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TECHNICAL PAPER

Bioelectricity: a new approach to provide the electrical power from vegetative and fruits at off-grid region

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Abstract

In this research, we studied the performance of different vegetative and fruits electrochemical cells namely PKL, Aloe Vera, Tomato and Lemon juice electrochemical cells with load condition for 2:1 Zn/Cu based electrodes. It was also studied the variation of Load Voltage (V_L), Load Current (I_L), and Load Power (P_L), with the variation of time for PKL, Aloe Vera, Tomato and Lemon juice electrochemical Cells. Among those cells the PKL electrochemical Cell was more efficient than the other three types of Cells regarding the load Current (I_L), Load Voltage (V_L), and Load Power (P_L). However, we investigated the performance of different types of Cells without load condition for 1:1 Zn/Cu based electrodes. Moreover, the variation of open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power (P_{max}) with the variation of time for those cells were explored. The discharge characteristic of the PKL electrochemical cell was more effective than the other three electrochemical Cells as the Open circuit voltage (V_{oc}), Short circuit current (I_{sc}) and Maximum Power (P_{max}) are more stable and steady in comparison with others. Heat treatment temperature was a new approach by which we can enhance the performance of these electrochemical cells. Most of the results have been tabulated and graphically discussed.

1 Introduction

The traditional energy sources are very limited in the world which would be exhausted in the near future what instigates the researchers to search the alternative sources of energy (Hossain and Badr 2007). As a continuation of such investigation we have chosen completely a new type of sources in the plant kingdom which will provide energy to the people in the off grid regions who are not getting electricity at all (Khan and Bosu 2010). To keep it in mind PKL has been used to generate electricity for practical utilization at the off grid areas in the world (Khan and Arafat 2010). This paper deals with comparative analysis on Pathor kuchi leaf (PKL), aloe vera leaf (AVL), tomato and lemon juice based Zn/Cu electrochemical cell and aim to find out which leaf or fruit of them would generate enough electricity and so as to identify the leaf or fruit which would illumine the bulb for the longest period (Gupta et al. 2011). This would be feasible to construct a mini power plant by any people using this technique with an affordable price in the rural areas (Al-Baghdadi and Al-Janabi 2007). Where the national grid is out of reach and can be a promising issue in the case of rural development by supplying electricity, especially for the school going children by supplying PKL (as better than aloe vera, lemon and tomato) lamp and other people facilitating information access on TV, radio and mobile using PKL cell (Huda et al. 2014, Khan and Hossain 2010). In the present investigations, we have conducted different experiments regarding Physics and Chemistry as well as cost analysis which leads to the findings that help to recognize the best

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electrochemical cells for practical utilization in off-grid region (Halder et al. 2014).

2 Materials and methods

Performance analysis on comparative study among PKL, aloe vera, tomato and lemon juice based electrochemical cell for 2:1 Zinc/Copper based electrodes is an important issue (Hasan and Khan 2016). There are some parameters through which we can measure the performance of PKL, AVL, tomato and lemon juice based electrochemical cell. A brief outlines of key parameters used to characterize a test cells are discussed below (Strik et al. 2008). Also it is shown that how these parameters may vary with the operating condition (Hasan et al. 2016).

2.1 Equipments and apparatus

Ampere-Volt-Ohm Meter (AVOM); model no. CD 800A 4000 counts, Sanwa Digital Multimeter, Sanwa Electric Instrument Co. Ltd., Tokyo, Japan.

Atomic Absorption Spectrophotometer (AAS), Shimadzu, Japan and *UV Visible spectrometer;* UV—1650 PC, Shimadzu, Japan. Analysis of different electro active species viz; the metals Cu (II), Zn (II) in juice was analyzed by using Atomic Absorption Spectrophotometer (AAS) and UV Visible spectrometer.

pH meter; PHS—25, LIDA Instrument, USA.

We have taken the mean value of 3 measurements throughout the experiments and accordingly the data has been tabulated and graphically presented.

2.2 Experimental setup of cell

The inner volume of the cell was 720 cm^3. The electrodes are immersed 120 mm deep in the sap. This depth is kept fixed throughout this experiment. Three copper plates are used as cathode and six zinc plates are used as anode (Ono et al. 2005). The connections among the electrodes are demonstrated in Figs. 1 and 2.

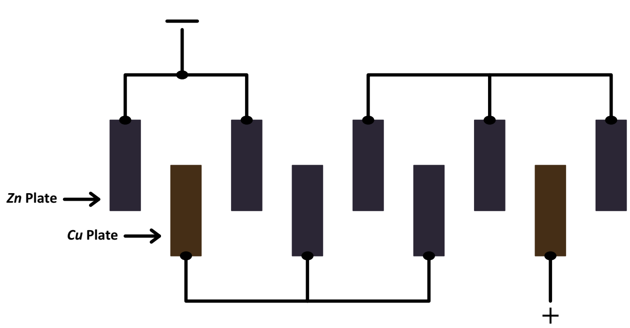

Fig. 1 Connections between anodes and cathodes

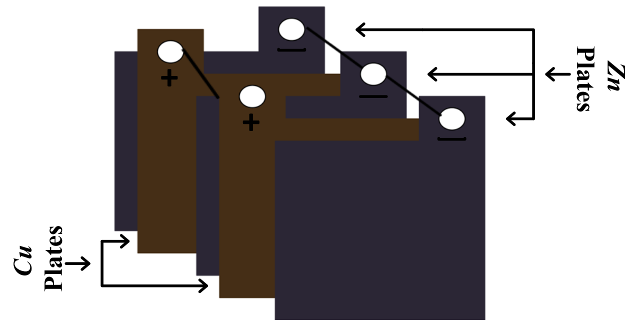

Fig. 2 Set-up of electrodes in a unit cell

In a cell (Fig. 2) there are six small compartments and in each compartment consists of two copper plates as one cathode and three zinc plates as a single anode. In this model (Fig. 3) we have to change the juice manually after certain periods and thus changing juice means recharging battery (Hasan et al. 2017).

An ammeter and a load of 1 Ω were connected with the two terminals of the electrodes in series and a voltmeter was connected across the load as shown in Fig. 4. The space (gap) between two consecutive electrodes was kept 5 mm (Fontana and Greene 1978).

3 Analysis and discussion

Three parameters such as load voltage, current and power are selected to check the performance analysis, which are depicted in Fig. 5, 6 and 7 respectively.

