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Origin of Weak Electrical Energy Production from Living-Plants

Ying Ying Choo*, Jedol Dayou*‡, Noumie Surugau**

** Energy, Vibration and Sound Research Group (e-VIBS), School of Science and Technology, University Malaysia Sabah

**Industrial Chemistry Programme, School of Science and Technology, University Malaysia Sabah

(ivy_choo@hotmail.com, lnoumie@ums.edu.my)

‡ Corresponding Author; Jedol Dayou, Industrial Chemistry Programme, School of Science and Technology, University Malaysia Sabah, Jalan UMS 88400 Kota Kinabalu, Sabah, Malaysia, +60-88 320 000, jed@ums.edu.my

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Abstract- Living-plants have been proven to have a potential for renewable energy source by embedding pairs of electrodes into it to allow flow of ions and hence generate electricity. Multiple tests using different type of electrodes and plants suggested that voltages are produced to greater or lesser extents where combination of copper (Cu)-zinc (Zn) and Aloe Vera produces the highest voltage output. To optimize the power output from the plant, a comprehensive knowledge regarding the mechanisms of energy generation is necessary. Initial hypothesis inferred this from electrochemistry process. Therefore, the presence of trace metals from the electrodes using Flame Atomic Absorption Spectroscopy (FAAS) was investigated in the plant to gain insight into the origin of the energy production. To further justify the stated hypothesis, comparison of trace metals concentration in electrodes immersed Aloe Vera between opened and closed circuit is also investigated. The obtained result confirmed that the electrochemistry process is responsible for the mechanism of the energy production from living plant.

Keywords- Renewable energy; weak energy source; atomic absorption spectroscopy; living-plants.

1. Introduction

The trend in the global economic currently hinges on the production rates of hydrocarbon energy sources such as petroleum, coal and natural gas. The ever rising cost of fossil fuels not only causes inflation but also hinders the economic growth [1]. According to the current consumption levels, worldwide reserves of oil will be exhausted in about 40 years, and reserves of natural gas in 60 years [2]. Many studies showed an inverse relationship between the rise of oil prices and economy activity [3]. An increase in the oil price also affects supply because oil is the engine of economic activities and energy is one of the basic inputs in the production process [4]. The impact of oil prices on different economic variables, such as investment, stock prices and inflation leads a decline in the output and productivity [4-5].

Besides that, the extensive use of burning fossil fuels raises the level of carbon dioxide in the atmosphere thus resulting in serious greenhouse effects. The greenhouse gases gradually increase the temperature of the Earth's surface and therefore bring us a warmer atmosphere and collapsing global environment. There is no doubt that climate change is upon us, therefore the next appropriate action is to minimize those long-term effects. Increasing the use of renewable energy has been encouraged by government in many countries [6] because this technology provides an excellent opportunity for the mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources [7].

Accordingly, we must aggressively utilize renewable energy in an effort to safeguard our future and the Earth [8]. There is a need to find out alternatives to produce energy in an environmentally benign way [9]. Switching to renewable energy sources for electricity generation provides beneficiary management strategies from the economic, as well as environment point of view [10]. Renewable energy sources include wind energy [11-12], ocean energy [13-14] and ambient power harvesting such as piezoelectric [15-16] that may replace batteries. The green technologies emit less greenhouse gases into the atmosphere and hence are pollution free and immensely available [9].

Recently, a new form of energy source based on plant was investigated by many researchers as the weak energy sources. Magcap, for example has developed a method to harvest electricity from trees and suggested that there is a way to refine the very faint source of electricity [17]. Meanwhile, a team of electrical engineers from University of Washington had also devised a voltage boost converter for energy harvesting from trees [18]. According to Wadle, although this development is in its infancy, it has the potential to provide an unlimited supply of constant, clean energy without relying on fossil fuels [19]. This new form of energy source is called living-plant fuel cells (LFCs) in this paper. This paper presents some fundamental procedures to harvest weak electricity from living and also the investigation into the origin mechanism of the energy production in LFCs.

2. Methodology

In this section, detail of the experimental procedures is discussed. The experimental work is divided into two parts: - selection of electrodes and energy sources and understand the origin of the energy production.

2.1. Investigation on the Type of Electrodes and Energy Sources

Since there are many types of electrodes available, the best pair that produces the highest power output has to be determined prior to any further optimization attempts. In the present work, four different materials of electrode had been selected because they are easily available. They consist of copper, iron, zinc and aluminum. The positive and negative terminal of the electrode is determined according to its electrochemical potential, E. Therefore, the electrode with higher and lower electrode potential, E° was selected as anode and cathode, respectively.

