

Plantain Pith Battery Powered Lighting System

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ABSTRACT

Environmental friendly, low cost, and simple low power electrical energy source will improve the life style of the people living in developing countries where grid power is unavailable. In this respect, biodegradable plantain pith battery powered lighting system was developed. The galvanic cell was fabricated by sandwiching tissues made out of plantain pith slices between parallel Zn and Cu electrodes. The performance of the plantain pith galvanic cell was improved by optimizing the parameters pith type, treatment type and duration, filling method, cell separation and cell area. The results revealed that chopped after boiling (CAB) method is the best treatment method and Suwadel and Ash (Alu) plantain piths are the best electrolytic materials for the Zn/Cu galvanic cells. CAB Ash plantain pith battery pack was fabricated using 60 units of Zn/Cu plantain pith galvanic cells, considering the abundance of the Ash plantain pith. Open circuit voltage of the battery pack is 3.86 V. A 3 W LED lighting system, which was powered by this battery pack, consumed about 33.8 mW and provided a constant illumination of about 3500 Lux. It was observed that this lighting system can be used for more than 600 hours with almost constant illumination.

Keywords: Zn/Cu galvanic cell; Plantain pith; LED lighting system; biodegradable electrolytes

1. INTRODUCTION

Many batteries available in the market are made by using one or more electrochemical cells which include considerable amount of heavy metals such as mercury, lead, cadmium and nickel. When these batteries are discarded improperly after their use, our environment gets polluted by increasing its heavy metal concentration. These heavy metals are very much harmful to the environment and also they are bad for the health of animals including humans, mostly causing lung, eye and skin diseases. These batteries are very expensive to be used for long term lighting purposes. Recently considerable amount of research work has been performed to produce a battery cell by using more efficient inorganic reactions based technology on one hand and the development of advanced organic galvanic batteries on the other hand. Davalos *et al.*, [1] reported the use of Zn/Cu electrolysis in animal tissues as a means for generation of internal electricity for powering both micro robots and/or implanted medical devices. This study revealed a new fundamental and measurable tissue specific property called the galvanic apparent internal impedance (GAI) of the galvanic cells. Using the tools and principles of modern battery research reported by Kiehne [2], Golberg *et al.*, [3] studied the Zn/Cu potato galvanic cell in detail and reported the basic response patterns of the Zn/Cu potato galvanic cell, the discharge properties, GAI, AC impedance, battery capacity, and energy production costs.

Daniel *et al.*, [4] reported the Zn/Cu lemon galvanic cells for possible low power applications. Potato and lemon show promising results for possible power applications, however, potato and lemon are staple foods in many countries and also it is not cheap for power generation as well. Bethke and Jansky [5] reported that mineral levels in tubers increases with boiling. Thus the electrical power of galvanic cells can be enhanced by boiling electrolytes. Jayashantha *et al.*, [6] reported that freely available plantain pith is an environment friendly electrolytic material for Zn/Cu galvanic cells. The performance of the cell was investigated by varying the separation between the electrodes and also by performing various treatments to the electrolytic material such as boiling and chopping after boiling. Their study revealed that best battery performance was obtained for chopped plantain pith after boiling and it was possible to light up a LED for more than 500 hours provided the electrolyte was prevented from drying. Since plantain pith is freely available in all the tropical countries, Zn/Cu plantain pith galvanic cell is a cheapest one compare to the Zn/Cu-potato and Zn/Cu lemon galvanic cells. Present investigation is to further improve the performances of the Zn/Cu plantain pith galvanic cell by optimizing the parameters of the cell and to produce a lighting system by using these cells to be used for households where grid power is unavailable.

2. EXPERIMENTAL

The galvanic cell was fabricated by sandwiching plantain pith between parallel Zn and Cu plates of area $5 \times 9 \text{ cm}^2$. Initially separation of the two plates was fixed to 2 cm as shown in the Fig. 1.