Load voltage in Fig. 5, of PKL remains always higher than the others during the observations. An important nature of load voltage of PKL, Lemon and Tomato shows that the load voltage can be considered as constant in all the three cases, which makes all of the three feasibilities to produce electricity. But for AVL the load voltage decreases rapidly than the others.

The Fig. 6, indicates that the load current is dropping with time. Although the load current is higher for PKL throughout the period, but the rate of decrease is much higher than the other three. For tomato and aloe vera, the current is comparatively small, but the reduction rate is significantly low. A constant nature of power output makes

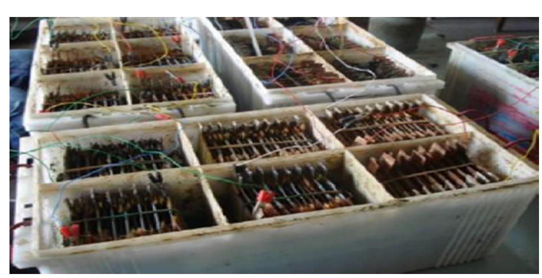

Fig. 3 PKL module

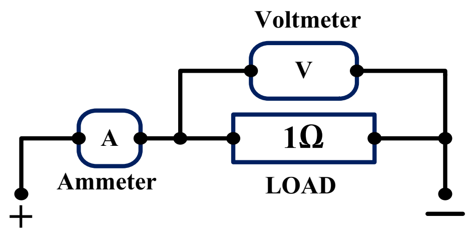

Fig. 4 Ammeter and voltmeter connection in cell with 1 O load

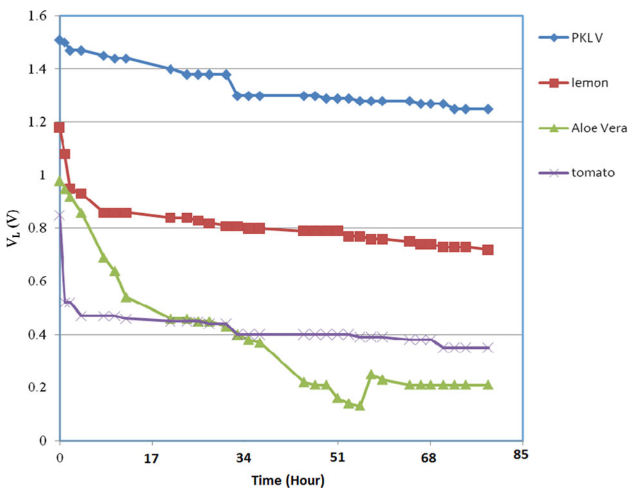

Fig. 5 Load voltage (V) with time (h)

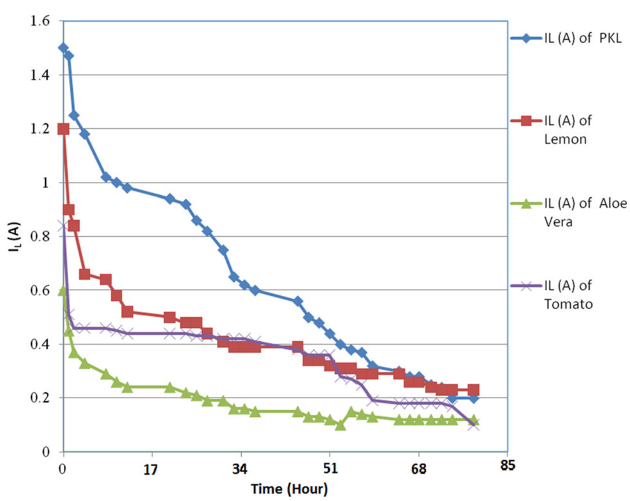

Fig. 6 Load current (A) with time (h)

a battery more efficient. Here in Fig. 7, shows an interesting character between them. The power is much higher for PKL than others despite the higher rate of decline. For the first 1800 min or 30 h (Cindrella et al. 2014), it can supply more than 1 W of electricity continuously.

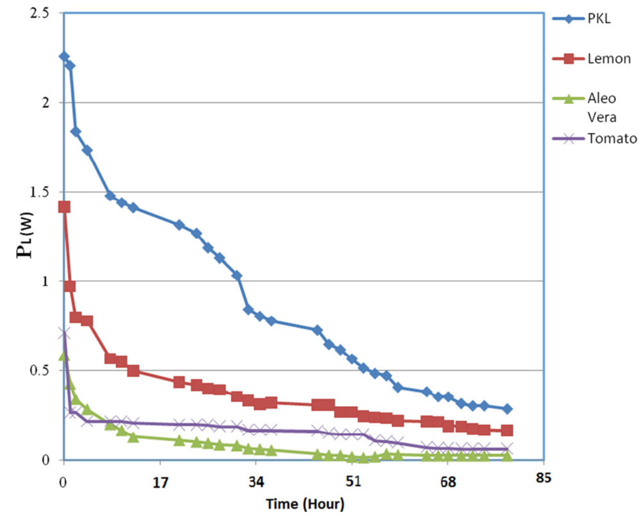

Fig. 7 Load power (W) with time (h)

3.1 Effect of sodium chloride as a secondary salt on different vegetative and fruits electrochemical cells

To enhance the performance of our system we added 100 g NaCl with PKL, aloe vera and lemon juice electrochemical cell. Due to the shortage of tomato juice, we did not conduct performance study on tomato juice electrochemical cell with NaCl (Blum and Shafer 1988).

According to the experimental analysis (Fig. 8), the parameters for aloe vera electrochemical cell (EC) had a decreasing tendency from the starting point compared to other cells. From Fig. 9, it is seen that the maximum load voltage of PKL cell is 2.85 V, lemon cell is 2.75 V and aloe vera cell is 2.68 V. From Fig. 10, it is observed that the maximum load current of PKL cell is 80 mA, lemon cell is 60 mA and aloe vera cell is 58 mA. Figure 11 reveals that the maximum load power of PKL cell is 228 mw, lemon cell is 165 mw and aloe vera cell is 155 mw, However, it is clear that the load power of PKL cell is higher and stable than others (Kuiters and Denneman 1987).

