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# A comparative study of Aloe Vera and Pandanus amaryllifolius Plant Microbial Fuel Cell's Performance in Voltage Generation

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***Abstract:*** *Microbial fuel cells (MFC) are more promising source of energy today and it should be cheaper and more efficient. The extended version of MFC is Plant Microbial Fuel Cells (PMFC). The construction and analysis of PMFC requires knowledge of different scientific and engineering fields, ranging from microbiology, electrochemistry to materials and engineering. The PMFC also depends on various factors like microorganism, electrode materials, pH value of the soil, photo synthesis, solar radiation, type of plant, temperature, etc. to produce electricity. The present study was done with two plants namely Aloe Vera and Pandanus amaryllifolius which are growing in Asian and in East Asian countries abundantly. The output voltages produced by these two plants were compared along with their response to solar radiation and type of electrode. The correlation with them was studied for a period of 14 days by keeping the other influencing parameters constant. It has been found that Pandanus amaryllifolius with graphite felt under direct sunlight generates better voltage than Aloe Vera under the same study conditions.*

***Keywords:*** *aloe vera, graphite, microorganism, pandanus amaryllifolius, solar radiation*

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## I. Introduction

A conventional fuel cell is an electrochemical power source that continuously converts the stored chemical energy in a fuel to electrical energy as long as there is a continuous supply of fuel. These cells consist of the fuel, oxidant, anode and cathode materials. However, biofuel cells differ slightly from conventional fuel cells, in that they employ naturally occurring proteins or microorganisms as the biocatalysts for the anodic and cathodic substrate materials to catalyze the electrochemical reactions between the fuel, oxidant, and the biocatalysts [1]. To supply the nutrients continuously to the microbes or to make the microbial fuel cells more sustainable, plants are employed in cells, and this type of cells are called plant microbial fuel cells (PMFC). In plant microbial fuel cells, plant roots provide substrate for electrochemically active bacteria in the anode by the loss of organic compounds [2]. The plant microbial fuel cell is an emerging technology which can produce electricity via living plants and a green energy. PMFC is sustainable because it is renewable, has a clean conversion without emissions and has no competition for arable land or nature [3]. In the PMFC, plants grow in the anode where rhizodeposits are the substrates oxidized by electrochemically active bacteria to generate electricity. Natural wetlands offer a new electricity source in which PMFC can be integrated without extensive excavation of the soil [4]. In addition to that the PMFC can be implemented in natural wet lands, rice fields and also can be integrated with the green roofs. Even though PMFC is based on photosynthesis, it is expected to deliver electricity 24 h per day and year round in case of suitable conditions (e.g. temperature and plant growth) [5]. The theoretical maximum electricity output of a PMFC is 3.2 $W/m^2$ plant growth areas (PGA) [6], currently a long term output of 0.155 $W/m^2$ PGA is reached [7]. Many studies have been done to improve the electricity production by using MFC from year 2005 up to date. These systems are operated under a range of conditions that include differences in temperature, pH, bio-film, internal resistance, electrode surface areas, reactor size, operation time, and ion conductivity [8-14]. However system performance is dependent on various factors like electrode materials and operating parameters. Plant and soil types are the drivers for shaping microbial communities that can ultimately alter the power output. The trend of voltage generation is affected by the nature of exudation utilized by microbes [15]. The present study is focused on the comparison of output voltage produced by two plant cells with the variation of different electrode material and solar radiation.

## II. Methodology

### 2.1 Preparation of Plant Microbial Fuel Cell Containers

Four plastic pots with a capacity of four liters and with dimensions of 20 cm top diameter and 15.5 cm of bottom diameter and 16.5 cm of height were used for constructing the plant microbial fuel cells as shown in Fig.1


**Figure 1:** Planting pot

The plastic pots were disinfected by rinsing with bleach followed by clean water and were kept in clean plastic bags until ready to be used.

