

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

Tun Ahmad Gazali 

Construction Department, Asahi Techno, Co., Ltd. Japan, Kitakami, Japan

Email: tun.ag@asahitechno.jp

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Abstract

The increasing global energy crisis and the urgent need for sustainable solid waste management have stimulated growing interest in renewable bioenergy technologies. Developing countries, in particular, face significant challenges in managing large volumes of organic agricultural residues. This study explores the feasibility of utilizing persimmon fruit waste (PW), an organic by-product representing approximately 15% of total persimmon production, as a substrate for bioelectricity generation in a Microbial Fuel Cell (MFC) system. PW contains abundant fermentable sugars such as sucrose, glucose, and fructose, which can serve as effective carbon sources for electroactive microorganisms. Laboratory-scale MFCs were constructed using rectangular acrylic chambers equipped with carbon felt electrodes serving as both anode and cathode. To evaluate substrate performance and validate the system, several experimental conditions were tested, including pure substrates (PW, soil (S), leaf mold (LM), and rice bran (RB)) and mixed substrates (PWS, PWLM, and PWRB). The pure substrates acted as experimental controls to provide a comparative baseline for assessing the electrochemical performance of PW-based mixtures. Among the tested configurations, the PW + soil (PWS) mixture exhibited the highest performance with a maximum power density of 16.180 mW/m², followed by PW + leaf mold (PWLM) with 9.663 mW/m², indicating a synergistic interaction between persimmon-derived sugars and mineral-rich soil that enhances microbial activity and electron transfer. Further validation through scale-up experiments demonstrated that increasing the electrode surface area from 100 cm² to 500 cm² significantly enhanced the power density, reaching 10317.19 mW/m², confirming the scalability of the system. Compared with other tested substrates, PW-based mixtures consistently generated higher electrical outputs, highlighting the effectiveness of persimmon waste as a bioelectrochemical feedstock. These findings demonstrate that persimmon fruit waste can serve as a promising substrate for MFC-based bioelectricity generation while simulta-

neously contributing to sustainable organic waste management and renewable energy development.

Keywords

Bioelectricity Generation, Microbial Fuel Cell (MFC), Organic Waste, Persimmon Fruit Waste, Power Density

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. Meanwhile, 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 & 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 wastes 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 becomes quite serious environmental problems. It considers about 15% of the whole fruit will be generated as abundant fruit without proper waste management, which 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).

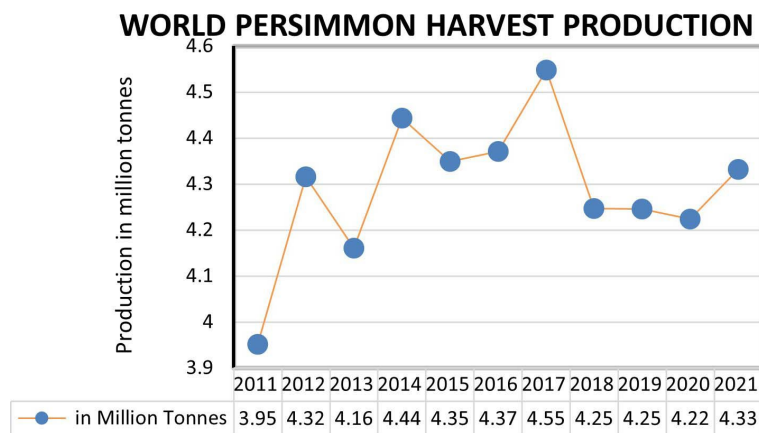
Among the various choices of substituent energy generation, microbial fuel cell (herewith call as MFC) is one example of alternative technology that has potential to be developed. MFC is bio-electrochemical transducers that convert microbial reducing power (generated by the metabolism of organic substrates), 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 et al., 2015). Therefore, the main aim of this study was to develop and explore the PW as a low cost feasible MFC bioreactors, where organic waste mixed with soil is utilized to generate bioelectricity as an efficient and eco-friendly solution for organic waste management.

