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An Estimation of the Extractable Electrical Energy from *Bryophyllum pinnatum* Leaf

MEHEDI HASAN[1]

[1]Department of Electrical and Electronic Engineering, City University Bangladesh, 13/A, Panthapoth, Dhaka-1215, Bangladesh,

KAMRUL ALAM KHAN[2]

[2]Department of Physics, Jagannath University, Dhaka-1100, Bangladesh

MOHAMMAD AL MAMUN[3]

[3]Department of Chemistry, Jagannath University, Dhaka-1100, Bangladesh

***Abstract**: The demand of electricity is increasing tremendously throughout the world, but the storage of conventional sources, like oils, coals and natural gases are getting reduced. Non-conventional and renewable energy are the alternates to meet the present and future demands of electricity. The energy extractors from those renewable energy resources are often costly and hard to maintain for the people living in the off-grid. Simpler but effective way of electrical energy extraction to meet off-grid people's small demand is needed. Non-conventional process, like electricity generation from Bryophyllum pinnatum leaf can be so effective considering those purposes. In this paper, we've calculated the approximate ampere-hour, energy density, power density and specific capacity i.e. the extractable electrical energy from Bryophyllum pinnatum leaf. We found the ampere-hour 0.6448Ah/L, energy density 209.7mWh/L, specific energy density 270.6mWh/Kg and the power density 974.16W/Kg. Moreover, this process will lead us to estimate extractable electrical energy from other biomass resources and to collect data for future use.*

***Keywords**: BPL cell; PKL cell; Biomass; Electricity for off-grid people; Fuel Cell.*

I. Introduction

Bangladesh is a developing country. But the shortage of electricity is creating a great barrier in our rapid development. The development of any country depends on how much energy she can produce, consume as well as reserve for the future generation. In Bangladesh, the electricity is available only for 60% of total people. Now the total demand of electricity in this country is about 12000MW, the capacity to produce electricity is 8525MW but the maximum production is only 6350MW (Bangladesh Economic Review-2013). About 85% electricity is produced from natural gas. Total reserve of gas in Bangladesh is 37TCF (Trillion Cubic Foot), available is 27TCF but already used 12TCF, and the remaining 15TCF is enough for only 12 years (BAPEX 2014.08.08). In these circumstances, it is very essential to take the necessary initiatives for the investigations of alternate energy sources, which is obviously focused on the renewable energy sources. In the perspective of Bangladesh, the generation of electricity from *Bryophyllum pinnatum* as a source of biomass using voltaic cell principle [1], will be a feasible means if necessary technology is developed as this leaf contains some organic acids [2], [3] which can be cultivated anywhere in this country without any special nursing.

II. Construction of BPL Test Cell

Construction of BPL cell is very simple. The leaf of *Bryophyllum pinnatum* contains some organic acids such as amino acids, oxalic acid, citric acid, palmitic acid, ascorbic acid, malic acid, iso-citric acid etc. which act as acidic electrolyte [4]- [6], [12]- [15]. By placing two electrodes like Zinc and Copper at the filtered BPL sap, we can get the significant flow of electricity [6], [7], [17].

A. *Collection of Bryophyllum pinnatum Leaf*

The cultivation of the BPL is very easy. It grows everywhere even in the cement and watery land without any special treatments. For BPL cultivation producing higher amount of electricity, no cultivable and crops lands are required, but the free spaces like roadsides. It can also be cultivated in the unused forests, islands and hilly areas of Bangladesh. During our study, we collected the leaves from free lands.

(a) (b) (c)

Figure 1 (a) *Bryophyllum pinnatum* Leaf (BPL), (b) BPL plant and (c) BPL plants at the laboratory.

B. Sap Preparation

For this, we need to wash the dirt from each leaf and put them on open air to dry out adhered water from the leaf surface. After weighing the leaves, we have to put them in a blender and add some water before starting blending. Water will help to blend each leaf rightly. The percentage of water influences the performance of this kind of cell. In this study, the amount of BPL in the sap was 85.308%, water was 14.214% and $CuSO_4.5H_2O$ was 0.4739% approximately. The $CuSO_4.5H_2O$ was used as secondary salt.

(a) (b)

Figure 2 (a) Leaves in blender and (b) Electrodes.

C. Electrode Preparation

We use Copper and Zinc plates as electrode which are cost effective and available in the local markets. Copper plates are used as cathodes and the Zinc plates are used as anodes for this kind of cell.