### 2.2 Preparation of Anode, Cathode and Circuits

Four sets of circuit were set up for four plant microbial fuel cells. Circular shape plate electrodes with the diameter of 12 cm for electrodes were made using carbon fiber cloth and graphite felt. The holes were made on (approximately 1 to 1.5cm, which is the diameter of a plant stem) the anode and cathode plates according to the diameter of the different plants as shown in Fig.2

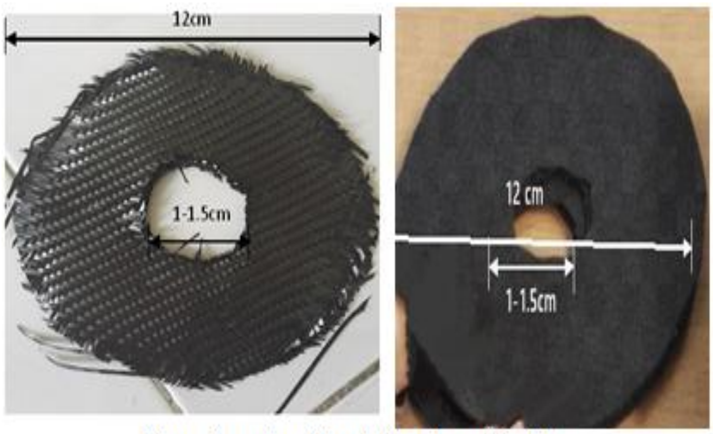


**Figure 2:** carbon fiber cloth and graphite felt

The anode and cathode were connected with epoxy-encapsulated copper wires to form a complete circuit, and a digital multimeter was connected into the circuit for measuring the output voltage.

### 2.3 Preparation of Plant-growth Medium

Organic Planting Soil 6 in 1 with amount of 16 L, which contents coco peat, burnt soil, river sand, burnt husk, rich humus, and charcoal powder, was obtained .The soil obtained was tested for pH by using pH meter. If the pH of soil is lower than 6.5, and then the required amount of $Ca(OH)_2$ or $CaCO_3$ will be added based on liming curve. Planting will be delayed for 3 to 4 days if $Ca(OH)_2$ was used to lime the soil and for 10 to 18 days if $CaCO_3$ was used to lime the soil to achieve the required pH value. The soil will be acidifying with acidifying fertilizers if the pH of the soil is higher than 7.5. The required amount of acidifying fertilizer will be added based on the acidifying curve that plots mg of acidifying material per kg soil to resulting pH. Planting will be delayed for 3 to 4 days if any of acidifying fertilizer is used.4L of the soil with the pH range of 6.5-7.5 was filled into each of the plastic pots without mixing any compost or organic fertilizer.

**2.4 Preparation of Plants and Transplanting.**

2.5 Plants of Aloe Vera, Pandanus amaryllifolius, were obtained and the stems of the plants were separated precisely from the soil. One or two stem(s) of the plants were transplanted directly into the prepared plant grown media as shown in Fig.3


**Figure 3:** Plant microbial fuel cells with (1) Pandanus amaryllifolius, (2) Aloe Vera

**2.5 Operation of Plant Microbial Fuel Cells**

Plant microbial fuel cells were observed and monitored for 14 days. They were watered regularly with tap water 2 to 3 times per week depending on the soil moisture so to maintain a level of moisture content of 6-8 when measured by a moisture sensor Three-Way Meter, as shown in Figure 4. The pH of the soil was maintained around 7. Daily temperature data was collected using the thermometer. The voltage was measured by a digital multimeter and recorded every day from 8 a.m. to 5 p.m. for two weeks period, as shown in Fig. 4


**Figure 4**: Three-Way Meter and Digital multimeter

**2.6 Assessment of the effect of solar radiation**

Two plant microbial fuel cells, one set with carbon fiber cloth electrodes and another with graphite felt electrodes, were placed in a shade under a roof. Another set of plant microbial fuel cells with carbon fiber cloth electrodes and another with graphite felt electrodes, were kept outside to the direct sun light. The amount of solar radiation was measured using METEON data logger in W/m$^2$ (Fig 5)


**Figure 5**: Meteon Data logger

**2.7 Assessment of voltage**

The output voltage was measured in millivolts (mV) in hourly basis from 8 a.m. to 5 p.m. for 14 days. The average voltage output for each of the cell for each day was calculated and plotted for comparative study to assess the performance. The cell that produced the maximum voltage was chosen and tried with two different electrodes in two different environments like, direct sunlight and under shade.

The output voltage along with the solar radiation was measured for each of the 14 days and its relation studied and plotted.

## III. Results And Discussion

Two cells with Aloe Vera and Pandanus amaryllifolius were designed using carbon fiber electrodes .The daily average voltage produced by 2 cells were recorded and a comparative graph was plotted against day (figure 6). Based on the result, the voltage values were low during the incubation period, which is from day 1 to day 3. This was low as because the plant was just adapting to the new environment and the growth of the bacteria just begins. The voltage for each of the cell increased drastically starting from day 3 to day 5 and after which it slight increased steadily with fluctuations. The cell with Aloe Vera reached its maximum voltage on the 12$^{th}$ day, which was 539. 6 mV and the cell with Pandanus amaryllifolius reached its maximum voltage on was 765.4 mV.