Due to a vast variety of plants available locally, only plants with good potential were considered. The primary consideration aspects include easy-embedding and stem moisture content. The current work selected three different kinds of plant which were Pulai tree (Alstonia sp.), banana tree (Musa acuminate) and also Aloe Vera (Aloe Barbadensis). They were selected because they grow in abundance throughout the year as well as their trunk or leaf structure allowed for easy electrode embedding.

Figure 1 shows the illustration of the experimental set-up where four distinct pairs of electrodes (Cu-Fe, Cu-Zn, Al-Zn, Cu-Al) were embedded into the Aloe Vera and connected with a multi-meter to measure its corresponding open circuit output voltage. Similar procedure was repeated for the other two potential plants, banana tree and Pulai tree.

2.2. Investigation on the Type of Electrodes and Energy Sources

As has been briefly mentioned before, the origin of the energy generation in LFCs could be from electrochemistry process. If this is true, then theoretically there is difference in metal concentration in the fresh Aloe Vera and Aloe Vera with immersed electrodes. Simultaneous, oxidation and reduction processes occur at anode and cathode allow the flow of negative ions to the anode and positive to cathode [19]. Thus, the investigation in this section is carried out with this hypothesis. Flame Atomic Absorption Spectroscopy (FAAS) was used to determine the metals concentration in the plant (Aloe Vera).

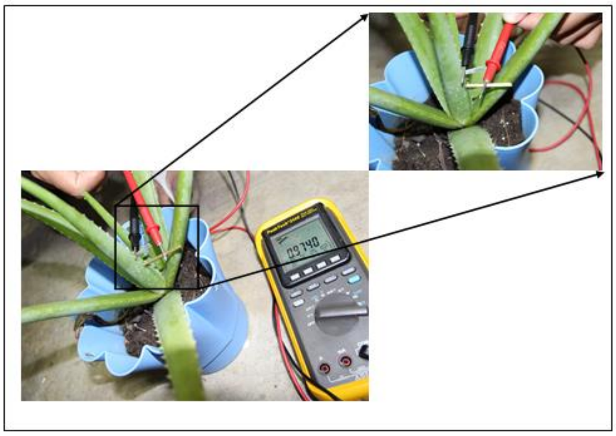

Fig. 1. Experimental setup. Electrode pairs immersed inside the Aloe Vera leaf and connected with a multi-meter.

2.2.1. Comparison of metal contents between fresh and immersed aloe vera

The Aloe Vera leaf without any electrodes immersed identified as the fresh Aloe Vera. Three pairs of copper-zinc electrodes were immersed into another Aloe Vera leaf for 24-hours with open circuit connection. The electrodes were positioned 1.5cm deep into Aloe Vera and 0.5cm apart between a pair of copper-zinc. There is about 2cm apart between each pair of copper-zinc electrodes. This experimental set up as shown in Fig. 2 is purposely designed to allow enough time for the hypothesize oxidation and reduction process to occur with significant results. The Aloe Vera leaves were then cut into pieces and the outer rind of the Aloe Vera was removed. The clear dense Aloe Vera juice and inner gel which had been immersed with the electrodes were then transferred into beakers separately for sample treatment.

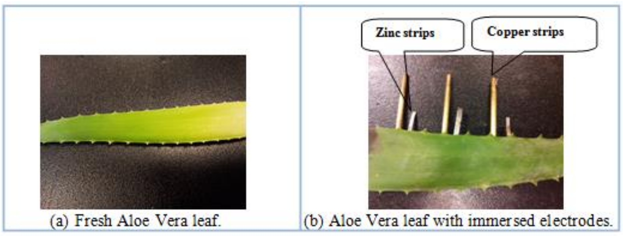

Fig. 2. Photos showing without electrodes immersed (fresh Aloe Vera) and with electrodes (copper and zinc) immersed.

2.2.2. Comparison between electrodes immersed aloe vera in opened and closed circuit.

The investigation is continued to ascertain if there is further difference in concentration between opened and closed circuit for Aloe Vera immersed with metals. Three strips of copper and zinc electrodes were immersed into the opposite end of the same leaf for 24-hours (shown in Fig. 3). Similar preparation set up as in section 2.2.1 was applied with 1.5cm depth of immersion, 0.5cm apart between same electrode while there is 5cm distant between copper and zinc electrodes. For the closed circuit connection, it was connected with the digital clock as a load. Similar gel extraction procedure used in section 2.1.1 was repeated for opened and closed circuit analysis. From Fig.3, the left hand side is known as zinc zone whereas the right hand side is known as the copper zone. To facilitate better understanding, two terminologies are first introduced here which are local (*) and migrated metal (**) as shown in Table 4.