Table I Properties and dimension of anode and cathode.

Properties	**Anode**	**Cathode**
Element	Zinc	Copper
Average Height	105.56 mm	105.39 mm
Average Length	53.12 mm	53.26 mm
Average Thickness	0.71 mm	0.17 mm
Average Mass	27.71 g	6.77 g

D. Design of BPL Test Cell

To characterize the performances of the BPL unit cell, we used a small rectangular box made of glass whose upper side is open with no-compartment, which is termed as unit cell because for producing higher energy, we use the cell whose parameters and dimensions are integral multiple of this kind of cell. The length of the cell is 10 cm, width 6 cm, height 12 cm and inner volume is 720 cm^3.

Figure 3 Design of BPL Test Cell.

E. Cell Mechanism

In the usual Daniel cell, at the anode, zinc is oxidized in the following half reaction:

$$Zn_{(s)} \rightarrow Zn^{2+}{}_{(aq)} + 2e^- \text{ (Standard electrode potential, } E^o = -0.7618 \text{ V)}$$

On the other hand, at the cathode, copper is reduced according to the following reaction:

$$Cu^{2+}_{(aq)} + 2e^{-} \rightarrow Cu_{(s)} \text{ (Standard electrode potential, } E^{o} = +0.340 \text{ V)}$$

The overall reaction:

$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s) \text{ (Open-circuit voltage 1.1018 V) [18]}$$

The Cell Diagram: $Zn/Zn^{2+} \mid Cu^{2+}/Cu$

The two half cells each support one half of the reactions described above. In BPL cell, the anode used is Zn plate but Cu plate used as cathode. The electrolyte used is BPL juice with a secondary salt ($CuSO_4.5H_2O$). Thus, the reactant ionic species present in solution are H^+ and Cu^{2+} ions. The overall reaction taking place is considered as follow:

$$Zn(s) + Cu^{2+}(aq) + H^{+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s) + H_2(g)\uparrow$$

The concentration of Cu^{2+} and H^+ decreases but that of Zn^{2+} increases with time since Cu^{2+} and H^+ are the electron acceptor and Zn is the electron donor and hence the potential and current flow decreases. This is because the electron acceptors accept electrons by reduction process.

III. Experimental Set-up

In this study, we took four zinc plates as one anode and two copper plates as single cathode. The surface area of each electrode (both Zn and Cu plates) were the same. And the increasing the plates number means increasing the surface area of each electrode. So, here the surface area of anode is almost double to the cathode. The electrodes were immersed 120 mm deep into the sap of resulting electrochemical cell. This depth was kept fixed throughout the experiment. A filament bulb of 2Ω was connected in between the anode and cathode. The two leads of a voltmeter and an ammeter were connected to the two electrodes to measure the open circuit voltage and short circuit current and a pH meter was immersed at the upper part of the glass container to get the pH reading continuously. The space (gap) between the electrodes was 5 mm and corresponding load-current and pH readings were taken during the progress of electricity generation.

Here we used a term named "Cycle" which is the number of uses of same sap for several periods. Cycle-1 means newly prepared sap, which was used for the study. When the pH meter showed the pH of the sap 7.00, we took the sap from the glass container to a beaker and used a small rod to stir the sap and then again put that in the glass container for further study. Thus, we have a new cycle, called Cycle-2 was investigated. We also continued this for Cycle-3.

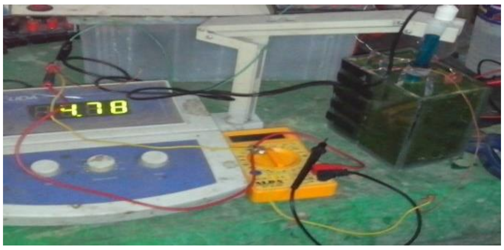


Figure 4 An experimental set-up of studying the self-discharge characteristics of BPL cell.

