^2). In our study, the anode area was used for the electrode calculation area.

3. **Results and Discussion**

Figure 2 illustrates the variation of voltage with duration of time by using persimmon waste (PW) mixed with some type of soil (S), leafmold (LM), and ricebran (RB include for all single sample's replicates). It can be seen that the voltage of each MFC increased gradually with elapsed time and the peak value were reached in between 2 dan 9 days. In the case of persimmon waste mixed with soil (PWS) and persimmon waste mixed with leafmold (PWLM), the voltage (m*V*) increased sharply during the initial time (4 days); after that, it increased gradually and peaked after 8 days.

During the initial stage, the bacteria got ample food and their activities increased very rapidly (Moqsud et al., 2011). Mixed MFC of PWLM and PWS seems to generate a higher value of stable voltage when compared to effect of the microbes MFC else individually. The reason for enhanced stability would be the use of mediators of one microbe by the other to transfer electrons to the electrode (Rakesh et al., 2014). For that reason, the voltage increased sharply. The voltage decreased gradually with time as the supply of food was used up by the bacteria. Peak voltage was around 127.2 mV using persimmon waste mixed with soil.

The peak voltage was considerably higher. This performance's stage is caused by the bacteria got ample food and their activities increased very rapidly; After the anaerobic condition prevailed, voltage increased sharply. The possible reason why the persimmon waste mixed with soil sample showed a higher value of voltage than the other is that in soil there were more mineral and nutrients which supplied the cell with a large amount of energy. Another, this ample amount of glucose inside the sample made the bacteria active and hence generated a higher voltage. This amount is the maximum amount of voltage generated in a one-chamber MFC using organic waste/organic matter to date. In this figure also shows that over 8 days, the voltage gradually decreased.

Over this period, bacteria reproduced and died out. It was expected that initially when there was enough food the bacterial colony would grow, and that after some period of time, as the food source depleted, and the remaining bacteria would die out leaving little or no bacteria to produce electricity (Jessica Li, 2013). However, the voltage generation for another samples were almost constant in all the stages. A small amount of voltage was generated due to the potential difference between the anode and cathode and also probably the phenomenon of organic matter decomposition in the soil (Moqsud et al., 2015). On all samples seen the voltage is still rising at a certain time. This is possible because the microbes are encouraged to metabolically more active than ever and the free electrons generated too much. This indicates that the MFC was able to recover his own electrical charge and this ability is a potential that can be developed. (Siti.L.A , 2012).

Figure 3 shows the polarization curve of the MFC using the persimmon waste. A polarization curve is used to characterize current as a function of voltage (Logan, 2007; Mohan et al., 2008). The polarization curve is a synthetic method to analyse the behaviour of a MFC (Logan et al., 2010): the curve represents the dependence of cell's voltage on the electrical current flowing in the circuit and allows to estimate the values of electrode overpotentials and the internal resistance of the cell, representing an overall measurement of cell's internal voltage losses and defined, geometrically, by the slope of the linear region of the polarization curve (Logan BE., 2008).

The power curve is calculated from the polarization curve and describes the power output of the cell as a function of the current. Usually it has a parabolic shape with a single point of maximum (called Maximum Power Point or MPP), which occurs when the external resistance of the circuit equals internal resistance of the cell. According to Moqsud et al (Moqsud et al., 2015) : a polarization curve is used to characterize current as a function of voltage. The polarization curve shows how well the MFC maintains voltage as a function of the current production.

