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

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***Abstract*— Considering the recent world situation of the electricity for mankind and also energy requirements have been increasing exponentially worldwide. People is facing on their energy challenge and most countries in the world are on their way searching for new renewable energy resources technologies which consider for environment protection. An estimated 1.3 billon people – 17.3% of the global population – did not have access to electricity services for their daily lives, especially at night. Various studies on alternative renewable energy generation are becoming more and more priority, because humanity's increasing concern for electricity needs and climate change is happening. One potential way to continue to be explored as a solution to solve this problem is the over-reliance on electricity based on fossil fuels. Then the microbial fuel cell (MFC) is an opportunity challenge that is very interesting for further development. There are still many open opportunities to find out the effect of increasing volume and environmental factors on MFC operations. The results showed that the maximum value for mixed samples was 12720 ± 114.31 mV / m2, 9830 ± 81.79 mV / m2 and 1650 ± 65.32 mV / m2 for mixed samples of persimmon and soil waste, leaf molds and rice bran respectively -one; the electromotive force of the sample mixture of persimmon and soil waste is around 22 ± 0.01 V / m2. In addition, the power density correlates with an increase in the MFC scale which reaches 2109.9 mW / m2, 2319.88 mW / m2, 4384.06 mW / m2 and 10317.19 mW / m2 for 100 cm2, 150 cm2, 300 respectively. cm2 and 500 cm2 respectively. And the voltage generator works well even on a number of environmental factors (especially pH and humidity). In summary, this study shows and agrees that voltage generation can be maintained to increase during reactor increases and MFC by using organic waste (especially using persimmon fruit waste) can be operated under any environmental conditions.**

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

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 billion 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 other parts of the world. In 2005, its production also still high, and if it considers about 10% of the whole fruit generated as a waste, it causes a waste disposal problem. It should be utilized, as a valuable resource to produce electrical energy or other high-value products as in [1]. Microbial Fuel Cell (MFC) is one of alternative technology that can change chemistry energy becomes electrical energy through a catalytic reaction using microorganisms. Over the last few years, Microbial Fuel Cell (MFC) has been the focus of increasing interest due to their sustainable approach towards wastewater treatment along with use as an alternative source for power generation [2], [3]. Reference [4] stated that microbial fuel cells (MFCs) are bio electrochemical 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. Reference [5]–[7] have been proven that the system to be feasible in some fields such as renewable energy production, biosensor, and wastes treatment. This study aimed 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*

In this research work, I will use several examples of organic waste that is quite popularly known, and they are commonly found around us. The persimmon fruit waste, rice bran, and leaf mold as organic waste was collected from the 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.

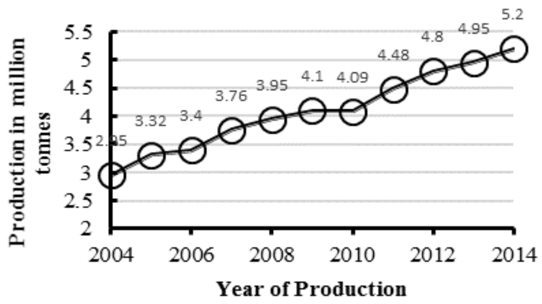

Fig. 1 Production of persimmons in the world

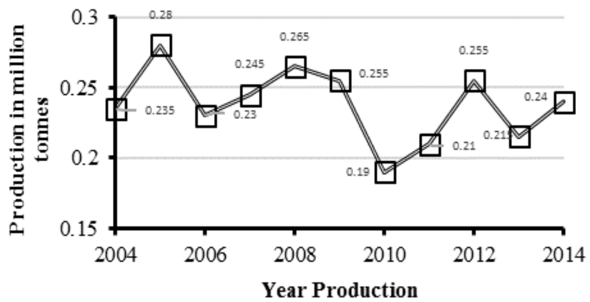

Fig. 2 Production of persimmons in Japan

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 I
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
Potassium (mg/kg)	310	187	1485
Calcium (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.