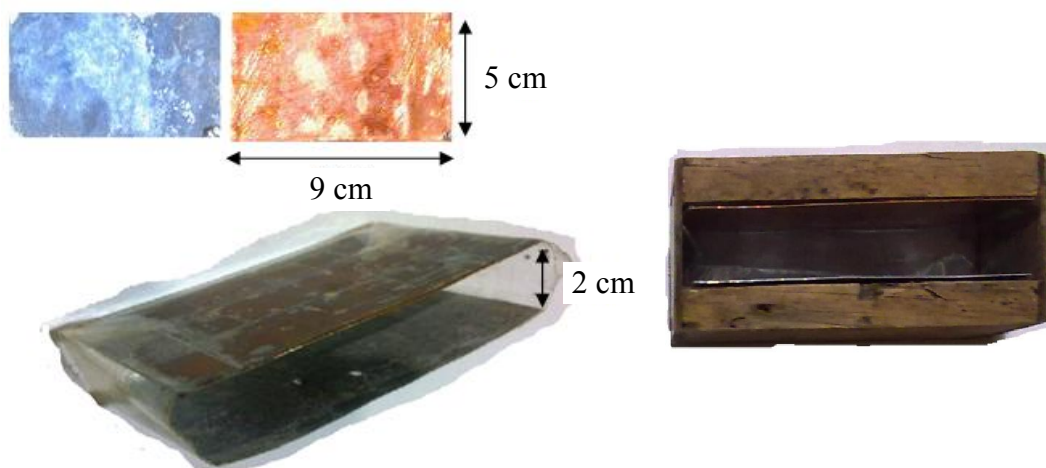


Fig. 1: Dimensions of the cell and cell fixed in a wood container

Entire air exposed surface of the electrolytic medium was covered with polythene to reduce drying and oxidation of the electrolytic medium and fixed in a wooden container having the same dimensions of the cell to avoid deformations. Electrical properties of the cells were characterized by discharging through 300Ω resistor. Discharging voltage and current values with time were measured by using fully automated system as shown in the Fig. 2.

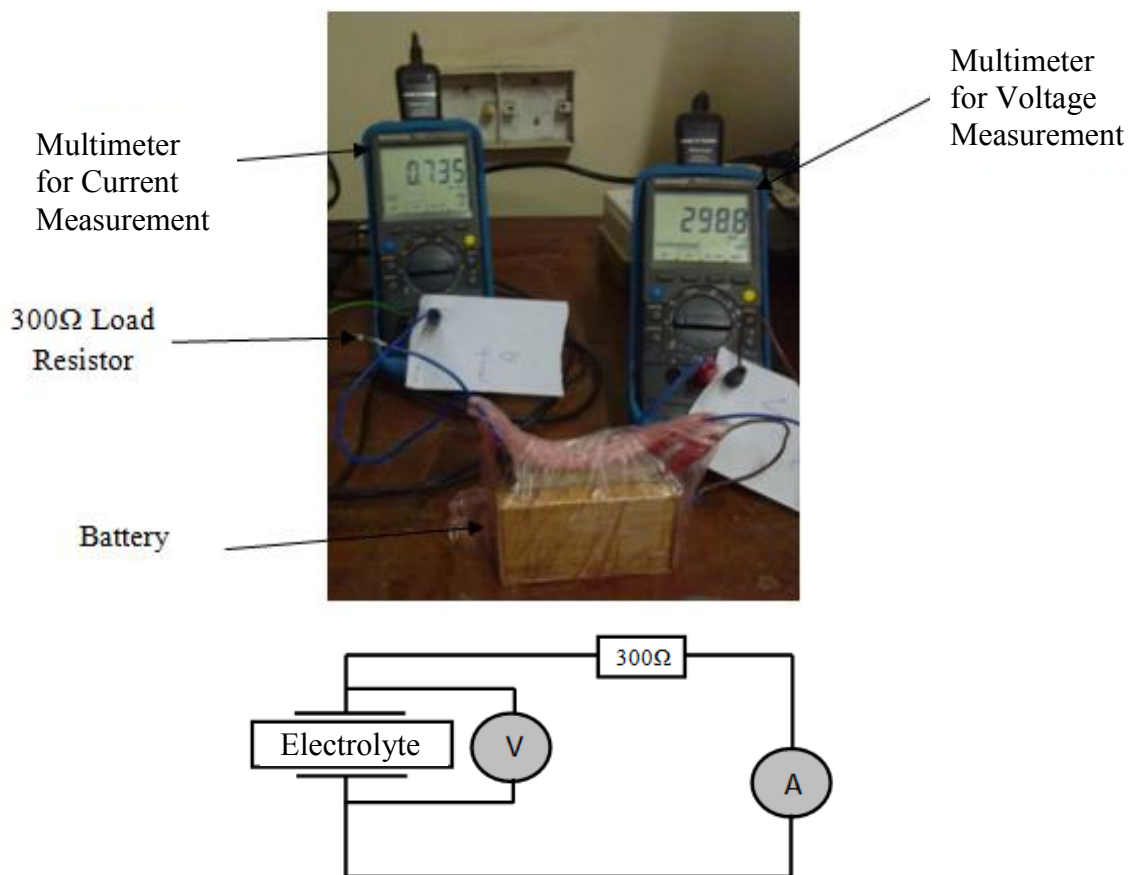


Fig. 2: Experimental set up used for discharging voltage and current measurements