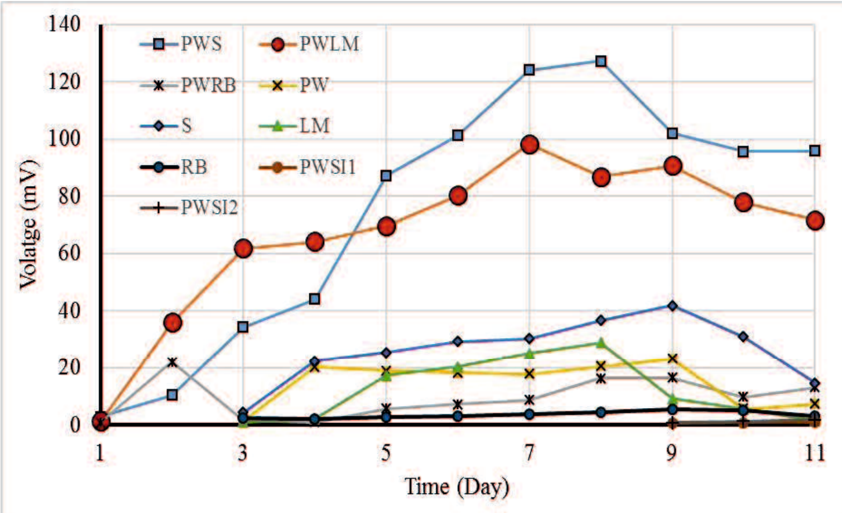

Figure 2. Variaton of voltage with time duration of MFC

Current was measured using Ohm's law, as stated in the 'Materials and method'. By changing the circuit`s external resistance (load) we obtain a new voltage, and hence a new current at that resistance. Therefore, to obtain a polarization curve, a series of different resistances on the circuit was used, measuring the voltage at each resistance as shown in Figure 3. Power density and current density were calculated as described in Logan et al, 2008.The polarization curve shows how well the MFC maintains a voltage as a function of the current production (Schamphelaire et al., 2008; Srikanth and Venkata Mohan, 2012). It was observed that the performance index, that is, maximum power density (W/m^2, normalized to the anode projection area), reached around 0.0098 W/m^2 and 0.162 W/m^2 using persimmon waste mixed with soil (PWS) and persimmon waste mixed with leafmold (PWLM), respectively.

The trend of the polarization curve was very much similar with the polarization curve which was stated in other literature concerning MFCs (Logan and Regan, 2006, Moqsud et al., 2014 and Moqsud et al., 2013). The power densities showed an incremental trend with decreasing external resistance and reaches to peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behaviour (Moqsud et al., 2015).

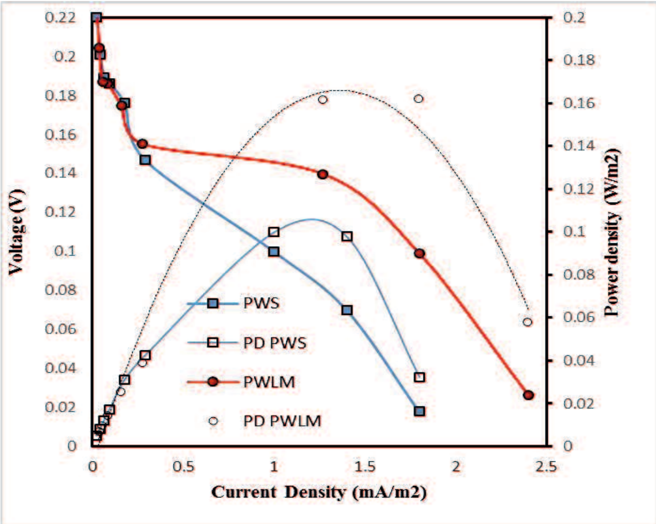

Fig.3 Polarization curve of MFC (Day 22)

Figure 4 shows the relationship between voltage and current in the MFCs for 22 day of elapsed time. It is found that the relationship was almost linear. The intercept and inclination of the line represents electromotive force and internal resistance for the MFCs, respectively. It represents that MFC with a good performance indicates high electromotive force and low internal resistance. The electromotive force of MFC was approximately 0.22 V. The internal resistance of MFC was relatively low.

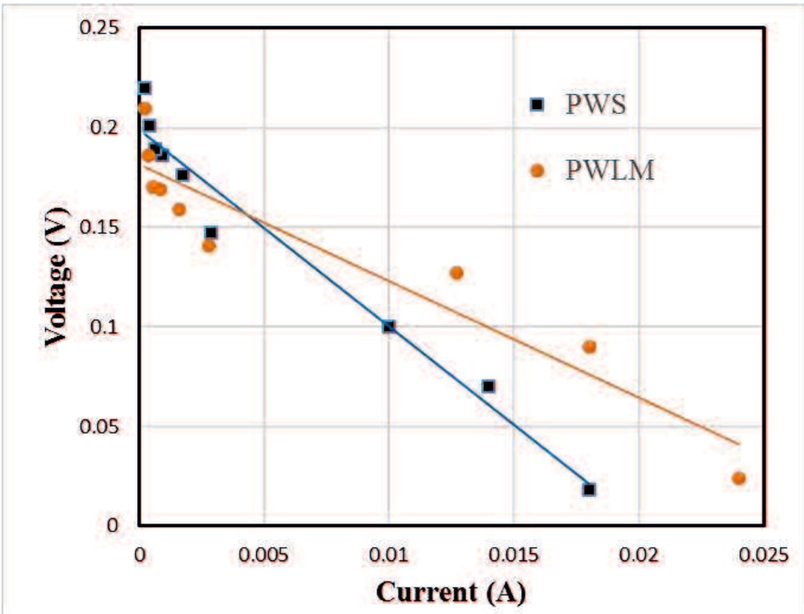

Fig. 4 Relationship between voltage and current in the MFCs (Day 22)