TABLE II
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

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, leaf mold, and rice bran), soils, the 10x10x15 cm of acrylic rectangular chambers, and some supporting test equipment. Setting both electrodes (which have a primary size of 10 cm x 10 cm x 1 cm respectively) related to a copper 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 was added into a rectangular acrylic container after they blended until mixed completely. For scale-up work, we prepared 4 buckets in a diameter of 10 cm, 15 cm, 30 cm, and 50 cm, as shown by Figure 4. Then for determining the effect of environmental condition for voltage generation, we did fieldwork as showed in 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.

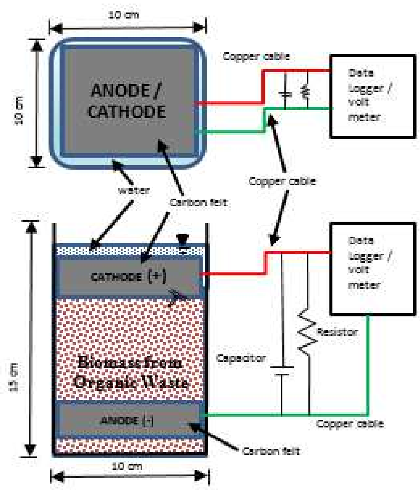

Fig.3 Schematic Diagram of MFC Cell Set Up

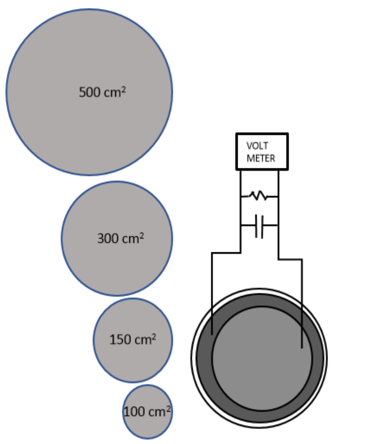

Fig.4 Schematic Diagram of MFC Scale-up

Fig.5. Image of Fieldwork

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

TABLE III
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, four samples of 400 g of persimmon waste (herewith call as PW), soil (herewith call as S), leaf mold (herewith call as LM), and rice bran (herewith call as RB), as the 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 leaf mold (herewith call as PWLM), and persimmon waste and rice bran (herewith call as PWRB) as the mixed sample under some condition as shown at Table 5.

TABLE IV
PARAMETER CONDITIONS FOR EACH PURE SAMPLE.

	PW (Persimmon Waste)	S (Soil)	LM (Leafmold)	RB (Rice bran)
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 V
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 catalyze 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 a 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 6 illustrates the variation of the voltage of each MFC that was increased gradually with elapsed time, and the peak values 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 [8]. 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 electrical charge, and this ability is a potential of MFC that can be developed as referenced [9].

The maximum values forthe 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.

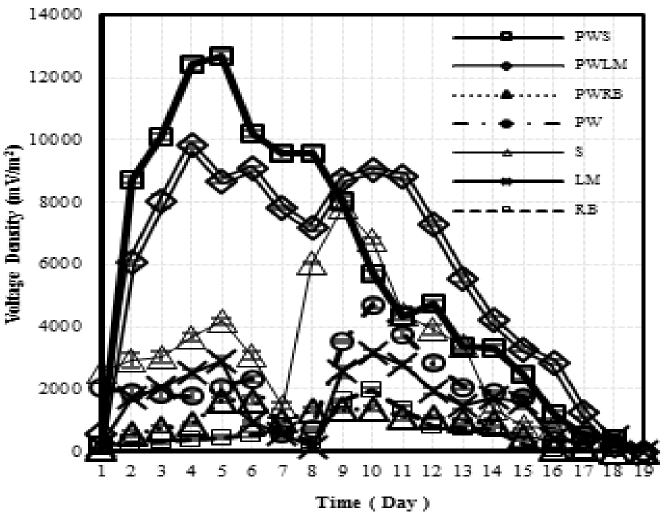

Fig.6 Variation of Voltage with Duration of Time in MFC

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].