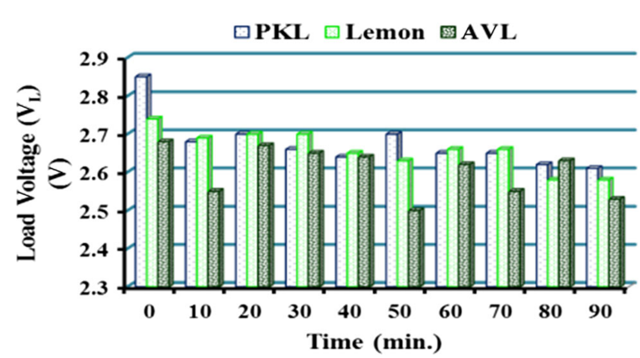

Fig. 8 Voltage (V_L) − time (with NaCl)

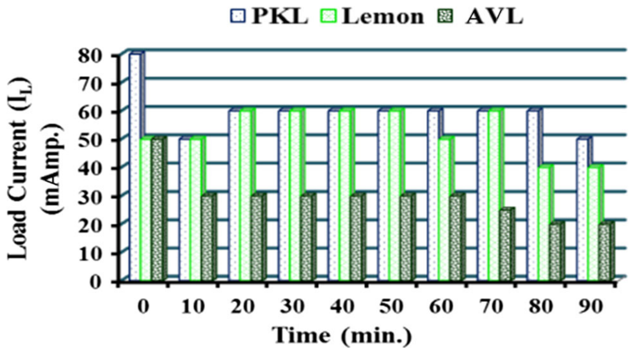

Fig. 9 Current (I_L) − time (with NaCl)

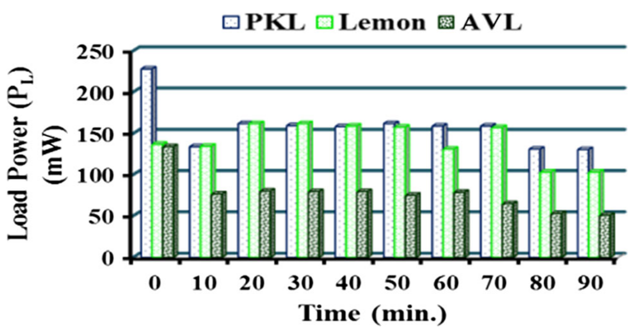

Fig. 10 Load power(P_L) − time(with NaCl)

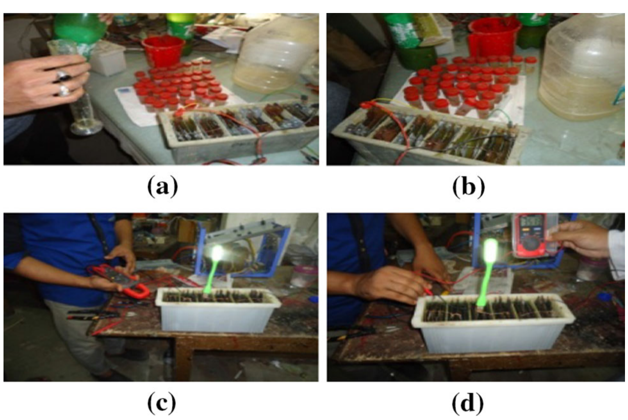

Fig. 11 **a** PKL EC, **b** aloe vera EC, **c** tomato EC, **d** lemon EC

3.2 Performance analysis by comparative study of vegetative and fruits electrochemical cell (EC) for 1:1 Zinc/Copper based electrodes

Electrode strips were cleaned with extra fine steel wool to remove any corrosion on the surface, thus, improve the conductivity. Fresh samples were used in each experiment.

The experiment was conducted with the same concentration for all PKL electrochemical cell (EC). The concentration of the PKL were measured by the following formula:

$$\textit{Concentration of the juice} = \frac{X - Y}{Z} \frac{\mathrm{g}}{\mathrm{ml}}$$

where weight of fresh leaves before blending (g) = X, weight of leaves after filtration (g) = Y, volume of water after filtration (ml) = Z. Experimental arrangement for measuring $\boldsymbol{V_{oc}}$ and $\boldsymbol{I_{sc}}$ of PKL, AVL, lemon and tomato are shown in Fig. 12 and 13, respectively.

The Fig. 14a–c illustrate the variation of open circuit voltage (V_{oc}), Fig. 15a–c indicate the variation of short circuit current (I_{sc}) as well as the Fig. 16a–c show the variation of maximum power (P_{max}) with the variation of time for 1st day, 2nd day and 3rd day. It was also observed that the value of the maximum power of the PKL electrochemical cell was decreased from the beginning of the 1st day (50 mW) to the end of the 3rd day(13 mW) having the decreasing rate of the PKL electro chemical cell as 74%. The value of the maximum power of aloe vera electrochemical cell was decreased from the staring with 32 mW in 1st day to the end of the 3rd day at 8 mW (Kahn et al. 2014). The decreasing rate of the AVL electro chemical cell is 75%. Beginning with 40 mW, the value of the maximum power of lemon electrochemical cell reduced to 9 mw having the decreasing rate of the Lemon electro chemical cell as 78%. The value of the maximum power of Tomato electrochemical cell decreased from the beginning of the 1st day (25 mW) to the end of the 3rd day (4 mW). The decreasing rate of the Tomato electro chemical cell is 84%. The self-discharge rate for different electrochemical cells are shown in Table 1.

By analyzing all the findings and the self-discharge characteristics of different vegetative and fruits electrochemical cells it can be concluded that the performance of PKL cell would be better than the other electrochemical cells.

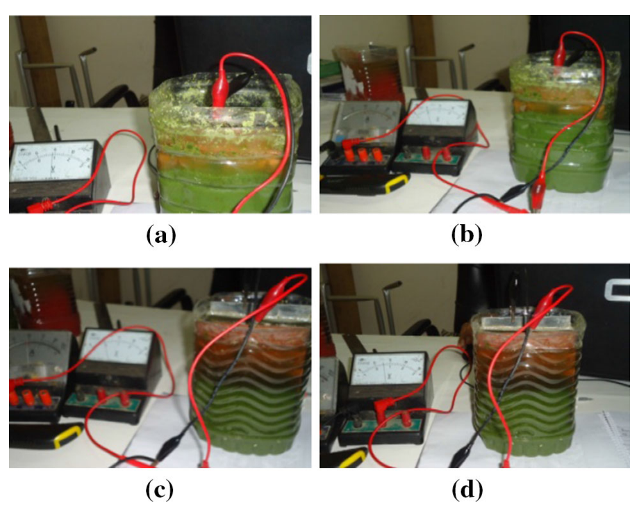

Fig. 12 **a** E.A.for V_{oc} of PKL and **b** E.A.for I_{sc} of PKL. **c** E.A. for V_{oc} of Aloe Vera. **d** E.A.for I_{sc} Aloe Vera