Performance of the cell was optimized by using different types of plantain piths (Ambul Plantain, Suwadel Plantain, Anamalu Plantain, Ash Plantain, Seeni Plantain), different states of the electrolyte (plantain piths were boiled for various durations 5, 10, 15, 20, 30 and 35 min and also chopped them), different separations between two electrodes (1.0, 1.5, 2.0, 2.5 cm) and different sizes of the electrodes ($5 \times 9 \text{ cm}^2$ and $11 \times 11 \text{ cm}^2$). All plantain types were selected from the same place and treated similarly.

Mineral composition of the plantain piths was investigated by using liquid juices obtained from fresh plantain piths. Major metals present in the plantain pith were determined by using the flame atomic absorption spectrometry (GBC 932 plus, compact Atomic Absorption Spectrometer). Other chemical concentrations were measured by the colorimetric method using the Colorimeter (PHOTOCHEM, SR.NO:05290, Photoelectric instrument LTD, New-Delhi, India) and titration method.

A 3 W LED light system was designed using three 1W LEDs. Plantain pith battery pack was prepared by using the 60 cells of Cu and Zn electrodes of area $5 \times 9 \text{ cm}^2$ with a separation of 1.5 cm between the electrodes. 60 cells were connected, 10 in series and 6 of them are in parallel as shown in Fig. 3.



Fig. 3: Plantain pith battery powered 3 W lighting system

In order to find the galvanic internal resistivity (GAIR) of the plantain pith battery pack, it was discharged across a variable external resistor and the discharging currents were recorded with different external resistor values. The stability and life time of the plantain pith battery pack was tested by measuring the emitted light intensity from the 3 W LED lighting system continuously till the end of the life time of the battery pack. Light intensity was measured by automated light sensing system by using Vernier Lab Pro interface.

3. RESULTS AND DISCUSSION

In order to optimize the performance of the galvanic cell, different treatments were employed to the electrolytic medium [1, 3, 6]. The effects of heating organic tissues during irreversible electroporation were discussed by Davalos *et al.*, [1], and Golberg *et al.*, [3] compared the cells' properties made of untreated potatoes with those of both irreversible electroporated and boiled potato tissues. It was reported that boiled potato tissues enhance the performances of Zn/Cu potato galvanic cells. Jayashantha *et al.*, [6] studied Zn/Cu plantain pith galvanic cells with untreated, boiled and chopped after boiling (CAB) plantain pith and reported that the performance of the cell improved with CAB plantain pith. In the present investigation, different states of the electrolytic medium, chopped after boiling (CAB), juice after boiling (JAB) and wet cotton pith juice after boiling (WCJ) were further tested. Results revealed that best treatment for the plantain pith is CAB.

The purpose of a battery is to store energy and release it at the desired time in a controlled manner. Hence when a current is drawn out from a battery, the variations of both cell current and voltage with time, which is normally called a discharge curve, are important characteristics of a battery. Therefore discharge curves through a 300 Ω resistor for different plantain pith galvanic cells were measured and compared. As stated above, CAB plantain piths were used as the electrolyte in all cells. Electrical performance of the

galvanic cells which were prepared using different types of plantain piths (Ambul Plantain, Suwadel Plantain, Anamalu Plantain, Ash Plantain, Seeni Plantain) as an electrolytic material between parallel Zn and Cu plates of area $5 \times 9 \text{ cm}^2$ having 2 cm separation of the two plates were obtained and they are shown in Table 1. The boiling time was also changed for each pith type and the cell weight of $115 \times 10^{-3} \text{ kg}$ was kept constant in all measurements.