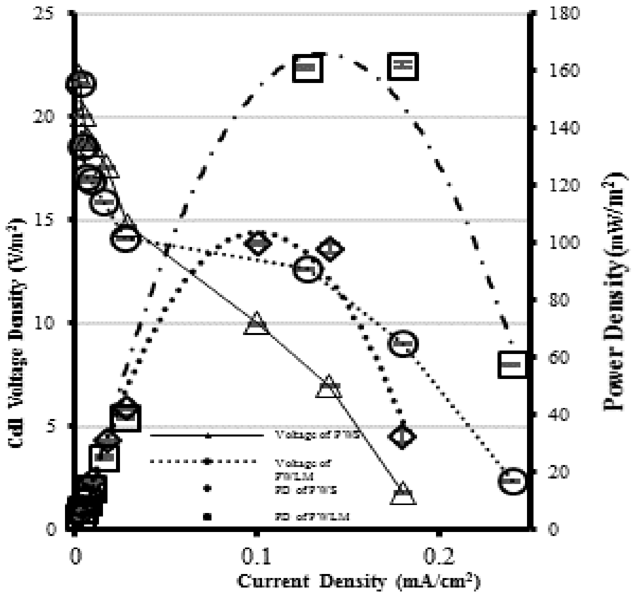

Fig.7 Polarization Curve of the MFC using Persimmon Waste

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 a 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 [12]. While Figure 8 shows the relationship between voltage and current in the MFCs for 12 days 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/m2, as well as 21.6 ± 0.6 V/m2 for PWLM. The internal resistance of MFC was relatively low. These approve persimmon fruit waste as a good green waste for bioelectricity generation.

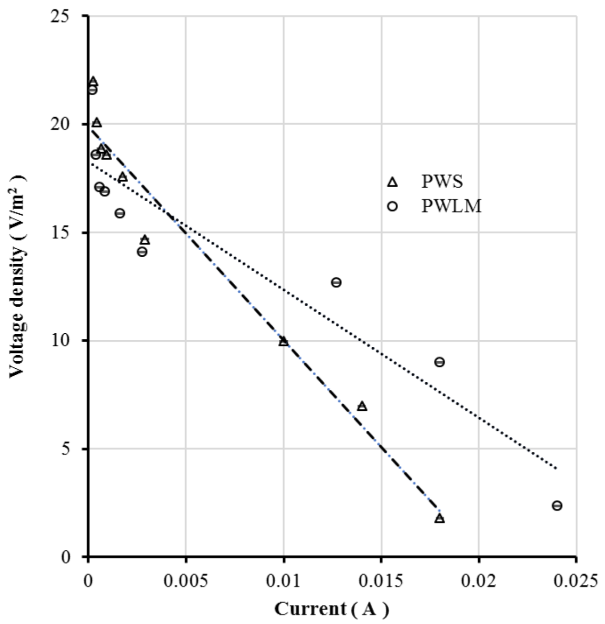

Fig. 8 Relationship voltage and current in the MFCs (Day 12)

B. Influence of Scale-up

Scale-up experiment with the 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/m2, 2319.88 mW/m2, 4384.06 mW/m2 and 10317.19 mW/m2 of power density are generated for 100 cm2, 150 cm2, 300 cm2 and 500 cm2 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.