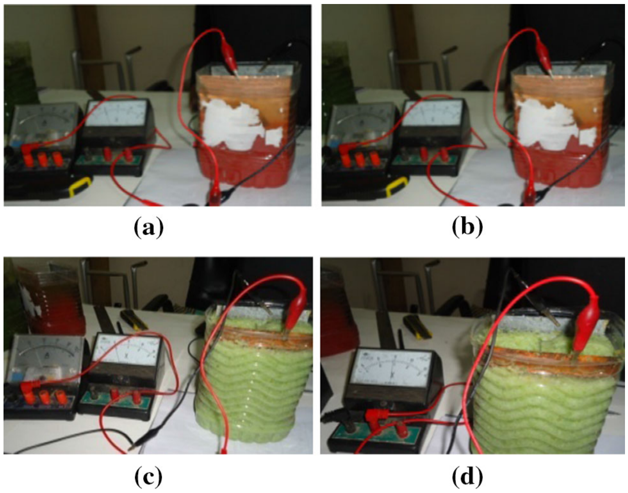

Fig. 13 **a** E.A. for V_{oc} of tomato. **b** E.A. for I_{sc} of tomato. **c** E.A. for V_{oc} of lemon. **d** E.A.for I_{sc} of lemon

3.3 Determination of optimum heat treatment temperature and holding time

The effect of physical disruption treatment of the PKL, aloe vera, lemon (with skin) and Tomato samples by heating at various holding time at various temperatures as well, were presented diagrammatically as shown in Fig. 17.

At each holding time during the heat treatment of the samples at varied temperatures, an increase in V_L was observed at the beginning which eventually dropped at temperature above 50 °C (Halder et al. 2015). It was evident that heat treatment at temperature of 50 °C for holding time of 20 min yields maximum V_L, I_L, P_L of PKL, Aloe Vera, Lemon and Tomato juice electrochemical cells (Fig. 18a, b, c).

Investigations on the performance of PKL, Aloe Vera, Tomato and Lemon (with skin) samples as an alternative source of renewable energy for small electric current generation allowed the following conclusions to be made: (1) An irreversible change in the cellular and tissue structures either through irreversible heating significantly affects the electrical characterization values, with the consequence of increasing the magnitude of the electrical power generation. (2) PKL and aloe vera are found to be the best vegetative battery sample in terms of electrical performance whereas Tomato is found to be the least. (3) Power generated by Zn/Cu fruits and vegetative samples are much cheaper than any conventional portable battery (Khan and Alam 2010). Overall, heat treatment leads to formation of micro-pores in cell membrane, leading to reduction in the internal resistance of the electrochemical cells (Khan and Alam 2010).

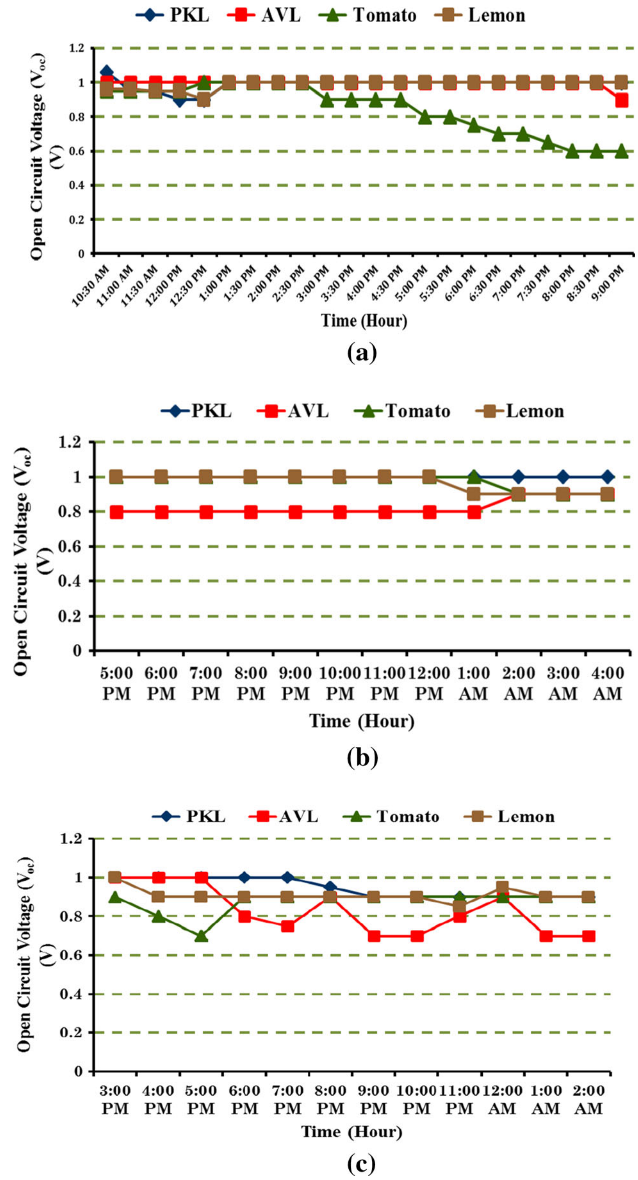

Fig. 14 **a** V_{oc} with Time for 1st day. **b** V_{oc} with time for 2nd day. **c** V_{oc} with time for 3rd day

3.4 Applications

The Fig. 19a indicates the model of 1kw PKL mini power plant for static method and the Fig. 19b shows the model for dynamic method.

The Fig. 19c also indicates the experimental design of 1 kW PKL mini power plant in static method. The Fig. 19d indicates the experimental set-up of 1 kW PKL mini power plant in static method for Practical utilization at the off grid region (Khan et al. 2016a, b). Based on these model (Fig. 19a, b) it was designed (Fig. 19c) and finally it was implemented experimentally (Fig. 19d) in the laboratory.