2. Materials and Methods

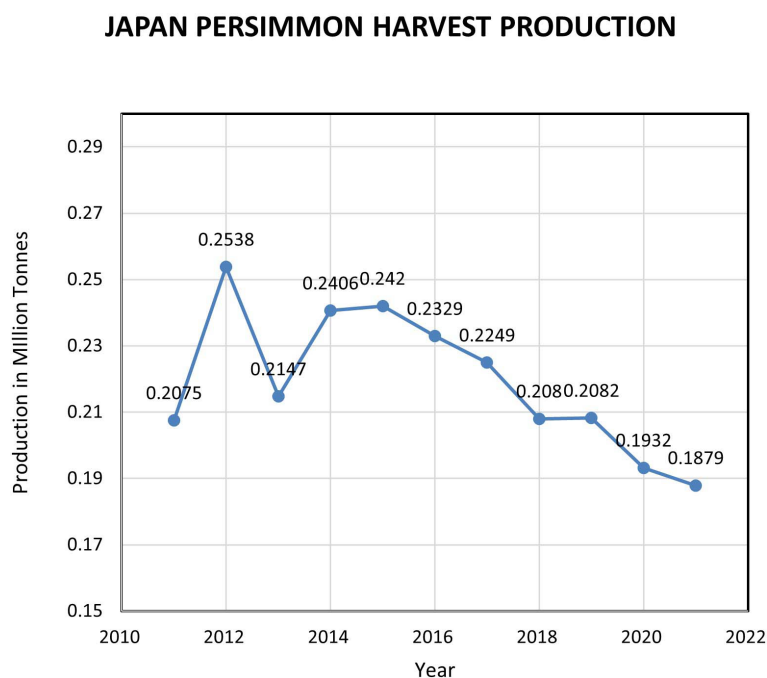
2.1. About Sample Collection

The PW was collected from Japan Agriculture Office. **Figure 1(a)** and **Figure 1(b)** show the production of persimmons which relatively abundant. As in 2021 was 4.332 million tonnes for the world's persimmon production, while in Japan ac-

counting for 0.188 million tonnes.



(a)



(b)

Figure 1. (a) Production of persimmons in the world; (b) Production of persimmons in Japan.

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 & Sugiura, 1990; Ittah, 1993). The nutritional value of persimmons (value per 100 grams) is elucidated in Table 1. Sucrose, which contain in the persimmon, can undergo hydrolysis in dilute acid solution or by the enzyme inverse into glucose and fructose

(Ihsan & Wahyudi, 2010). The content of glycosylated in this fruit which will be utilized by the bacteria to produce electricity next.

Table 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 |

Table 2 shows the properties of the soils.

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 g |

2.2. Assembly of the Microbial Fuel Cell (MFC)

The MFC used electrochemically active microorganisms (EAM) to generate electricity (Logan, 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 2.** Illustrates the laboratory test device set up for the MFC's schematic diagram.

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 increase the nutrient ability supplying food for