On the other hand, the performance of MFC with soil is lower than mixed with leafmold. But this result is still interesting to prove persimmon fruit waste as a good green waste for bioelectricity generation. As described above, it is considered that soil does not work well in dry conditions. Maximum electric power is calculated from the linear relationship between voltage and current. The maximum power per anode area is 0.162 W/m^2 for the MFC with persimmon waste mixed with leafmold and 0.0098 W/m^2 for the MFC with persimmon waste mixed with soil.

4. **Conclusions**

This investigation established the feasibility of producing electricity directly from persimmon waste using MFCs.

It was observed that some of the planet's tiniest inhabitants might help address two of society's biggest environ mental challenges: how to deal with the vast quantities of organic waste produced and where to find clean, renewable energy. MFCs using persimmon fruit waste have proved to be a good way to get green electricity generation and to recycle organic waste in order to maintain healthy and pollution free environments, particularly in developing countries where solid waste management is a great concern. A small amount of electricity is also necessary for electricity-scarce populations (25% of the world's population are deprived of electricity). Small amounts of electricity can be used for lighting light-emitting diode lamps or just to charge a mobile phone in a particular household using their own waste. Though the amount of electricity is smaller in MFCs when using persimmon waste mixed with soil (0.0098 W/m^2) compared with persimmon waste mixed with leafmold (0.162 W/m^2), it is still very much needed for the future green energy era, as it is an abundant source of biomass in many developing countries. Increasing the portion of biomass in the energy matrix will help to diminish the negative environmental impact of atmospheric CO_2 accumulation and to meet the targets predicted in the Kyoto protocol.

So, by using persimmon waste we can address some important problems currently faced by the world: first, the health and pollution of geo-environment problems due to unmanaged organic waste, as this organic waste would be used as raw material to generate electricity (people will reuse it carefully); second, we need not use our valuable food products (corn and soybean) to obtain transportation fuel, while at the same time millions of people, including children, cannot get food regularly; third, the urgent need to reuse bamboo is very much an important concern for the sustainable geo-environment in Japan, as well as other countries in the world—if we consider a 200 kW rated bioelectricity generator by MFC, then an average of huge amounts of persimmon waste will be required to conceptually extrapolate our findings; finally, it is clear that bioelectricity can be produced by persimmon waste, which could provide some sort of 'light of hope' to the 1.6 billion people who still live in the dark at night all.

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Evaluation of Scale-Up And Environmental Factors On Microbial Fuel Cell

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***Abstract*— There is still plenty of open opportunity to know the effect of scale-up volume and environmental factors on the operation of MFC. Results showed that the maximum values for mixed sample were 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for mixed sample of persimmon waste and soils, leaf mold and rice bran respectively; the electromotive force of mixed sample of persimmon waste and soils was approximately 22 ± 0.01 V/m^2. Moreover, the power density correlated with scale up of the MFC which reach 2109.9 mW/m^{2,} 2319.88 mW/m^2, 4384.06 mW/m^2 and 10317.19 mW/m^2 for100 cm^2, 150 cm^2, 300 cm^2 and 500 cm^2 of size scale-up respectively. And the voltage generation working well even at some environmental factor (especially pH and humidity). In summary, this study demonstrated and approved that voltage generation can be maintained increase during reactor scale-up and MFC by using organic wastes (especially by using persimmon fruit wastes) can operated at any kind environment condition.**

Keywords*— bioelectricity; eco-friendly solution ; energy challenge; organic waste; microbial fuel cell