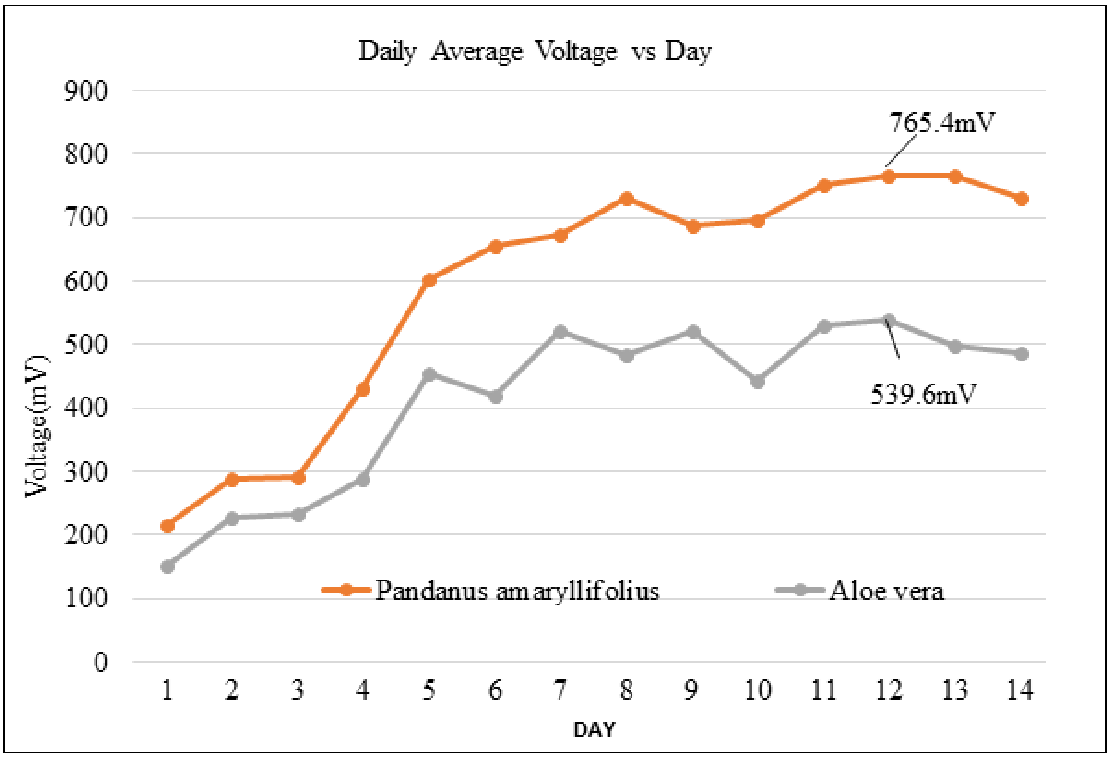


**Figure 6:** Variation of average daily voltage with day

The possible explanation for the difference in cell voltages in between the plant microbial fuel cell could be the differences in both leaves size and root development. The longer growth of the plant root could provide more rhizodeposition in the soil. Pandanus amaryllifolius has shown higher growth of the root and hence the maximum output voltage. The plant with broader leaf would have higher photosynthesis rate result in the generation of more voltage. Since Pandanus amaryllifolius produced higher voltage with days, that particular plant has been chosen to study the variation of voltage with different electrode materials. Two cells with carbon fiber cloth and two cells with graphite felt have been prepared. One in each type was placed under shade and in sun light for a period of 2 weeks. It has been noticed that there is only a slightly difference in average daily cell voltage generated during the first 5 days between the cells and were very minimal. There is a drastic variation in the voltage after 5$^{th}$ day. The graphite felts achieved higher cell voltage compared to the cells with carbon fiber cloth. This indicates that the graphite felt is better in electron transfer due to the bacterial activity to the external circuit.