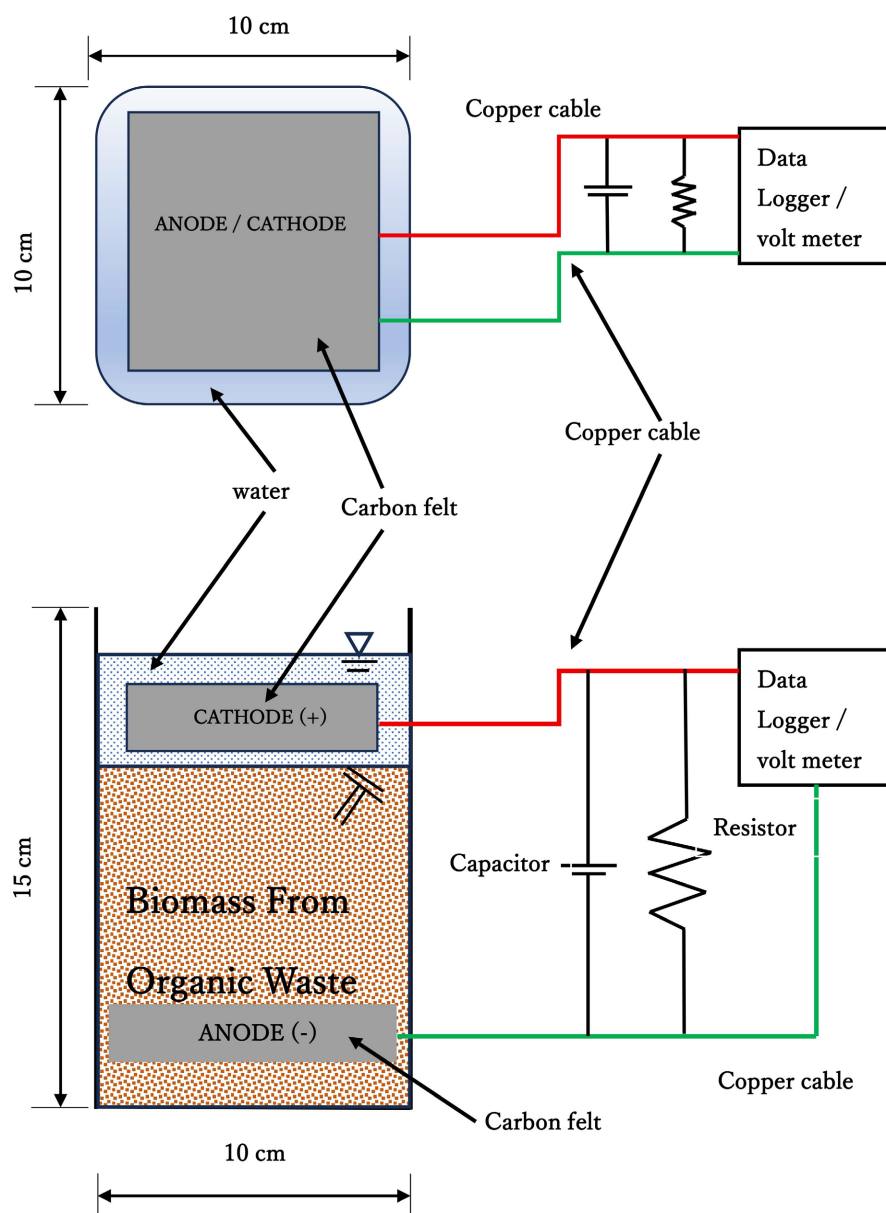


Figure 2. Schematic diagram of MFC cell set up.

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 ($100\ \Omega$). 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 $10\ \text{cm} \times 10\ \text{cm} \times 1\ \text{cm}$ respectively. **Table 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 ef-

efficiency at all temperatures between the freezing point of water (0°C) and the temperature at which protein or protoplasm coagulates (40°C) (Li, 2013).

Table 3. Properties of carbon felt.

| Properties | Fiber Grade | Ash (%) | Thickness (mm) | Unit Mass (g/m ²) | Density (kg/m ³) | Carbon Content (%) |
|---------------|-------------|---------|----------------|-------------------------------|------------------------------|--------------------|
| Measure Value | Carbonized | ≤1.0 | 10 | 500 | 50 | ≥97 |

According to 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/m²) and current density (mA/m²) were calculated as:

$$\text{Power density} = (I^* V)/\alpha \quad (3)$$

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

where V (mV) is the voltage, R (Ω) is the resistance, and α is the projected surface area of the anode (0.01 m²). In our study, the anode area was used for the electrode calculation area.

3. Results and Discussion

The cell power data across the external resistor R (100 Ω) was measured at every 1:00 pm for each day. The measurements were conducted at a fixed time each day to ensure experimental consistency and to minimize diurnal variation in environmental conditions, particularly temperature and solar radiation, which may influence microbial metabolic activity and electrochemical performance of the Microbial Fuel Cell (MFC). Voltage (V) was recorded using a digital multimeter, and power density (mW/m²) was calculated according to Ohm's law and normalized to the projected surface area of the electrode. In this study, 4 types of pure substrate samples were prepared, each with a total mass of 400 g: persimmon waste (PW), soil (hereafter referred to as S), leaf mold (LM), and rice bran (RB). These substrates were selected based on their organic content and potential to support microbial metabolism within the MFC system. The experimental conditions for the pure substrates are summarized in Table 4. While for another several mixed substrate samples were prepared to evaluate the synergistic effects of nutrient composition on bioelectricity generation. These mixtures consisted of persimmon waste combined with soil (PWS), persimmon waste with leaf mold (PWLM), and persimmon waste with rice bran (PWRB). Each mixed sample was prepared at the same total mass (400 g) to maintain experimental comparability. The compositions of these mixed substrates are presented in Table 5.

Figure 3 illustrates the variation in power density as a function of operational

time. The results indicate that the power density increased rapidly during the initial phase of operation and reached a peak between day 2 and day 12.

Table 4. Parameter conditions for each pure sample.

| Parameter \ Coding of Sample | 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 5. Parameters for organic wastes mixed sample conditions.

| Parameter \ Coding of Sample | PWS (Persimmon + soil) | PWLM (Persimmon + Leafmold) | PWRB (Persimmon + Ricebran) |
|------------------------------|------------------------------|-----------------------------------|-----------------------------------|
| Persimmon waste (g) | 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 |

This phenomenon can be attributed to the rapid growth of electroactive microorganisms during the early stage when abundant organic substrates were available (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 $16.180 \text{ mW}/\text{m}^2$ and $9.663 \text{ mW}/\text{m}^2$.