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I. Introduction

Energy requirements have been increasing exponentially worldwide. Recently, humanity is facing on their energy challenge and most countries in the world are on their way searching for new renewable energy resources thus technologies for environment protection. An estimated 1.3 billon people – 17.3% of the global population – did not have access to electricity. Organic waste is interesting to develop as a renewable energy source. One of them is persimmon fruit wastes. This fruit is popular in Japan and in other parts of the world. In 2005, it production also still high and if it considers about 10% of the whole fruit will generated as waste, it causes a waste disposal problem. It should be utilized, as a valuable resource to produce electrical energy or other high value products. Biochemical conversion technologies of waste-to-energy are much eco-friendlier as compared to the thermal and thermo-chemical techniques discussed in the foregoing. as in [1]. Over the last few years, Microbial Fuel Cell (MFC) have been the focus of increasing interest due to their sustainable approach towards wastewater treatment along with use as an alternative source for power generation thus becoming an alternative technology for cleaning water with zero or positive energy budget [2], [3], [4]. Microbial fuel cells (MFCs) are bioelectrochemical systems (BES) that employ microorganism as catalysts to oxidize organic or inorganic matters for electricity generation. The electrons released by bacteria are transferred to the anode and then transferred to the cathode where they are used to reduce electron acceptors, commonly oxygen. Moreover, reference [5],[6],[7] have been proven that the system to be feasible in some fields such as renewable energy production, biosensor and wastes treatment. The aim of this study was to evaluate a scale-up and environmental factors of low cost feasible MFC reactor by using organic wastes (especially by using persimmon fruit wastes) as an efficient and eco-friendly solution for organic waste to generate bioelectricity.

II. Material and Methods

A. Sample Collection

The persimmon fruit waste, rice bran and leaf mold as organic waste, was collected from Japan Agriculture Office, Ube city branch. Figure 1 and Figure 2 show the production of persimmons which relatively abundant. The economic value of persimmon fruit itself generally is now no longer expected by the farmers, but they contain a lot of nutrients, vitamins and minerals which will be utilized by the bacteria to produce electricity next.

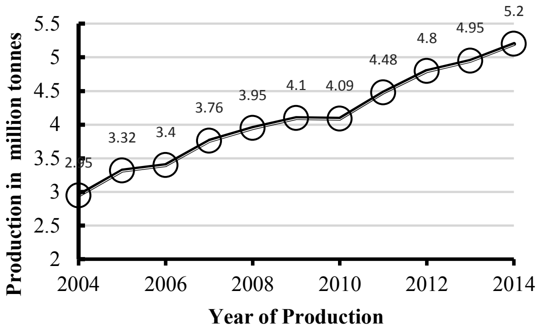

Fig. 1 Production of persimmons in the world

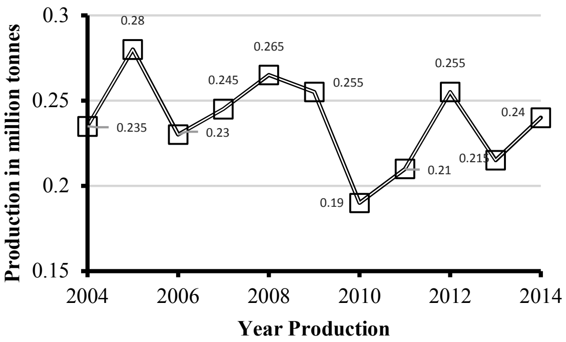

Fig. 2 Production of persimmons in Japan

More, consider the average production of rice bran in Japan from 2004-2014 which reaches 1.078 million tons per year, if not handled properly will be an environmental problem. The nutritional value of persimmons, rice bran and leaf mold (value per 100 grams) is elucidated in Table 1.

TABLE 1. Nutritional value of persimmon fruit and organic waste (value per 100 grams)

	Persimmon Fruit	Leaf mold	Rice bran
pH	5.96 ± 0.21	.5± 0.21	6.85 ± 0.1
Moisture content (%)	68.9 ± 1.27	77.4 ± 2.25	12.12 ± 0.25
Total Sugar (g)	21 ± 0.31	0.5± 0.017	0.9± 0.01
C/N Ratio	14.84	17.6	12
Water (g)	135	95.64	6.13
Sodium (mg/kg)	1.7	25	5.0
Pottasium (mg/kg)	310	187	1485
Kalsium (mg/kg)	27	33	57.3

Soil which used in whole experiments were sampled in the 10-cm layer of natural Tokiwa Park soil, located in the plant area of Tokiwa Park (33°57'02.9" N, 131°16'47.5" E) at Ube city, Yamaguchi Prefecture, Japan. Table 2 shows the properties of the soils.

Soil can be used to generate electrical power in microbial fuel cells (MFCs), which convert chemical energy from soil organic compounds into electricity via catalysis by soil source exoelectrogenic microorganisms [7].