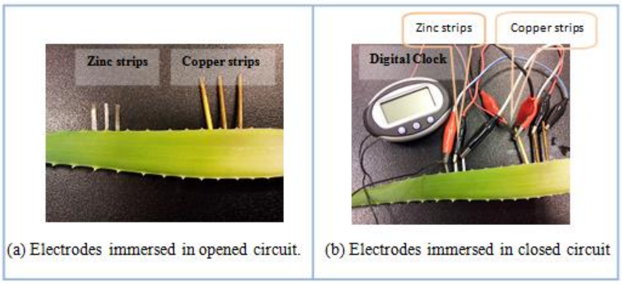

Fig. 3. Photos showing Aloe Vera with electrodes immersed in opened circuit and with closed circuit (connected with digital clock as load).

2.2.3. Sample Preparation

For the preparation of all samples, 20 ml of each sample of Aloe Vera inner gel from the previous two sections were used for further analysis. 8 ml of nitric acid was added into the samples in a 100 ml beaker. In the elemental analysis by FAAS, nitric acid was used as a matrix compound for determining trace metals in solutions and was used in the digestion process of the samples [20]. Then, the treated samples were heated on a hot plate at 95°C for 15 min. The samples were stirred until boiling to remove oxides of nitrogen. After that the beakers were put on ice cube to cool down the temperature. The cool samples were then filtered through a Whatman filter paper with 0.45µm pore size [21]. The digestion samples were transferred into an appropriate volumetric flask and were made up to 100 ml with the distilled water [22].

2.2.4. Procedures for analysis of metals concentrations

The treated samples with distilled water from section 2.2.3 were then investigated for elemental composition of copper and zinc by using FAAS (Perkin Elmer 4100). Figure 4 shows the complete procedure of the analysis of the metal concentrations.

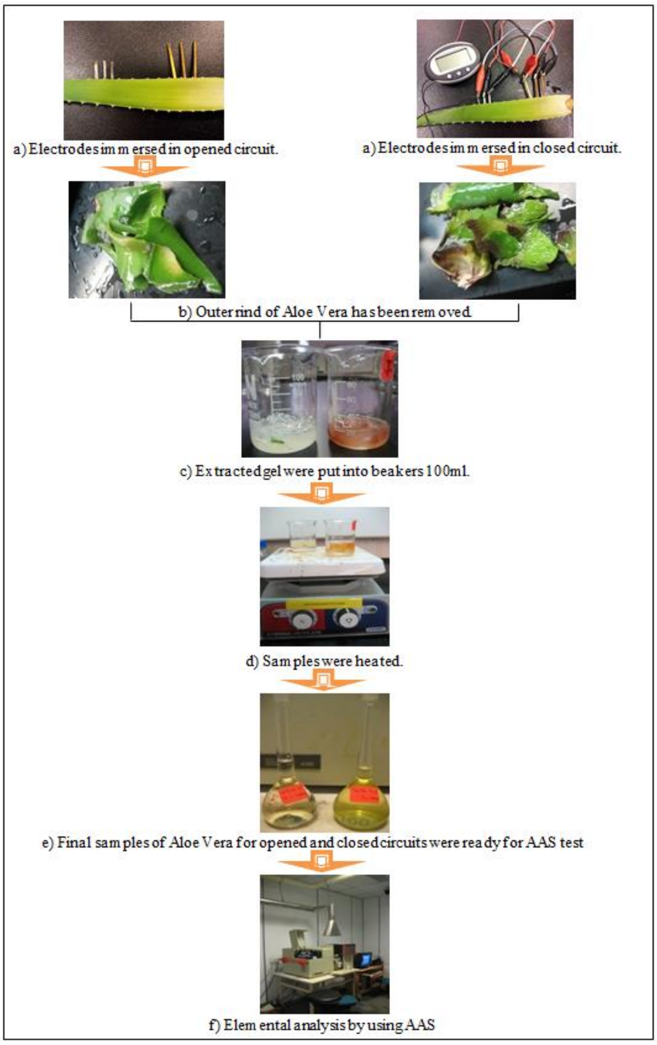

Fig. 4. Complete procedure of the analysis of the metal concentrations using FAAS.

2.2.5. Sample and statistical analysis

The samples and standard solutions were analyzed in triplicate to ensure accuracy and precision [23]. The absorption wavelengths for the determination of Cu and Zn together with its linear working range are given in Table 1.