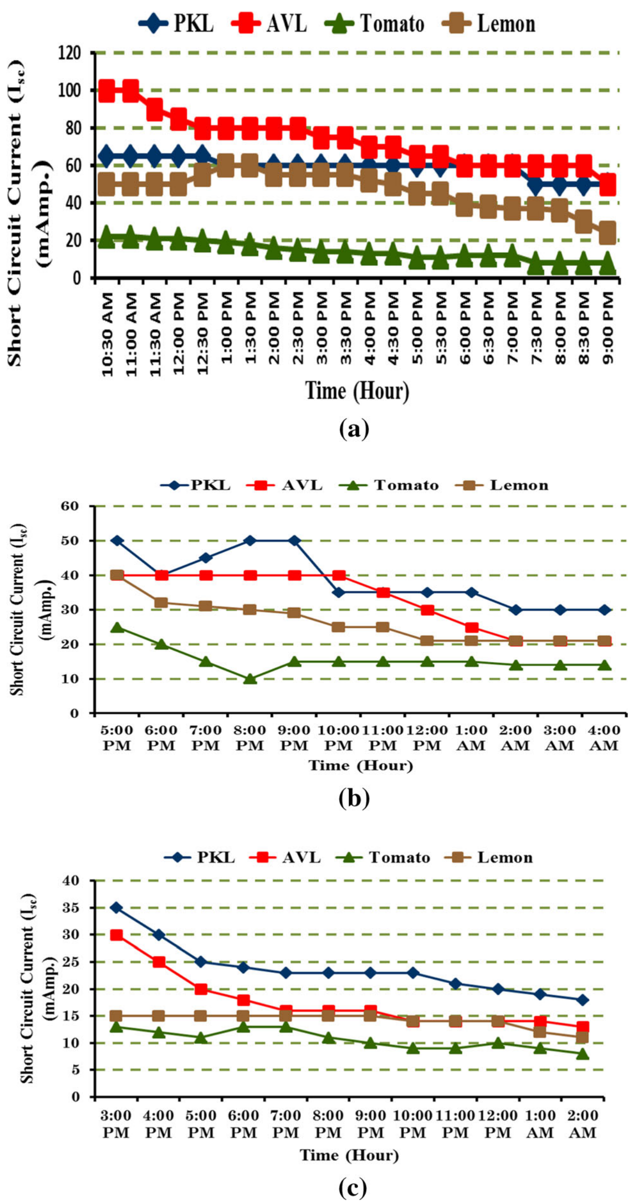

Fig. 15 **a** I_{sc} with time for 1st day. **b** I_{sc} with time for 2nd day. **c** I_{sc} with time for 3rd day

3.5 Cost (1$ ≈ 80 Tk) of the PKL electricity

From 150 kg Zn can get = 140 plates, we need = 120 plates, cost of 50 kg *Zn = 12,500 Tk, cost of 150 kg Zn = 37,500 Tk. Cost of 120 Cu Plates = 22,000 Tk,* 20 kW pure sine wave inverter = 40,000 Tk, Pump device = 70,000 Tk, total glass box = 15,000 Tk, total glass box making charge = 10,000 Tk. *Grand total cost(excluding pump device) of 20 kW AC system = 1,24,500 Tk. Cost of PKL electric system compare to PKL home system:* cost of 20 kW diesel generator system = 13 Lac, cost of 20 kW SPV

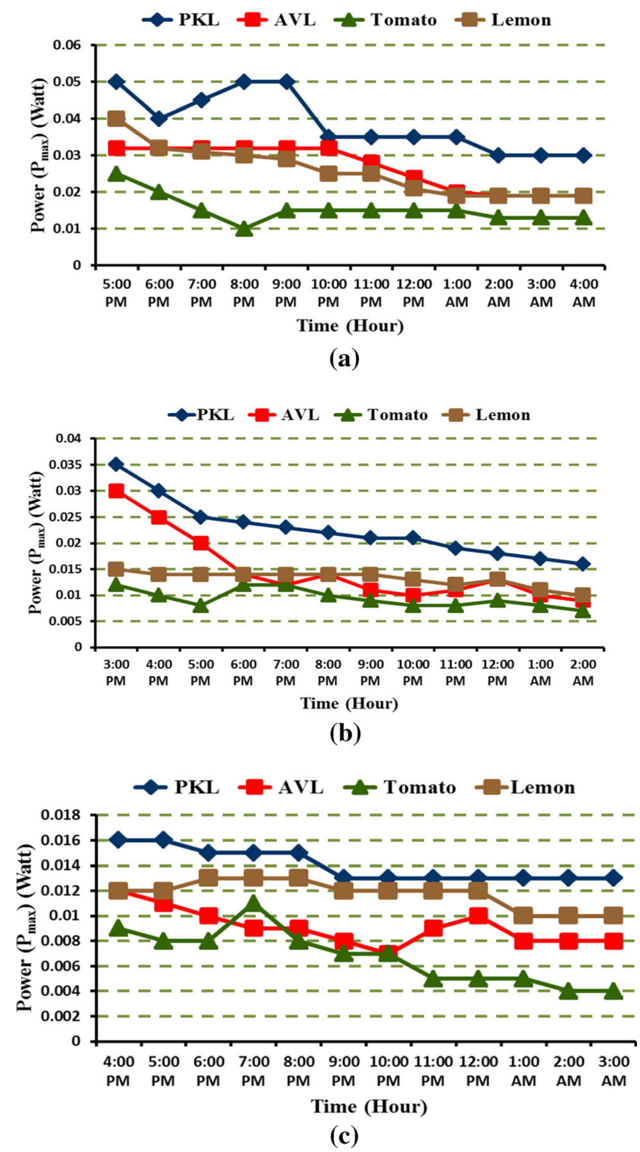

Fig. 16 **a** P_{max} with time for 1st day. **b** P_{max} with Time for 2nd day. **c** P_{max} with time for 3rd day

Table 1 Self-discharge rate for different electrochemical cells

Name of the EC	Discharge rate (%) for 3 days
PKL	74
Aloe vera (AVL)	75
Lemon	78
Tomato	84

system = 20,000 W × 250 Tk = 50 Lac, cost of 20 kW PKL system = 1.25 Lac.

Cost (1$ ≈ 80 Tk.) Comparison of PKL Electricity: (1) gas based electricity/MW = TK 12 Crore = BDT 120 Million (2) Wind energy/MW = TK 20 Crore = BDT