IV. Extractable Ampere-hour from BPL Sap

The amount of energy that can be supplied by any cell (or battery of cells) is defined in terms of its rating in ampere-hours and expressed as Ah [8].

$$\text{Ampere-hour} = \text{Current} \times \text{Time}$$

For example, if a cell can supply a current of 5 A for a maximum time for 1 h, then its rating is

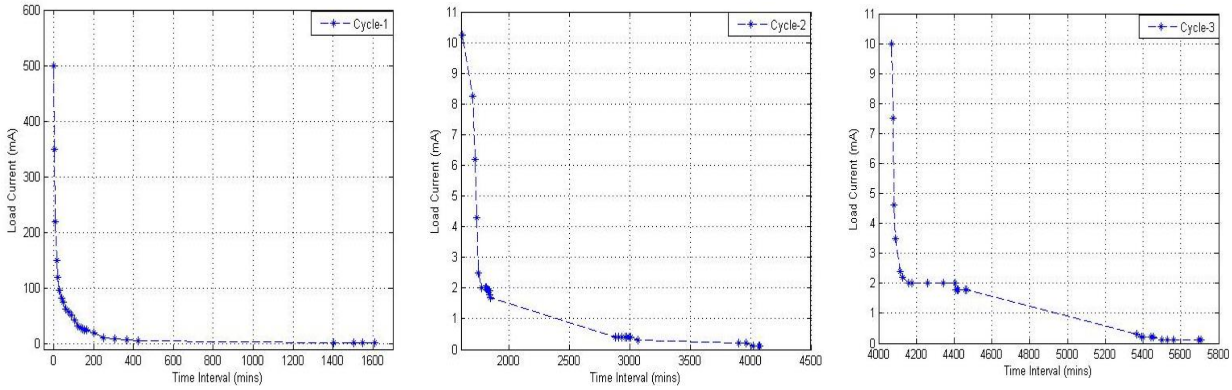
$$I \times t = 5A \times 1h = 5Ah$$

In short, the ampere-hour expresses how much current will flow for how long times. If we draw a current vs time graph, the value of the ampere-hour will be the area under the curve.

Usually a cell's Ah rating applies only to a certain range of load currents. For a given cell, the Ah rating when supplying a high current is not as great as that at a low current level. One reason for this is that polarization occurs more rapidly when the load current is high [8].

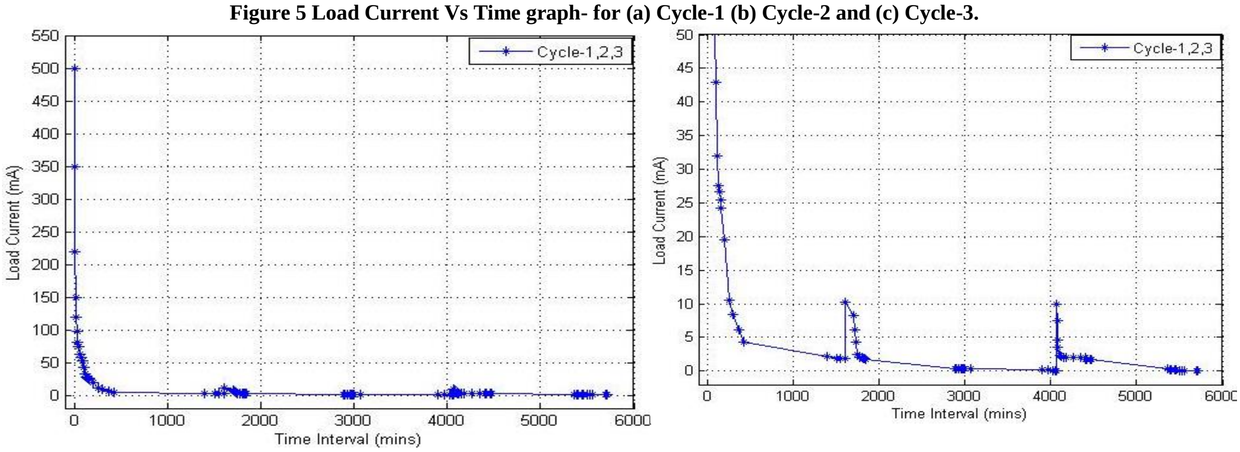
A. *Experimental Data*

We got 128.77g solid malt from 1155 g BPL sap where 5 g $CuSO_4.5H_2O$ and 150 g water were presented. So, the percentage of solid malt is 11.15% and water is 7.7% and liquid sap is 80.8% approximately which was 933.24g. The amount of 1155g sap was 920ml approximately when we put it in to a beaker. So, the amount of liquid BPL was (920ml×80.8%) = 723.36ml. So, we can write, in our study, 933.24g of BPL made 723.36ml sap. That means, at that time 1gm BPL can produce 0.7751ml sap. In our study, we used 614.12ml sap, i.e. 476g BPL.
The variation of Load Current and pH with time are depicted below:



(a) **(b)** **(c)**

Figure 5 Load Current Vs Time graph- for (a) Cycle-1 (b) Cycle-2 and (c) Cycle-3.