Table 1. Operating parameter for Cu and Zn

Element	Current (mA)	Slit width (nm)	λ_{max} (nm)	Flame Color	Flame Type	AAS Technique
Cu	15	0.7	324.8	Blue	Air/Acetylene	Flame
Zn	15	0.7	213.9	Blue	Air/Acetylene	Flame

The concentration of metal in Aloe Vera is calculated using

$$y = mx + c \qquad (1)$$

Where y is the absorbance, m is the slope from calibration plot, x is the concentration and c is the intercept at y-axis.

3. Results and Discussions

3.1. Selection of Electrodes Pair and Energy Sources.

Figure 5 shows the open circuit voltage harvested from the Pulai trees over time. It suggests that copper-zinc produces the highest voltage approximately 0.8V. This is followed by Cu-Fe (0.5V), Cu-Al (0.4V) and Al-Zn is the lowest (0.38V). It was also found that for all combination, the harvested voltage is stable up to 60minutes.

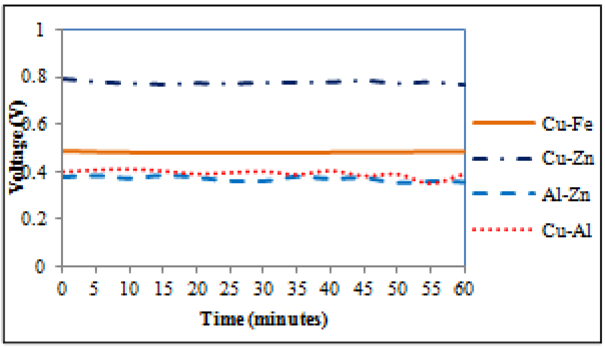

Fig. 5. Voltage profile over time obtained from Pulai tree (Alstonia sp.) by using different pairs of electrodes.

Similar trend of voltage output was obtained when banana tree and Aloe Vera were used as the energy source (Figs. 6-7). However, it was found that Aloe Vera (0.945 V) produces the highest open circuit compared with Pulai tree (0.8V) and banana tree (0.913 V). It can be seen that the output voltage obtained from banana and Aloe Vera is 0.913V and 0.945V, respectively (Figs. 6 and 7). Therefore, Aloe Vera and Cu-Zn were selected as the samples for AAS test to investigate the origin of the energy production.

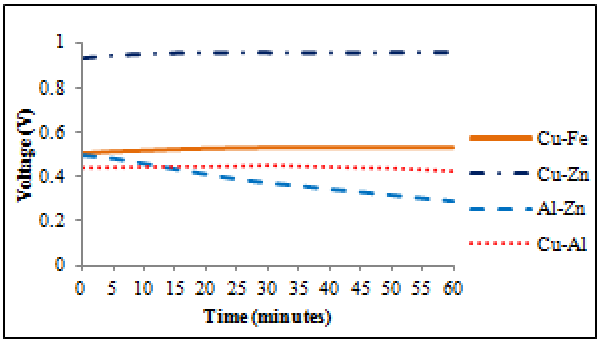

Fig. 6. Voltage profile over time obtained from banana tree (Musa acuminate) using different pairs of electrodes.

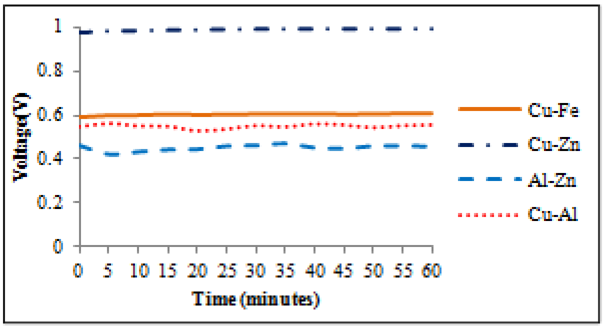

Fig. 7. Voltage profile over time obtained from Aloe Vera (Aloe Barbadensis) using different pairs of electrodes.

3.2. Concentration of Copper and Zinc in Samples

3.2.1. Comparison between fresh and immersed aloe vera.

The detailed calibration blank for standard solutions containing copper and zinc is shown in Table 2 from the range of 2.0 ppm-10.0 ppm. These data are used as the standards and validations for the analysis of samples (Aloe Vera).