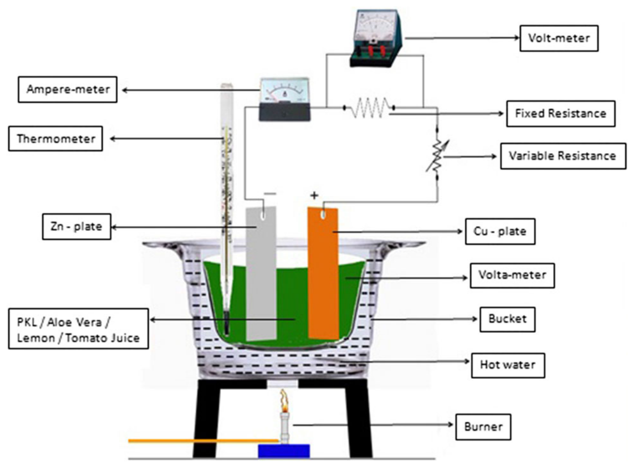

Fig. 17 Arrangement for measuring heat treatment temperature

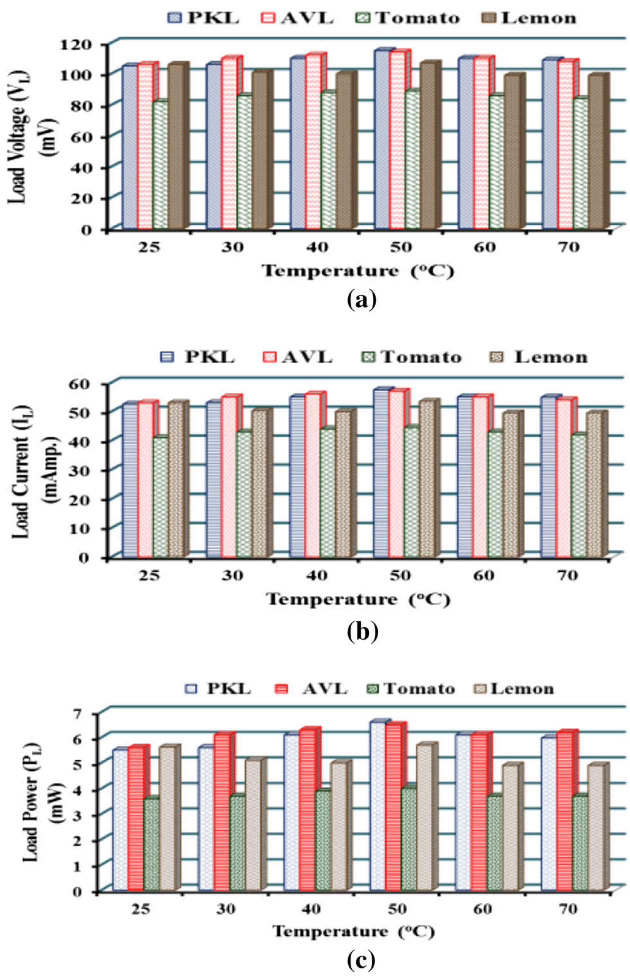

Fig. 18 **a** V_L with temperature (°C). **b** I_L with temperature (°C). **c** P_L with temperature (°C)

200 Million (3) Solar PV (Off grid—AC system) = TK 75 Crore = BDT 750 Million (4) PKL electricity (Off grid—AC system) = TK 1.50 Crore = BDT 15 Million.

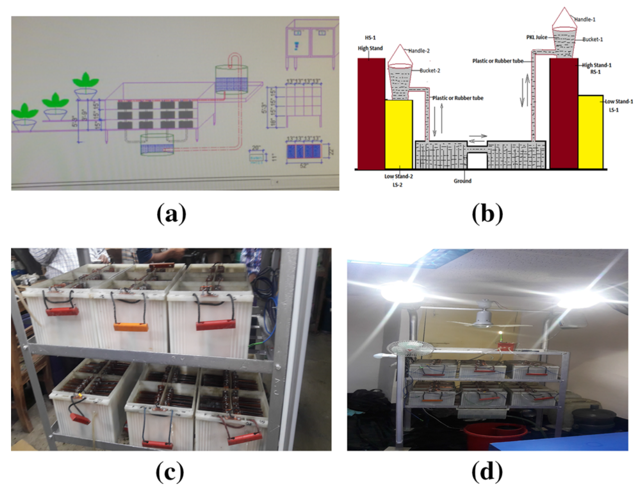

Fig. 19 **a** Diagram of a 1kw PKL power plant. **b** Diagram of a 1 kW PKL power plant in dynamic method. **c** 1 kW vegetative and fruits power plant. **d** Experimental Set-up of 1 kW vegetative and fruits power plant

Fig. 20 Pathor kuchi leaf

Below 500 Watt The cost (1\$ ≈ 80 Tk) of the electricity for off grid system is BDT.300 Tk/Watt, The Cost of the electricity for on grid system is BDT.270 Tk/Watt.

Above 500 Watt The Cost of the electricity for off grid system is BDT.200 Tk/W. The Cost of the electricity for on grid system is BDT. 170 Tk/W.

3.6 Cost comparison between SPV (3 W)(4) = 12 W home system and PKL home system

For SPV system (1) Cost (1\$ ≈ 80 Tk) of 50 W SPV System (Tk 120/W) = Tk 6000 (2) Cost of the Battery = Tk 4000, (3) Cost of the Charge Controller = Tk 1000, (4) Cost of the 3 W LED lamp = 4 (Tk 150) = Tk. 600. Total Cost = Tk 11,600.

For PKL System (1) Cost (1\$ ≈ 80 Tk) of the Insulated Container = Tk 200 (2) Cost of the Plates = Tk 1500 (3) Cost of the Juice = Tk.100, (4) Cost of the 3w LED lamp = 4(Tk 110) = Tk 440, (5) Cover = Tk 100. Total cost = Tk 2300.

Cost (1\$ ≈ 80Tk) Analysis for Single Bike Battery (for 5 years) (1) cost of the Insulated Container = Tk 1000 (2) cost of the electrodes/plates = Tk 2500 (3) cost of the

Juice/Sap = Tk 100 (4) manage mental cost = Tk 400 (5) battery cover = Tk 300 (6) Assembling cost = Tk 100 (7) miscellaneous = Tk 100. Total = Tk 4500.

Specification of the Battery Bike (For 6/7 passengers, Power = 1145 W) total voltage needs = 60 V, no. of required batteries = 10 (6 V each) = 5 (12 V each), power required = 1200 W, required current = 20 A, For Power = 500 W (2/3 Passenger), total voltage needed = 24 V, no. Of required batteries = 4 (6 V each) = 2(12 V each), quantity of Power required = 500 W, Required amount of current = 21 A.

Present Energy Scenario of Bangladesh Electricity generation capacity = 7646 MW, generation going on/capacity = (5000–5300) MW, maximum demand = 6000 MW, At 29.08.2011 maximum generation = 5244 MW, transmission line (230 kV/132 kV) = 8662 km, number of grid station in Bangladesh = 115, distribution line (up 33 kV) = 278,000 km, no. of consumer = 12,500,000, electricity USER = 50%, annual electricity consumed per person = 252 kWh, system loss in Bangladesh = 12.75%, installed solar photovoltaic home system (SHS) = 10 Lacs, at present generated from renewable energy = 55 MW.