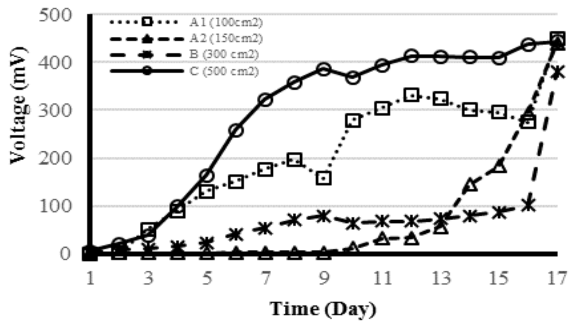

Fig.9 Voltage with a duration of time in Scale-up work

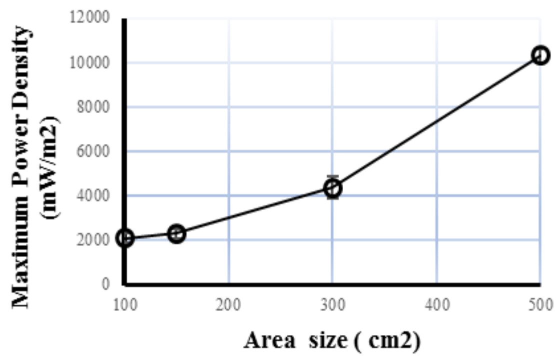

Fig. 10 Power density of the scale-up the area

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 field research using 12 MFC samples. We examined their voltage generated by 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. It found that the environmental factors did not have any substantial effects on the MFC operation work. Thus, MFC is applicable to any kind of environmental situations and conditions to get bioelectricity.

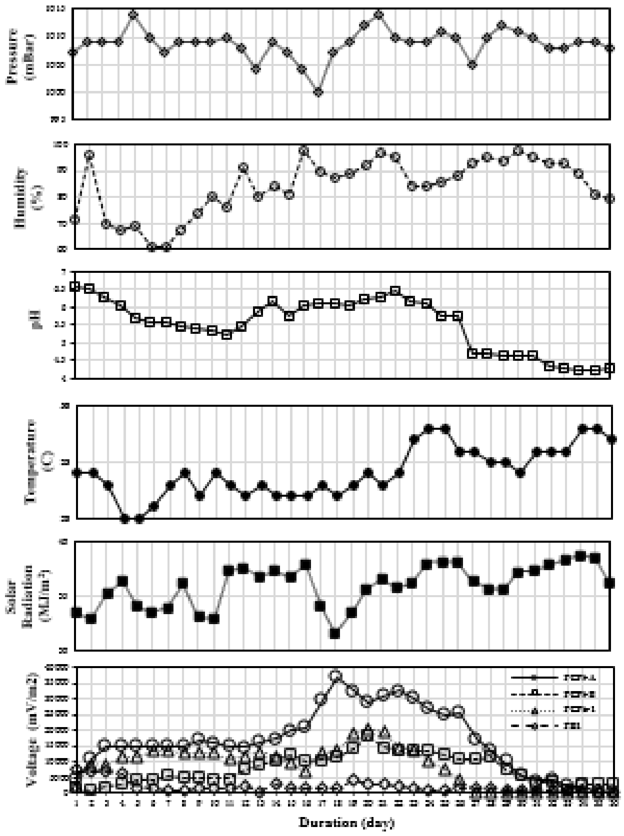

Fig. 11 Some environmental factor effects to the voltage generation on MFC

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 analyses 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.

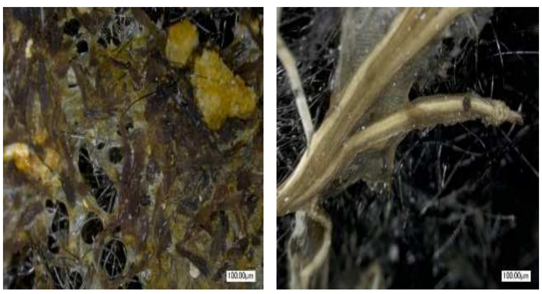

Fig. 12 Digital Microscope Image of MFC

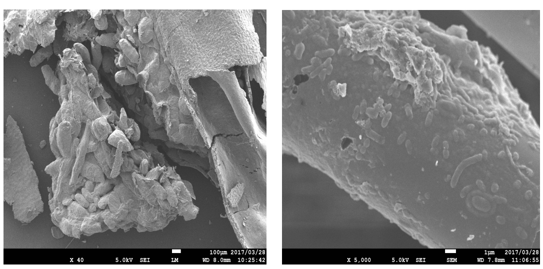

Fig. 13 SEM image and EDS of MFC

IV. Conclusions

This research consider some issues. 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. Therefore, this research proved some points. Persimmon wastes 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. The power output in MFCs can be improved in the future by scale-up the electrode surface area, and volume of the samples. Ultimately, 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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