Table 1: Electrical Performances of Galvanic cells having different plantain pith electrolyte

Ambul Plantain							
<i>Boiling Time (Minute)</i>	5	10	15	20	25	30	35
<i>Power(μW)</i>	194.00	146.99	153.60	231.00	98.166		
<i>Stable Current(μA)</i>	767.44	667.41	682.24	836.51	545.41		
<i>Stable Voltage(mV)</i>	287.58	269.07	255.32	208.69	216.32		
<i>Initial Current(μA)</i>	1492.29	969.09	319.56	149.62	637.06		
<i>Initial Voltage(mV)</i>	842.20	642.43	862.59	801.92	732.49		
Suwadel Plantain							
<i>Power(μW)</i>	169.00	262.80	178.45	238.76	309.80	376.40	274.86
<i>Stable Current(μA)</i>	715.57	892.39	735.38	850.60	968.91	068.03	912.64
<i>Stable Voltage(mV)</i>	248.34	336.01	291.51	337.44	375.16	433.43	401.16
<i>Initial Current(μA)</i>	1595.23	659.34	470.18	501.82	625.92	583.78	461.97
<i>Initial Voltage(mV)</i>	475.85	819.11	520.38	563.37	632.28	703.43	823.85
Aanamalu Plantain							
<i>Power(μW)</i>	111.12	128.28	99.410	119.82	34.60		
<i>Stable Current(μA)</i>	580.29	623.48	548.88	602.58	323.82		
<i>Stable Voltage(mV)</i>	253.034	263.28	219.16	247.69	207.45		
<i>Initial Current(μA)</i>	1490.57	152.46	298.52	332.71	558.55		
<i>Initial Voltage(mV)</i>	642.73	395.68	654.89	489.91	432.12		
Ash Plantain							
<i>Power(μW)</i>	128.70	148.67	155.37	238.83	162.94		
<i>Stable Current(μA)</i>	624.49	671.22	686.16	850.72	702.69		

<i>Stable Voltage(mV)</i>	247·28	249·59	281·27	319·20	280·69		
<i>Initial Current(μA)</i>	1236·07	349·90	485·68	902·22	647·43		
<i>Initial Voltage(mV)</i>	656·52	612·83	765·63	850·35	848·38		
Seeni Plantain							
<i>Power(μW)</i>	44·51	25·82	44·050	34·65	3·85		
<i>Stable Current(μA)</i>	367·26	279·74	365·34	324·07	108·02		
<i>Stable Voltage(mV)</i>	138·262	167·40	140·57	124·48	41·49		
<i>Initial Current(μA)</i>	1092·83	157·65	483·73	311·71	962·75		
<i>Initial Voltage(mV)</i>	421·24	618·52	586·64	739·55	582·48		

A maximum value of 376.4 μW was obtained as the electrical power of the galvanic cell prepared using CAB Suwadel plantain pith which was boiled for 30 min. The second best value of 238.8 μW was obtained for the CAB Ash plantain pith which was boiled for 20 min. Since Suwadel plantain is not widely available, the Ash plantain pith was selected as the electrolyte for the galvanic cells in our battery pack due to the abundance of the material in Sri Lanka.

Optimization of the CAB Ash plantain pith galvanic cell was further studied by changing the electrodes separation. The electrodes separation (d) was varied as 1·0, 1·5, 2·0 and 2·5 cm by keeping other parameters constant and electrical performance of the galvanic cells are shown in Table 2. At the stable state, nearly the same discharge current was obtained for the 1.0 cm and 2.0 cm separation, but highest performance was observed when the electrode separation is 1.5 cm. Stable state current was increased only slightly when the cell area was increased from 5 × 9 to 11 × 11 cm² and it was not proportional to the increment of cell area. Therefore use of large area galvanic cells are insignificant when compared to performance of the cells having electrode area of 9 × 5 cm².

Table 2: Performance of CAB plantain pith galvanic cell with different electrode separations

d (cm)	1·0	1·5	2·0	2·5
Power(μW)	261·85	330·81	254·47	147·21
Initial Current (μA)	1854·03	1234·63	1364·53	1378·47
Initial Voltage(mV)	934·32	1032·01	986·74	981·38
Stable Current(μA)	890·77	1001·23	878·13	667·91
Stable Voltage(mV)	601·55	612·58	578·17	574·85

In order to explain the reactions taking place inside the Zn/Cu plantain pith cell, the mineral composition of plantain pith was determined by colorimetric method, flame

atomic absorption spectrometry and titration method and the results obtained for best pith types (Suwadel and Ash Plantain piths) are listed in Table 3. The highest anions concentration is dominated by PO_4^{3-} in plantain pith. Thus the main contributor of hydrogen ions to the solution is mild phosphoric acid (H_3PO_4) and the net electrical potential of the cell is governed by the following reaction.