PDB'S PURCHASE RATE (1$ ≈ 80 Tk) (Before 20.09.2012): Per Unit of Power (1) oil-based rental: Tk 7–9, (2) gas-based: Tk 4.80, (3) state-owned plants: Tk 2.5–3.5. (The Daily Star, Date: 29.02.2012).

3.7 Cultivation (Fig. 20) and land situation in Bangladesh

Present land situation in Bangladesh—The role of PKL electricity: total land = 55,000 square miles, 1 square mile = 640 acres, total land (TL) in hectors = 35,200,000 acres/2.5 = 14,080,000 ha (1 ha = 2.5 acre), Presently the agricultural land (AL) in Bangladesh = 8,500,000 hectors. Therefore the NAL (non agricultural land) = 5,580,000 hectors., The 2% of NAL = 111,600 hectares = (111,600 ha) (7.5) = 837,000 Bigha (1 hectares = 7.5 Bigha), From 1 Bigha PKL we can get = 100 KW electricity, From 837,000 Bigha PKL we can get = 83,700,000 KW electricity = 83,700 MW electricity. [N.B: The AL is needed to cultivate foods and crops, the NAL is needed for housing, roads and other multipurpose uses (Khan et al. 2016a, b). So that the NAL of coastal areas, hilly areas and both sides of the road can be used for cultivation of PKL to generate electricity in Bangladesh, which would be approximately 2% of NAL].

The cultivation of *Bryophyllum* is very much easy. This plant grows whether its leaf is kept on the ground and hence can be cultivated in a vested land, roof top of house, courtyard and tubs whatsoever. Its leaves can be used for producing electricity within a month after cultivation of the plants.

3.8 Morphological change of the Cu and Zn plates

There is a morphological change in the Cu and Zn Plate between before and after electricity generation depicted in Fig. 21a and b. The performance of the electricity generation is different before and after electricity generation system. The current and voltage are decreased with time duration. The Zn Plate became blackish and the current and voltage decreased slowly. The product ions [Zn^{2+}] are increased and reactant ions [Cu^{2+}] and [H^+] are decreased. It is very important to determine the real reason of decreasing current and voltages of the vegetative electrochemical cell. The blackish color on the Zn plate during electricity production is the threat of this project.

3.9 Identification of the gas evolved from PKL cell

PKL contains many organic acids (Khan 2009).The pH of 10% juice solution is of around 4.2. Because of acidity the reduction process of H^+ will be continued. Here the reducing agent is Zn metal (anode). By the redox process H^+ ion converts into H_2 gas and evolved from the solution phase (Khan and Alam 2010). The considered overall process is as follow

$$Zn \rightarrow Zn^{2+} + 2e^- [\text{ At anode}]$$
$$H^+ + e^- \rightarrow H\ [\text{At cathode}]$$
$$H + H \rightarrow H_2 \uparrow [\text{Evolved from cathode}]$$

Here, the evolved gas should be identified so as to ascertain the redox process which is responsible for emf of the cell. There is, however, a simple test that can be used to detect hydrogen (Khan et al. 2016a, b).

3.10 Principle

Hydrogen burns cleanly. Its blue flame is barely visible, and it does not pollute the atmosphere with smoke. If the gas inside is hydrogen, the flame will be quickly sucked

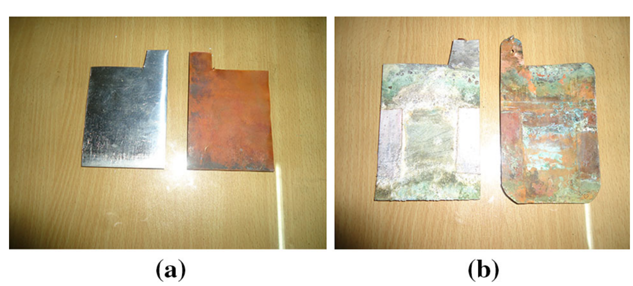

Fig. 21 **a** Cu and Zn plates before electricity generation. **b** Cu and Zn plates after electricity generation

into the mouth of the container, creating a "pop" sound. This is the sound of the hydrogen combusting rapidly and the pressures equalizing inside and outside of the container. This is the sound of a miniature explosion. When hydrogen burns, the hydrogen reacts with oxygen and produces only water as shown below:

$$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O\ (g)\Delta H = -285.85\ \text{kJ mol}^{-1}$$

A PKL cell is covered such a way that the produced gas can not escape. To collect the produced gas an outlet was made with a long tube. The tube is added below a water containing jar so that we can collect the produced gas into test tube safely (Paul et al. 2012). The tube is inserted with full of water so that no air can stay into it. When the test tube is filled with gas then it was exit and a stopper was put quickly in the mouth of the test tube.

3.11 Gas identification

The emitted gas (Fig. 22) was identified by observing some physical characteristics (Table 2) and visual perception and the physical characteristics were: Color, Test, Odor and the burning capability. Unplugging the test tube, and quickly the light was splint. The burning end of the splint was placed into the mouth of the test tube it ignited making a "popping" sound.

Experimentally, it was found that the gas evolved was hydrogen. Hydrogen gas evolved from the cell was due to the reduction of H^+ ion to H_2 (g). The pH of the 10% PKL solution was 4.2. After mixing the 10% Copper–sulphate ($CuSO4{\cdot}5H_2O$) as a secondary salt, the pH of the 10% PKL solution became 3.8. Therefore, it is an obvious that during electricity production from the PKL, Hydrogen gas can be extracted as a by-product during PKL electricity generation.

Fig. 22 An experimental set-up of hydrogen gas production by a PKL module

Table 2 The observations during the identification of hydrogen gas

No	Properties	Observations
1	Test	Test less
2	Odor	Odorless
3	Color	Colorless
4	Burning capability	Burns with pop sound

3.12 Comparative study of the motorbike battery and PKL cell

It is shown from the comparative study (Fig. 23a, b) of the motorbike and PKL Cell that the performance of PKL cell is quite comparable and even better than the motor bike battery.

Tables 3 and 4 demonstrated that the initial pH of Cell-1 and Cell-6 were 3.37 and 3.40, respectively. This variation was not only for the variation of % of PKL juice but also with the variation of % of Secondary salt ($CuSO_4{\cdot}5H_2O$) which was shown in Table 5. As the % of PKL juice increases the pH of the solution decreases. In this table we can see that the pH of 5% $CuSO_4{\cdot}5H_2O$ solution was 4.2 and that of 60% PKL juice was 5.12 alone but when both of them were mixed together then the pH reduces to 3.37 from which we can propose that $CuSO_4{\cdot}5H_2O$ can act as a secondary salt.