TABLE 2. Characteristics of soil used in this experiment

AVS	pH	Water Content	LOI	EC	Amount
0.0051 mg/g	6.27	86.91%	10.24%	0.395 mS/cm	400

B. Microbial Fuel Cell (MFC) Scale-up Assembly and Field Work Preparation.

First, we assemble a basic prototype of one-chamber type of MFC. We used carbon felt (as electrodes), organic wastes (persimmon fruit waste, leafmold, ricebran), soils, the 10x10x15 cm of acrylic rectangular chambers and some supporting test equipment. Setting the both electrodes (which have a basic size of 10 cm x 10 cm x 1 cm respectively) related to a coper wire, external resistance and capacitor to a data-logger as shown by Figure 3. All experiments were performed in a controlled constant room temperature of 25 °C. Then all each sample were added in to a rectangular acrylic container after they blended until mixed completely. For scale-up work, we prepared 4 buckets in diameter of 10 cm, 15 cm, 30 cm and 50 cm as shown by Figure 4. Then for determine the effect of environmental condition for voltage generation, we did fieldwork as showed at Figure 5. For field research, in addition to equipment that is essentially the same as the equipment on the basic prototype, we also use carbon and charcoal fiber as electrodes as the same size and treatment for 12 samples in the fieldwork.

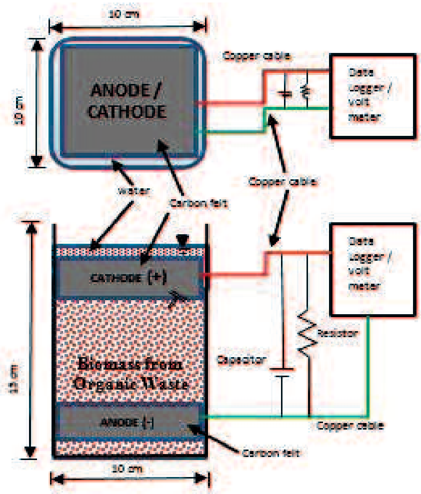

Fig.3 Schematic Diagram of MFC Cell Set Up

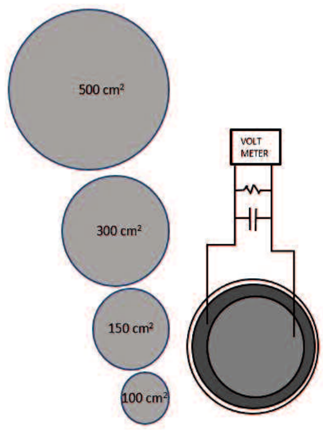

Fig.4 Schematic Diagram of MFC Scale-up

Fig.5 . Image of Fieldwork

Next we prefer to use carbon felt as electrodes because they commercially available, easy to manufacture as compact reactor, fiber diameter is good match to bacteria and they has high surface area, per volume up to 15,000 m2/m3. The properties of carbon felt as illustrated at Table 3.

TABLE 3. Properties of Carbon felt

PROPERTIES	MEASURE VALUE
Fiber grade	Carbonized
Ash content (%)	≤ 1.0
Thickness (mm)	10
Unit Mass (g/m^2)	500
Bulk density (kg/m^3)	50
Carbon Content (%)	≥ 97

Then, 4 samples of 400 g of persimmon waste (herewith call as PW), soil (herewith call as S), leafmold (herewith call as LM), and ricebran (herewith call as RB), as pure sample under some condition as shown at Table 4. While for another mixed samples of persimmon waste with some type of soil ((herewith call as PWS), persimmon waste and leafmold (herewith call as PWLM), and persimmon waste and ricebran (herewith call as PWRB) as mixed sample under some condition as shown at Table 5.

TABLE 4. Parameter conditions for each pure sample.

	PW (Persimmon Waste)	S (Soil)	LM (Leafmold)	RB (Ricebran)
Soil (g)	0	400	0	0
Organic Waste (g)	400	0	400	400
pH	6.32	5.48	6.72	6.22
Electrodes	Yes	Yes	Yes	Yes
EM (g)	4	4	4	4
Water (g)	100	100	100	100

TABLE 5. Parameters for organic wastes mixed sample conditions

	PWS	PWLM	PWRB
PW (g)	400	400	400
Organic Waste (g)	400	200	200
pH	6.83	6.48	7.2
Electrodes	Yes	Yes	Yes
EM (g)	4	4	4
Water (g)	100	100	100

III. RESULTS AND DISCUSSION

A. *Variation of Voltage Generation with Time, Polarization Curve and Relationship between Voltage and Current in the MFC*

Conventionally in an MFC, bacteria catalyse the oxidation of reduced substrates, releasing some of the electrons produced from cell respiration to the anode in the anaerobic compartment, where they flow to transferred through an external wiring circuit to the counter electrode (cathode) and create current. Recently, great attentions have been paid to microbial fuel cells (MFCs) due to their mild operating conditions and using variety of biodegradable substrates as fuel [8]. The cell voltage (V) current (I) and power (P) were measured at every 1:00 pm for each day as the most appropriate time for research measurement and it calculated using Ohm' s law equation as well as the root-mean-square deviation (RMSD) is used as a statistical analysis which is a good accuracy measurement.