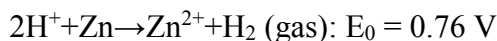


Table 3: Mineral composition of plantain pith

Pith Type	Concentration (ppm)							
	Zn	Pb	Cu	Ni	Cr	PO_4^{3-}	NO_3^-	Cl^-
Suwadel	13.86	N.D	0.073	N.D	N.D	15.87	0.29	2.41
Ash	13.03	0.279	0.405	N.D	N.D	14.30	0.24	2.09

In order to prepare plantain pith battery powered 3 W LED light system using three 1W LEDs, plantain pith battery pack was prepared by using the 60 cells having the size of $5 \times 9 \text{ cm}^2$. Separation between two electrodes were kept at 1.5 cm. As stated above, 60 cells were connected 10 in series and 6 of them were in parallel. Open circuit voltage of the battery pack is 3.86 V. The battery pack supplied a continuous voltage of 2.82 V and a current of 12 mA under constant illumination of the 3 W LED lighting system.

In order to find the galvanic internal resistivity (GAIR) of the plantain pith battery pack, it was discharged across a variable external resistor and the discharging currents were recorded with different external resistor values. The internal resistance of the final pith battery was obtain by using following equations.

$$\frac{1}{I} = \frac{R_{ext}}{V_{OC}} + \frac{R_{int}}{V_{OC}} \dots\dots\dots (1)$$

Where R_{ext} , R_{int} , V_{OC} and I are external resistance, internal resistance, open circuit voltage and current respectively. Graph of $1/I$ vs. R_{ext} is shown in Fig. 4. Internal resistance was determined according to the above equation and it is 140 Ω .

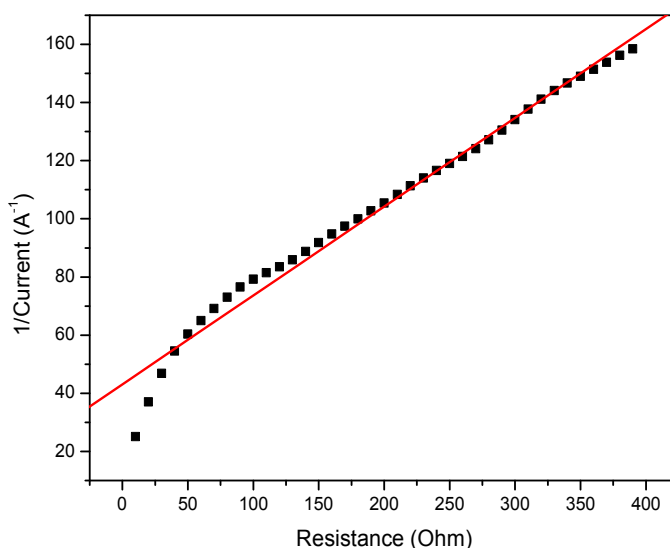


Fig. 4: $(\text{Current})^{-1}$ vs. External resistance of the CAB Ash plantain pith battery pack

The stability and life time of the plantain pith battery pack was tested by measuring emitted light intensity from the 3 W LED lighting system continuously till the end of the life time of the battery pack. Light intensity was measured by automated light sensing system (Light sensor LS-BTA) by using Vernier Lab Pro interface. Fig. 5 shows the emitted light intensity variation of the 3 W light system with time. Emitted light intensity was very high initially and it quickly drops to the stable state of 3500 Lux as shown in the inset of the Fig. 5. This high light intensity is due to the sudden discharge through the load of the some trapped electron in the terminals. Zn/Cu CAB plantain pith battery pack was dead after 975 hours but it produced constant intensity till 600 hours by supplying constant voltage of 2.82 Vand current of 12 mA. Possibility of recharging AA battery from the Zn/Cu CAB plantain pith battery pack was also studied and AA rechargeable battery can be fully charged within about 16 hours.

In operation, only the zinc metal is decayed and it was observed that the battery pack consumed only about 0.27 g of zinc per hour. At 1 USD kg^{-1} for Zn [7] and excluding the costs for Copper electrode (not consumed), the running cost of the battery pack is merely SLR 0.035 per hour (At 1 USD = 132 SLR, 20/10/2014). The energy cost estimated by Golberg *et al.*, [3] for boiled potato Zn/Cu battery was 9 USD/kW h without the cost of potato whereas our estimation of the energy cost for CAB plantain pith Zn/Cu battery is about 7.82 USD/kW h. Potato is a staple food in many countries and it costs about 132 SLR/kg (20/10/2014). Since plantain pith is a freely available biodegradable waste material, we believe the use of CAB plantain pith Zn/Cu batteries for lighting purposes in rural areas where grid power is not available, is a good option for many economically disadvantaged households.