**Table 1:** Voltage production with different electrode materials

| DAY | Carbon Fiber Cloth(Under shade) in mV | Graphite felt(Under shade) in mV | Carbon Fiber Cloth(Direct Sunlight) in mV | Graphite felt (Direct Sunlight) in mV |
|---|---|---|---|---|
| 1 | 80.3 | 88.1 | 100.4 | 104.6 |
| 2 | 110.0 | 114.4 | 122.4 | 129.8 |
| 3 | 139.0 | 154.5 | 178.1 | 204.0 |
| 4 | 160.7 | 202.4 | 238.6 | 268.2 |
| 5 | 229.7 | 251.8 | 270.5 | 276.7 |
| 6 | 296.7 | 313.3 | 381.4 | 397.4 |
| 7 | 362.2 | 376.9 | 483.0 | 491.9 |
| 8 | 384.9 | 398.3 | 515.4 | 523.5 |
| 9 | 426.5 | 435.5 | 567.3 | 579.5 |
| 10 | 434.3 | 455.0 | 577.0 | 580.1 |
| 11 | 454.6 | 460.1 | 600.3 | 616.6 |
| 12 | 478.0 | 494.6 | 614.9 | 644.0 |
| 13 | 461.9 | 473.9 | 599.6 | 618.3 |
| 14 | 466.9 | 483.9 | 597.0 | 611.4 |