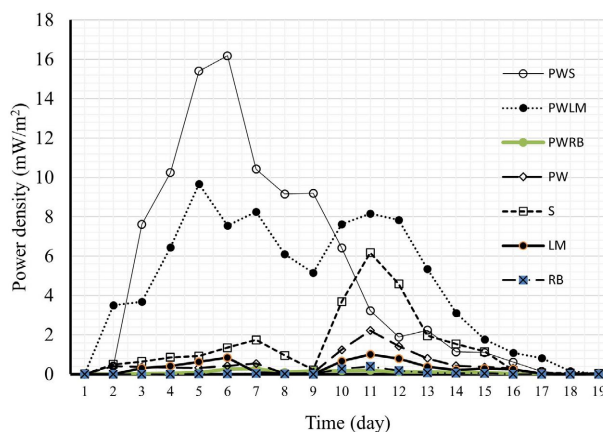


Figure 3. The variation of power density with duration.

The mixed sample of PWS showed a higher value of voltage than the other due to the synergistic interaction between the high glucose content of persimmon waste and the mineral-rich composition of the soil, which enhances microbial growth and electron transfer activity. The glucose present in persimmon waste serves as a readily biodegradable carbon source that stimulates microbial metabolism, thereby increasing electron generation and voltage output. The enhanced microbial activity during the initial stage resulted in higher electron transfer rates at the anode, leading to increased power generation. However, as the available organic substrates were gradually consumed, microbial activity decreased, which consequently reduced electricity generation. Another possible explanation for the observed stability during the intermediate phase is the microbial consortium effect, where metabolic intermediates produced by one microorganism may act as electron mediators for other microorganisms, facilitating electron transfer to the electrode surface (Rakesh et al., 2014). Then, the power decreased gradually with time. After approximately 12 days of operation, the power density gradually declined. This decrease is attributed to substrate depletion and the natural lifecycle dynamics of the microbial population, including microbial decay and reduced metabolic activity. Initially, when sufficient nutrients were available, the bacterial population increased rapidly; however, as the organic substrates were depleted, microbial growth slowed and the population eventually declined, resulting in reduced electricity production (Li, 2013). However, the power generation for other samples remain almost constant in all the stages. The relatively low but stable voltage output in these samples may be attributed to the inherent electrochemical potential difference between the anode and cathode as well as the slow decomposition of organic matter within the soil matrix (Moqsud et al., 2015). On some samples seen the power is still rising at a certain time. This behaviour suggests that the MFC system possesses a self-recovery capability, where microbial communities gradually adapt to the substrate environment and restore their electrochemical activity over time (Siti, 2012). The results presented in Figure 3 demonstrate that PW has strong potential as a material for power generation when compared with parameters reported for other MFC systems using 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.

To evaluate the scalability of the system, scale-up experiments were conducted using the same operational conditions as the laboratory-scale setup. The objective of the scale-up experiment was to investigate the influence of electrode surface area on power generation performance. As illustrated at Figure 4 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. It shows that increasing the electrode surface area significantly en-

hances the power density generated by the MFC system. The larger electrode surface provides more active sites for microbial colonization and electron transfer, thereby improving the overall electrochemical performance of the system.

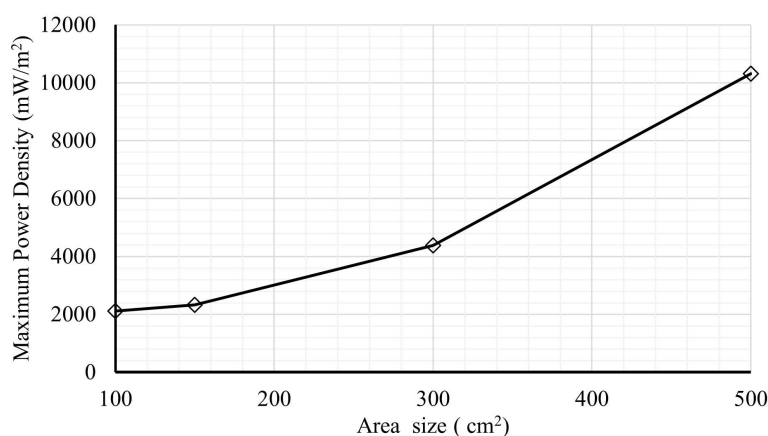


Figure 4. Power density of the scale-up area.

4. Conclusion

Persimmon fruit waste has the potential to be recycled as a substrate for bioelectricity generation. Though the power generates of 16.180 mW/m² and 9.663 mW/m² 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

The author declares no conflicts of interest regarding the publication of this paper.

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