Table 2. Standards Calibration data for Copper and Zinc

Standard solution for Copper	Absorbance	Concentration, mg/L	Standard solution for Zinc	Absorbance	Concentration, mg/L
2 ppm	0.13	2.14	2 ppm	0.03	2.08
4 ppm	0.25	4.19	4 ppm	0.06	4.43
6 ppm	0.37	6.03	6 ppm	0.09	6.54
8 ppm	0.48	7.95	8 ppm	0.10	7.70
10 ppm	0.60	9.91	10 ppm	0.13	9.65

The data presented in Table 3 as compared with Table 2 shows that the copper concentration in both fresh and metal immersed Aloe vera is less than 2ppm of standard calibration. The content of zinc in fresh Aloe vera indicates less than 2ppm of standard solution. However, its concentration is relatively higher than 6ppm of standard solution after immersed with electrodes. There is a remarkable increment in both copper and zinc concentration. The increment percentages of copper and zinc with electrodes immersed are approximately 55 times and 33 times greater than of the fresh Aloe Vera respectively.

Table 3. Concentration of copper and zinc in the fresh and electrodes immersed Aloe Vera.

Aloe Vera sample for copper test	Absorbance	Sample Concentration, mg/L	Aloe Vera sample for zinc test	Absorbance	Sample Concentration, mg/L
Fresh Aloe Vera	0.0016	0.0260	Fresh Aloe Vera	0.0027	0.2060
Metal immersed Aloe Vera	0.0864	1.4310	Metal immersed Aloe Vera	0.0911	6.9040

3.2.2. Comparison between electrodes immersed aloe vera in opened and closed circuit.

Table 4 shows the comparison between concentration of local copper and zinc as well as migrated copper and zinc in opened and closed circuit connection. The local copper in closed circuit is about three times greater than that in opened circuit. The oxidation occurs spontaneously at the zinc electrode and releases electrons which lead to the reduction of copper ions at the copper electrode. Equilibrium exists at the copper strips prior to connection: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ [24]. This causes the concentration of copper is higher in closed circuit when being compared to the opened circuit.

Table 4. Comparison of copper and zinc concentration (in mg/L) in electrodes immersed Aloe Vera between opened and close circuit.

	Types							
	Fresh Aloe Vera		Metal immersed Aloe Vera					
	Mean	σ	Series electrodes		Opposite end identical electrodes in opened circuit		Opposite end identical electrodes in closed circuit	
			Mean	σ	Mean	σ	Mean	σ
Concentration of Copper	0.0260	0.0004	1.4310	0.0081	1.5670*	0.0056	4.1330*	0.0235
					0.0350**	0.0039	0.0300**	0.0041
Concentration of Zinc	0.2060	0.0018	6.9040	0.0264	17.0500**	0.0483	21.6200**	0.3194
					10.7100*	0.0454	50.8000*	0.3022

* Local ** Migrated

The concentration of migrated copper to the zinc between opened and closed circuit is only 0.005 mg/L different. According to the electrochemistry process, the direction of electron flow in a cell is determined partly by the relative ease of oxidation of the electrode materials [24]. Between copper and zinc, zinc is more reactive, therefore, a greater electric potential accumulates on the zinc strip when it is placed in the zinc solution [24]. This insignificant difference may due to the close distance between copper and zinc electrodes.

On the other hand, a slight increment is observed in migrated zinc to the copper from opened circuit to closed circuit. This increment is significant when compared to the readings revealed by the fresh Aloe Vera. The concentration of migrated zinc increases about 83 times (opened circuit) and 105 times (closed circuit) in contrast to the fresh Aloe Vera. The electrons released in oxidation process have been flow through Aloe Vera inner gel to the copper part although in an opened circuit connection [25]. This is due to the inner gel of Aloe Vera itself as a porous barrier that permitting the ion migration [24].

Nevertheless, the local zinc showed a significant increment which approximately 5 times increment from opened to closed circuit. This is because the oxidation occurs in zinc metal releases electron ($Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$), through the connected wire to enable reduction of copper ions [24].

4. Conclusion

This paper presented selection of the best combination of electrode pairs with energy sources and origin mechanism of the electrical energy harvested by embedding electrodes into living plant. Within the tested plants and electrodes, Aloe Vera produced the highest voltage when Cu-Zn was used. From the FAAS result, significant increment of the metal was found in the aloe Vera after immersion. It is due to the simultaneous oxidation and reduction process that occur at the electrodes which permit the flow of ions within the Aloe Vera itself. On the other hand, the flow of ions becomes more efficient when the electrodes were connected in closed circuit. This is because the wires that connect the electrodes provide an alternative pathway for the ions to flow between anode-cathode. Therefore, the electrochemistry process is believed to be responsible for the mechanism of the energy production from living plant.

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