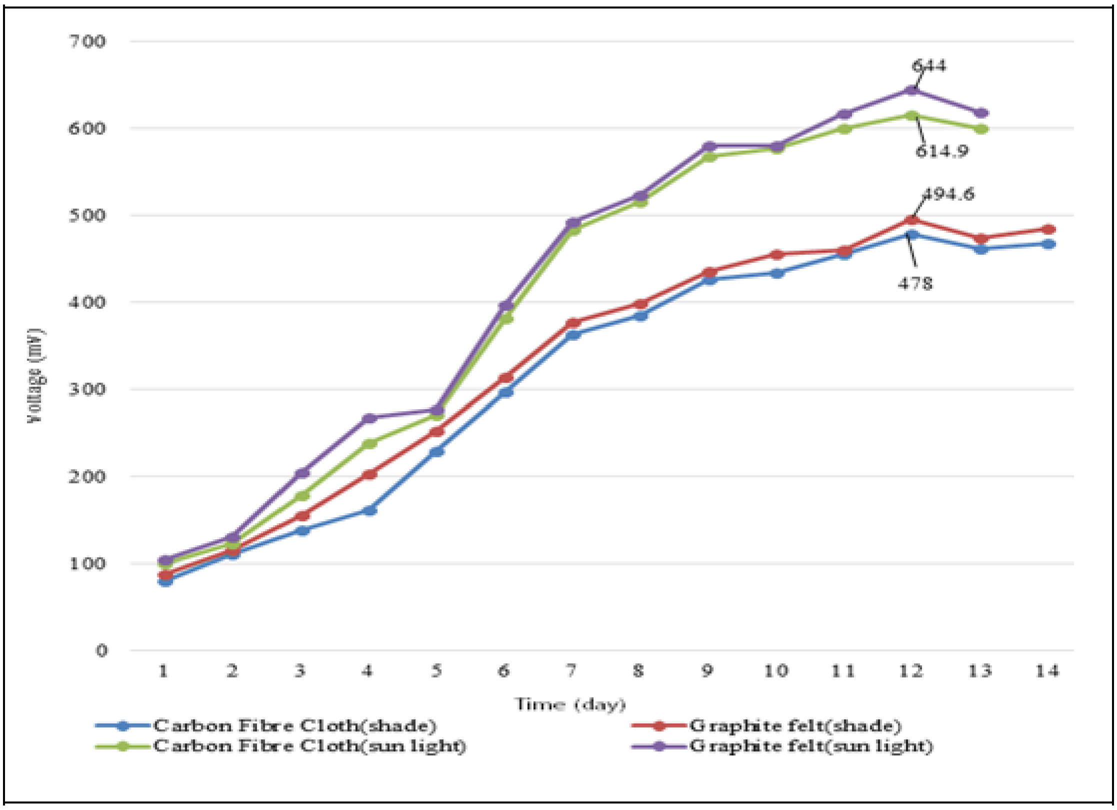


**Figure 7:** variation of average daily voltage with electrode material

Also it was observed from the result that the voltage values are higher for the cell placed in open field to direct sun light than under shade. The peak voltage for the cell with graphite felt electrodes was 644mV and carbon cloth fiber was 614.9mV. The peak voltage for the cell under the shade with graphite felt electrodes was 494.6mV and carbon cloth fiber was 478mV. Higher voltages have been achieved for both the plants when the temperature was recorded the maximum of 35°C on 13$^{th}$ and 14$^{th}$ day respectively. This indicates that the plant cells in the sunlight produces higher voltage than by the plants placed under shade. The plants had higher rate of photosynthesis, and more substrates could be generated for bacterial chemical reaction in the cells, which resulted in higher voltage. The variation in daily cell voltage among the cells is also due to the difference in local weather. Figure 8 illustrates the variation of daily voltage against daily solar radiation for Pandanus amaryllifolius and Aloe Vera with graphite felt, since graphite felt produces better result than carbon fiber. Based on the data recorded, it is very obvious that Pandanus amaryllifolius is producing better voltage than Aloe Vera with carbon fiber electrode. Also concludes the variation is directly related to the amount of solar radiation they receive.

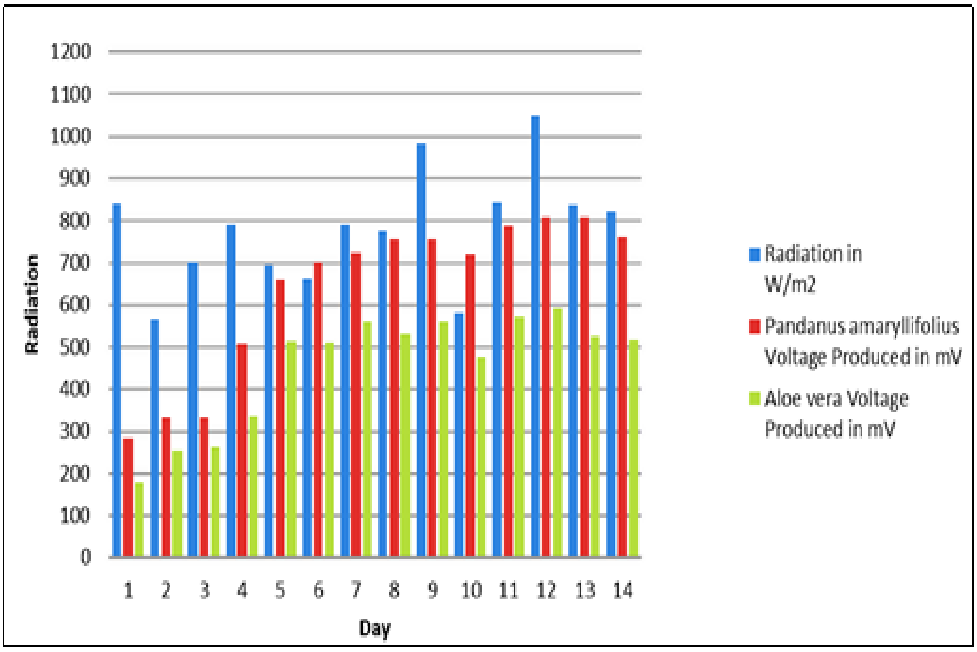


**Figure 8:** Variation of Daily average voltage against daily average solar radiation

From figure 8, on day 12, 1050 $W/m^2$ of solar radiation has generated a maximum voltage of 809mV for Pandanus amaryllifolius and 592mV for Aloe Vera. Also it is very clear from the data, that the output is directly proportional to the amount of incoming solar radiation and also the microbial activity. It is seen that in the earlier days tough the radiation was high the voltage was somewhat low due to adaptation during the incubation period. The solar radiation increases the temperature and thus increasing of formations of biofilm and microbial activity in the later days, which then leads to an increase of redox reaction and increase of rate of flow of electron. Therefore, it leads to the increase of the cell voltage. Since the solar radiation is dependent factor of other meteorological factors, they also will influence the voltage production.

## IV. Conclusion

It is concluded that the plants are able to supply the substrates for microbial activity and to improve the voltage production of a cell. The cell with Pandanus amaryllifolius with graphite felt electrodes showed potential to generate higher cell voltages. The cell also shown and achieved higher voltage production at high solar radiation and temperature. However, in this study, effects of electrodes and solar radiation are considered, and further research can be done to ascertain the best voltage production with multiple parameters and its performance. Also, anticorrosive materials are suggested to be applied in different parts of a circuit of plant microbial fuel cell, such as electrodes, wires and crocodile clips to enhance the free flow of electrons. An automated and water-proof recording system is recommended for assessing the voltage production of a plant microbial fuel cell during the rainy seasons. The wet-weather plants are suggested for the plant microbial fuel cells that operate in all seasons, as the wet-weather plants have the specialized structures and organelles that protecting them from damage in heavy rainfall.

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