Figure 6 illustrates the variation of the voltage of each MFC that was increased gradually with elapsed time and the peak value were reached in between 2 and 12 days. It shows, during the initial stage since the bacteria got ample food and their activities increased very rapidly [9]. After that, it increased gradually and peaked after 4-11 as the supply of food was used up by the bacteria. For some samples the voltage increased after days 7, this indicates that the MFC could recover his own electrical charge and this ability is a potential of MFC that can be developed.

The maximum values for pure sample were 4710 ± 122.84 mV/m^2, 7860 ± 100.78 mV/m^2, 3170 ± 126.58 mV/m^2 and 1980 ± 124.72 mV/m^2 for pure sample of PW, S, LM and RB respectively, while the maximum values for mixed sample were 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for mixed sample of PWS and PWLM and PWRB respectively. It showed that the voltage value result for mixed sample of PWS is the highest one than the other because in the soil there were more mineral and nutrients which supplied the cell with a large amount of energy.

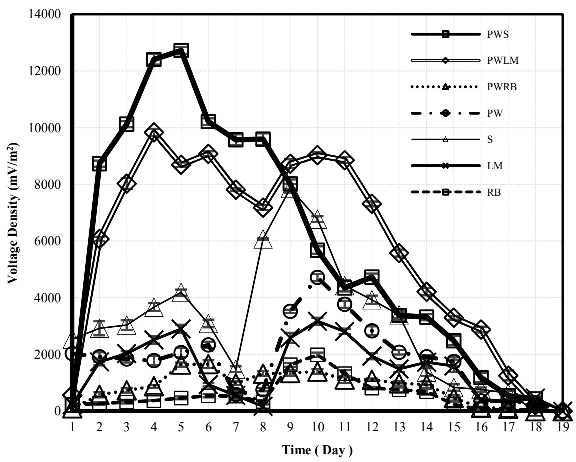

Fig.6 Variation of Voltage with Duration of Time in MFC

Figure 7 shows the polarization curve of the MFC using the persimmon waste which used to characterize current as a function of voltage [10], [11].

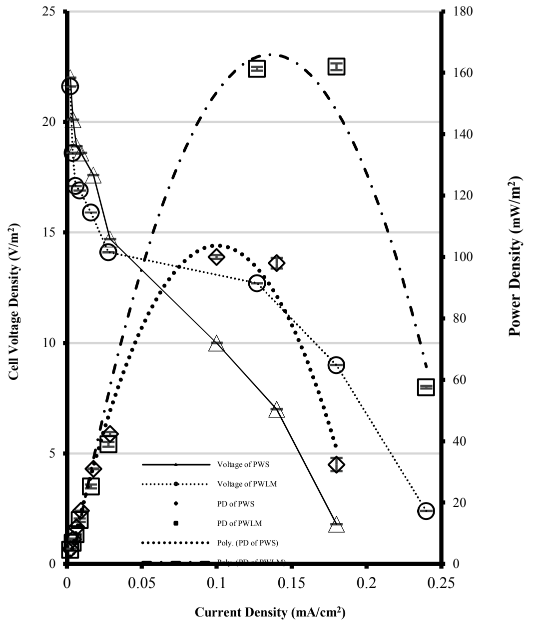

Fig.7 Polarization Curve of the MFC using Persimmon Waste

It shows how well the MFC maintains voltage as a function of the current production. at each different resistance. It was observed that the maximum power density reached around 100 ± 0.01 mW/m2 and 161.29 ± 0.74 mW/m2 for mixed sample of PWS and PWLM, respectively. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behaviour [12]. While Figure 8 shows the relationship between voltage and current in the MFCs for 12 day of elapsed time. As well as figure 6 that MFC has a good performance indicates high electromotive force and low internal resistance which was almost linear. The electromotive force of PWS was 22 ± 0.01 V/m^2, as well as 21.6 ± 0.6 V/m^2 for PWLM. The internal resistance of MFC was relatively low. This approve persimmon fruit waste as a good green waste for bioelectricity generation.