(a) **(b)**

Figure 6 (a) Load Current Vs Time graph for all three cycles and (b) Load Current Vs Time graph for all three cycles, zooming from 50mA.

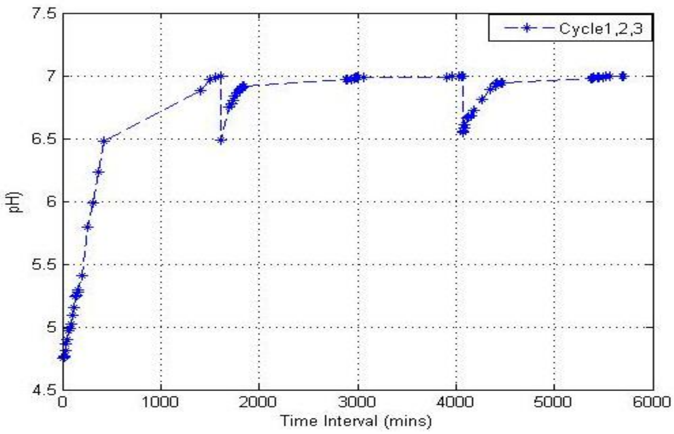


Figure 7 pH (at the upper part of the container) Vs Time graph for all three cycles.

B. Calculation

The area under the curve in Figure 6(a), is the milli-ampere-minutes rating of the cell. The area under the curve can be found by using "MATLAB R2013a" and the area is 23773 square unit.

Therefore, the Ah rating of this cell = 23773 milli-ampere-minute = $\frac{23773}{60\times1000}$ Ah = 0.396 Ah

In our study, the amount of sap was 720 ml where the percentage of leaf was 85.304%. The used BPL sap, 720ml × 85.304% = 614.12 ml. Thus, 614.12 ml sap gives 0.396 Ah and 1L will provide 0.6448 Ah.

V. Amount of Energy in BPL

A. Energy Density

The energy density, Wh/L or Watt-hour/Litre is the energy that can be extracted per unit volume of a cell [9], [20].

This value is dependent upon the density of the components and the design by which the various materials are interfaced together. So, the total energy, $ED_t = \int W.\,dt$

And, Energy Density, ED = $\frac{ED_t}{\text{Total amount of sap in liter}}$

B. Specific Energy Density

The specific energy density, Wh/Kg, is the energy that can be derived per unit mass of the cell (or sometimes per unit mass of the active electrode material) [20]. It is the product of the specific capacity and the operating voltage in one full discharge cycle. Both the current and the voltage may vary within a discharge cycle and, therefore, the specific energy, E, derived is calculated by integrating the product of the current and the voltage over time, $E = \int V \cdot I\, dt$

The maximum and minimum voltage thresholds depend on the discharge time and also depend on the active material's accessibility and/or, for a rechargeable battery, the escaping of an irreversible state. The maximum voltage threshold may be related to an irreversible drop of voltage in the first cycle, after which that part of the cycle is not available. The minimum threshold voltage may be determined by a lower limit below which the voltage is deemed to be too low for practical use or sets the limit for some irreversible losses, such that the system can only inadequately provide energy and power [10], [20].

An active component may be less available due to side reactions, such as: (i) Zinc reacting with the electrolyte in alkaline or silver oxide–zinc batteries, (ii) dendrite formation in rechargeable batteries, (iii) formation of passivation layers on the active components. Since batteries are used mainly as energy storage devices, the amount of energy (Wh) per unit mass (Kg) is the most important property quoted for a battery. It must be noted that the quoted values only apply for the typical rates at which a particular type of battery is discharged [10], [20].

C. Power Density

The power density is the power that can be derived per unit mass of the cell (W/Kg) [11]. At higher drains, signifying higher currents relating to higher power densities, the specific energy tends to fall off rapidly, hence, decreasing the capacity. In order to derive the maximum amount of energy, the current or the power drain must be at the lowest practical level.

D. Experimental Data

Now, from the following graph we can get the value of total output power.