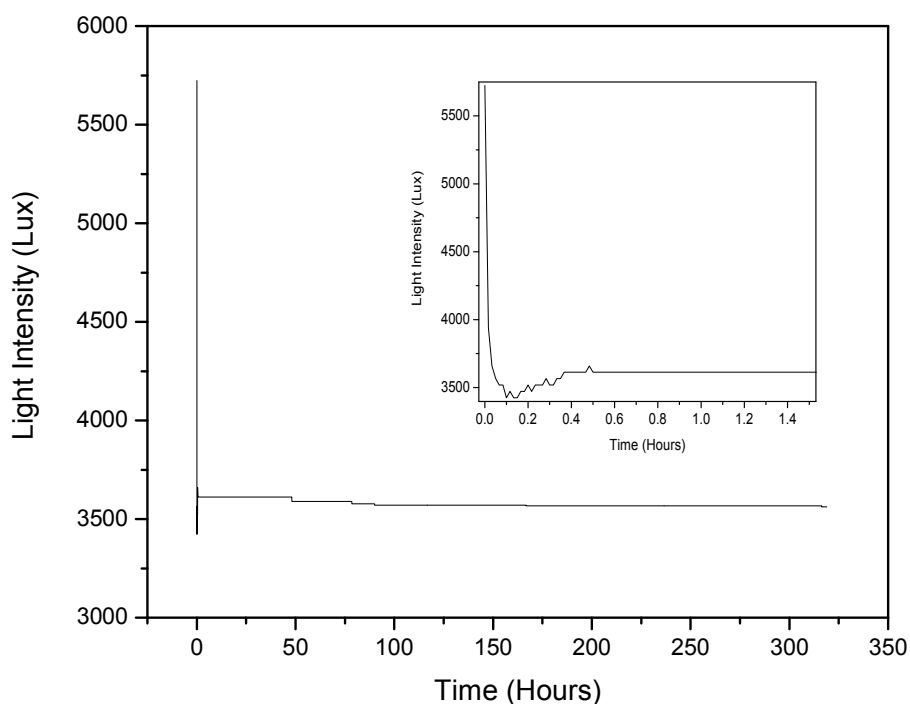


Fig. 5: Light intensity variation with time of the CAB ash plantain pith battery pack

4. CONCLUSION

Considering the cost and abundance of the material, biodegradable plantain pith is a very good candidate for the electrolytic medium for galvanic cells. Electrical performance of the cell can be enhanced by using chopped plantain pith after boiling and maintaining the electrode separation at 1.5 cm. Ash plantain pith was found to be the most suitable candidate for the electrolyte of low cost environment friendly galvanic cells. The best boiling time for Ash plantain pith is 20 min. Results revealed that it is possible to light up 3W LEDs for more than 600 hours having constant illumination of 3500 Lux continuously using Zn/Cu CAB Ash plantain pith battery pack (60 cells connecting 10 in series and 6 of them in parallel having the size of $5 \times 9 \text{ cm}^2$).

REFERENCE

1. Davalos, R.D., Rubinsky, B. and Mir, L.M., *Theoretical analysis of the thermal effects during in vivo tissue electroporation*, Bio electrochemistry 61, (2003) 99
2. Kiehne, H.A., *Battery Technology Handbook, 2nd Ed.*, (Dekker, New York, 2003)
3. Golberg, A., Rabinowitch, H.D. and Rubinsky, B., *Zn/Cu-vegetative batteries, bioelectrical characterizations, and primary cost analyses*, Journal of Renewable and Sustainable Energy 2, (2010) 033103
4. Swartling, D.J. and Morgan, C., *Lemon Cells Revisited-The Lemon-Powered Calculator*, Journal of Chemical Education, 75, (1998) 181
5. Bethke, P.C. and Jansky, S.H., *The effects of boiling and leaching on the content of potassium and other minerals in potatoes*, Journal of Food Sci., 73(5), H80-5, (2008)
6. Jayashantha, N., Jayasuriya, K.D. and Wijesundara, R.P., *Biodegradable Plantain Pith for Galvanic Cells*, Proc. 28th Tech. Sess. Inst. Phys., Sri Lanka, (2012) 92
7. http://www.alibaba.com/product-detail/Pure-zinc-plate-zinc-sheet-supply_727692713.htm