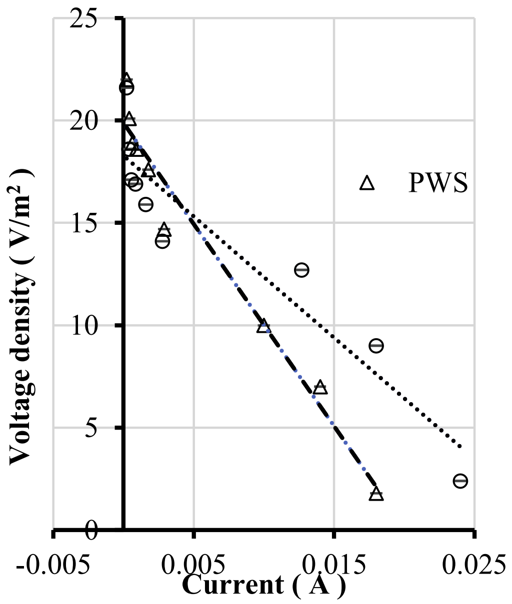

Fig. 8 Relationship voltage and current in the MFCs (Day 12)

B. *Influence of Scale-up*

Scale-up experiment with same treatment as laboratories scale has done to analyze the feasibility and to improve the resulting voltage generated on larger designs with the same quality results as on a laboratory scale. As illustrated at Figure 7 and 8 that 2109.9 $mW/m^{2,}$ 2319.88 mW/m^2, 4384.06 mW/m^2 and 10317.19 mW/m^2 of power density are generated for 100 cm^2, 150 cm^2, 300 cm^2 and 500 cm^2 of size scale-up respectively. Figure 9 and 10 show that increasing scale-up of the electrode size will lead to increases voltage generated as well as the power density.

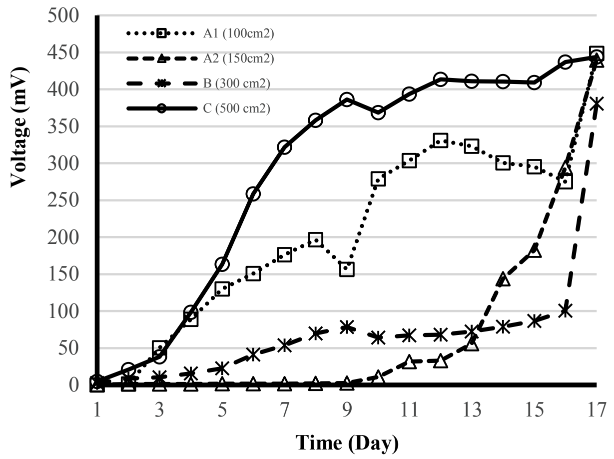

Fig.9 Voltage with duration of time in Scale-up work

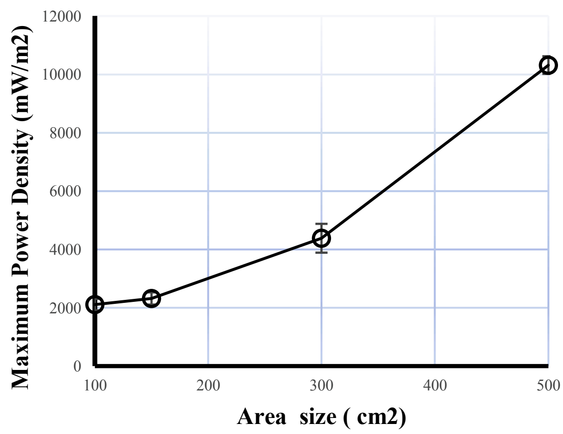

Fig. 10 Power density of the scale-up the area

C. *Effect of Environmental Factors*

To obtain the result of the effect of the surrounding environmental factors which may influent to the research work and to create a condition as the natural environments/conditions to be applied, we did a field research using 12 MFC samples. We examined their voltage generated with considering their surrounding environmental factors such as pH, humidity, air pressure, solar radiation and temperature conditions and it illustrated in Figure 11. It is observed that at day of 18, the higher values of voltage with higher amounts of humidity as well as pH, while solar radiation, as well as pressure and temperature sufficiently affects the voltage, although at the end of the experiment tends to be incompatible because at that time it is predicted that many dead bacteria and nutrient content in the sample has been considerably reduced. Totally, it found that the environmental factors did not have any substantial effects on the MFC operation work. Thus, MFC is applicable at any kind of environmental situations and conditions to get bioelectricity.