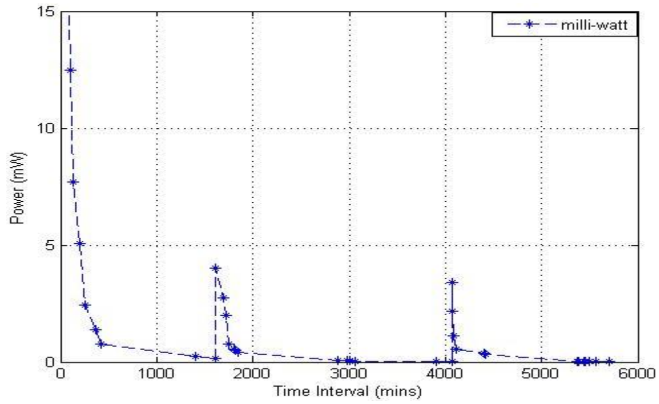


Figure 8 Power Vs Time graph.

Like section IV-B the area under the curve in Figure 8, is the milli-watt-minutes rating of the cell. Again, the area under the curve can be found by using "MATLAB R2013a" and the area is 7726.8 square unit.

$$\text{So, the watt-hour of this cell} = \frac{7726.8}{60\times1000}\ \text{Wh} = 0.12878\ \text{Wh}$$

$$\text{In this case, the Energy Density}= \frac{0.12878\ \text{Wh}}{0.61412\text{L}} = 0.2097\ \text{Wh/L}= 209.7\ \text{mWh/L}$$

$$\text{The Specific Energy Density} = \frac{0.12878\ \text{Wh}}{0.476\text{Kg}} = 0.2706\ \text{Wh/Kg} = 270.6\ \text{mWh/Kg}$$

$$\text{And the Power Density} = (0.2706\times3600)\ \text{W/Kg} = 974.16\ \text{W/Kg}$$

VI. Result and Discussions

It is found that, 0.396 is the value of the ampere-hour of this kind of cell and 1 liter of that kind of sap can provide 0.6448 Ah. Actually, it is the value of the measurement of the ability of sap used in this cell to supply how much current for how long time. However, this can't be said as the exact value of Ah under this condition. This value of Ah depends on many factors. But by this method we can get an expectation value of life-time for sap. Again, our study showed the energy density is 209.7 mWh/L, the specific energy density is 270.6 mWh/Kg and the power density is 974.16 W/Kg. The values we found can hardly be said as the exact values of those terms, but the approximate or the marginal value. We used almost 720 mL BPL sap which contains 85.308% of BPL, 14.214% of water and $CuSO_4.5H_2O$ was 0.4739% approximately. Adding $CuSO_4.5H_2O$ has showed a great impact on current flow in all cases, so adding some more can increase the Ah rating and the other parameters of BPL cell. Moreover, much electrolyte means much supply of currents for longer periods. Those values also depend on how superfine almost all the BPL sap is. If we can use the more superfine BPL sap as electrolyte, the values of those findings will increase [16] [17].

VII. Conclusion

By analyzing the experimental data, it can be inferred that after filtration using filter the BPL sap demonstrates better performance than without filtration of BPL juice. This filtration depends on how superfine the paste of the leaf is. Because bigger piece of leaf or particle size is not suitable to use as electrolyte as it will not release the acids in solution easily. So, if we can make superfine paste of leaf at optimum level, the maximum ampere-hour can be possible to achieve. Another finding of this study is by shaking and whipping the sap we can increase its performance. This happened because of the redistribution of reactant ions which helps to come in contact with the electrode surface to exchange easily. However, the removal of polarization might be another reason behind this. That's why though the pH meter showed the value 7, the current was still passing. That might be due to the pH meter was dipped into the upper part of the electrolyte solution and after certain period of time the ions in the upper zone reduced to zero, i.e. the concentration of the ions was reduced at the upper part due to the downward movement of the heavy ions containing solid BPL sap because of gravity or higher density, and hence the concentration of ions at the lower parts of the container is increased due to the sedimentation of BPL paste. So, when we did shake and stir the electrolyte mixture, the electrolytic ions were redistributed. Therefore, during the second and third cycle we still found a lower value of pH than 7. Finally, we can say that any flow inside the electrolytes can redistribute ions uniformly, and enhance the performance and life-time of the BPL cell. Using this information, we can design a continuous flow cell instead of static design in order to build a Nano-leveled power plant for the off-grid people [19].

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