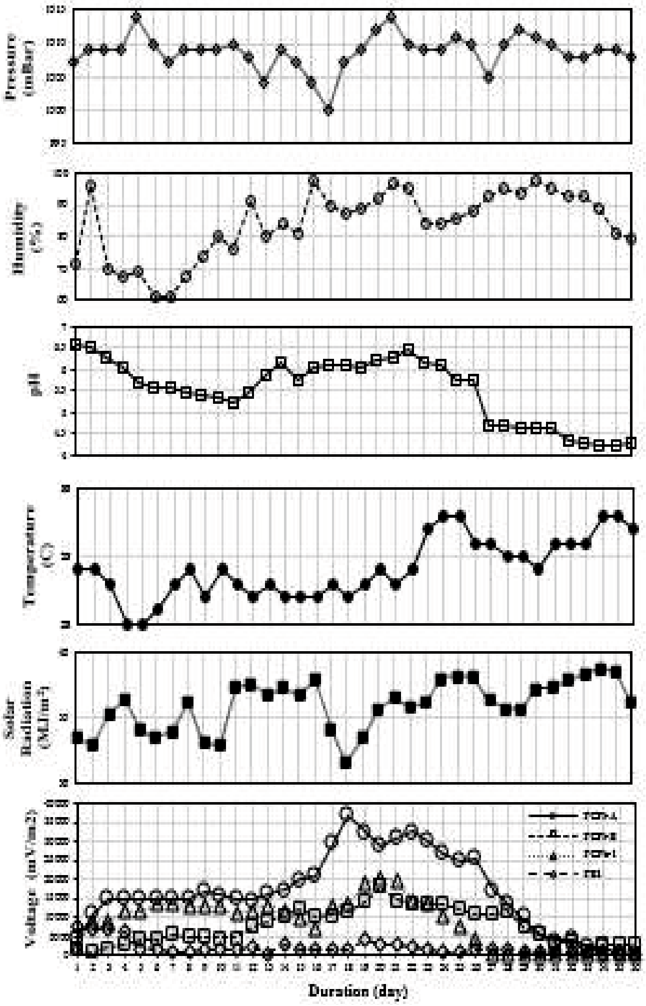

Fig. 11 Some environmental factor effects to the voltage generation on MFC

D. *Digital Microscope Images, SEM Image of MFC*

In purpose for helps in studying surface detail structures of samples, The VHX-1000 Digital Microscope from Keyence was used. While to analyse the surface morphology and the elemental, we use SEM and EDS. Figure 12 and 13 illustrated the how well the bonding between persimmon fruit waste and in the surface of electrodes. That is the good point to show how well the performance of persimmon fruit waste and the existence of microorganism.

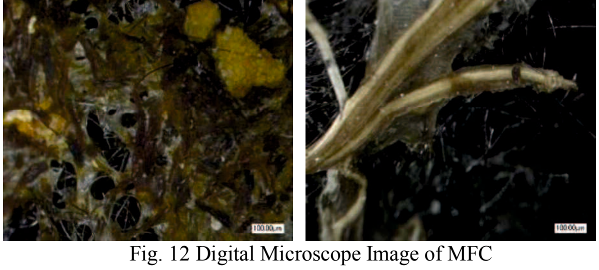
Fig. 12 Digital Microscope Image of MFC

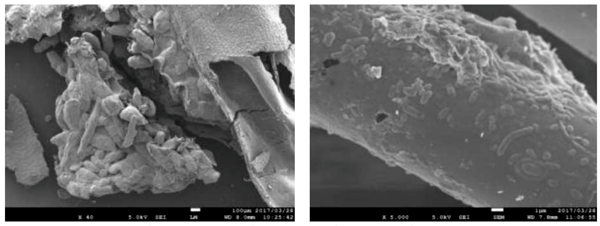
Fig. 13 SEM image and EDS of MFC

IV. Conclusions

Consider:

- The voltage values generate were 12720 ± 114.31 mV/m^2, 9830 ± 81.79 mV/m^2 and 1650 ± 65.32 mV/m^2 for mixed sample of PWS and PWLM and PWRB respectively,
- The electromotive force of mixed sample of PWS was approximately 22 ± 0.01 V/m^2,
- The scale up voltage generate and environmental factor effects,

it proved that:

a. Persimmon waste have a potential impact as a low cost feasible material of MFC to generate bioelectricity. It is an efficient and applied eco-friendly solution by utilized the organic waste particularly in developing countries.

b. The power output in MFCs can be improved in the future by scale-up the electrode surface area, and volume of the samples.

c. It was seen that the environmental factors did not have any substantial effects on the MFC operation work. In summary, MFC is applicable at any kind of environmental situations and conditions to get bioelectricity.

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