Figure 24a and b shows how the pH of a PKL cell reduces. At first the pH was minimum that is for cell-1 this was 3.37 and that is for cell-6 was 3.40 and after a certain time they were 6.80 and 6.50, respectively.

3.13 Chemical analysis

From AAS, UV–Vis, and pH metric analysis it is found that both Cu^{2+} and H^+ ions simultaneously reduces with the

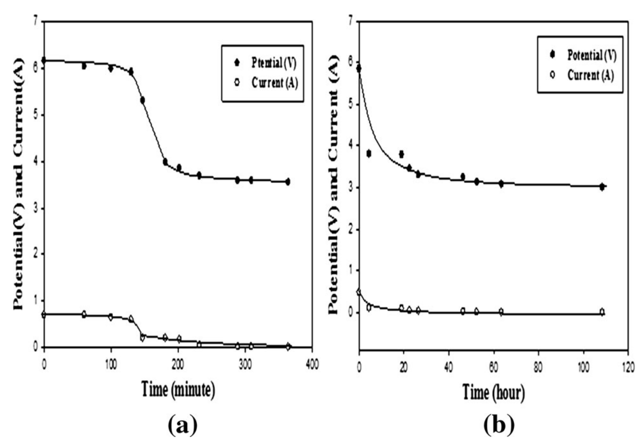

Fig. 23 **a** A plot of potential and current for a motorbike battery. **b** A plot of potential and current for a vegetative and fruits cell battery

Table 3 Determination of pH of PKL solution with time using a pH meter of Cell-1

Date	Local time (p.m.)	Total time (min)	pH of the solution
18.07.2014	4.14	00	3.45
	4.34	20	3.70
	4.54	40	4.39
	5.04	50	4.60
	5.14	60	4.50
	5.24	70	4.59
	5.54	110	4.83
	6.07	123	4.90
	9.17	313	5.91
	10.27	383	6.28
	11.07	423	6.40
19.07.2014	5.07	1503	6.80

Table 4 Determination of pH of PKL solution with time using a pH meter of Cell-6

Date	Local time	Total time (min)	pH of the solution
15.04.2014	1.15 p.m.	00	3.70
	1.45 p.m.	30	4.40
	1.55 p.m.	40	4.94
	2.10 p.m.	55	5.19
	3.10 p.m.	115	5.22
	3.30 p.m.	125	5.20
16.04.2014	8.25 a.m.	1125	6.00
	9.25 a.m.	1185	6.10
	10.30 a.m.	1250	6.18
	11.30 a.m.	1310	6.25
	1.05 p.m.	1405	6.50
	2.15 p.m.	1475	6.50

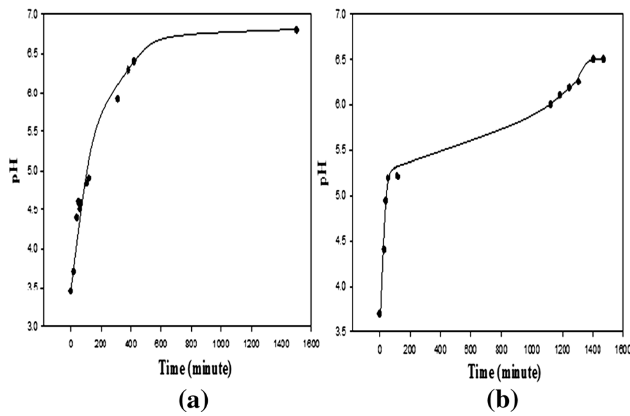

Fig. 24 **a** A plot pH vs time (min) for cell-1. **b** A plot pH vs time (min) for cell-6

Table 5 The variation of pH with the % of Secondary Salt ($CuSO_4.5H_2O$) PKL juice

Cell no.	% of secondary salt ($CuSO_4 \cdot 5H_2O$)	pH of 5% $CuSO_4.5H_2O$	% of PKL juice	pH of PKL juice	pH of solution (PKL juice + Secondary salt)
Cell-1	5	4.20	60	5.12	3.37
Cell-2	5	4.20	40	5.34	3.62
Cell-3	0	–	40	5.34	5.34
Cell-4	5	4.20	0	–	4.20
Cell-5	5	4.20	50	5.25	3.41
Cell-6	5	4.20	50	5.25	3.40

progress of electrochemical reaction whereas the concentration of Zn^{2+} increases rapidly. Thus we can infer that H^+ and Cu^{2+} ions behave as reactant species, i.e., act as oxidant while Zn behaves as reductant species. However, the visual inspection and the reduction of weight of Zn plates also strongly support that Zn electrode is the main source of electron. On the other hand from the VOM data it can be decided that the potential and current flow decreases with the decrease of concentration of H^+ and Cu^{2+} ions in PKL juice solution (Chaurasia et al. 2007). Therefore, it can be proposed the electrochemical reaction occurred in the PKL electrochemical cell as follows:

$$2Zn + Cu^{2+} + 2H^{+} \rightarrow 2Zn^{2+} + Cu + H_2 \uparrow$$

Reaction at anode: $2Zn + 4e^{-} \rightarrow 2Zn^{2+}$.

Reactions at cathode: $Cu^{2+} + 2e^{-} \rightarrow Cu$, $2H^{+} + 2e^{-} \rightarrow H_2\uparrow$.

Hence the cell diagram can be symbolized as,

$$Zn|Zn^{2+}|H^{+},\ H_2|\ Cu^{2+}|Cu$$

From the visual observation of evolved gas as bubble and the physical test of the gas also claim that during electricity production H_2 gas is generated as a by-product.

Modification of electrode by electroplating the performance of the PKL electrochemical cell enhances may be due to the increasing of surface area of electrode and the minimizing of local action.

The columbic efficiency data illustrate that this efficiency was lower comparing to other efficiencies may be the absence of salt bridge or separator between the electrodes. However, the highest efficiency was obtained for 40% PKL sap with 5% secondary salt in 55% aqueous solution, which implies that the concentration of PKL juice can play an important role regarding efficiency. The large value of equilibrium constant revealed that the rate of forward electrochemical reaction was higher at higher concentration of oxidants.

The presence of secondary salt (5% $CuSO_4 \cdot 5H_2O$) enhances the current and the potential. This may be due to the secondary salt effect, where the secondary salt increases the rate of dissociation of weak organic acids of PKL juice.

The traditional battery available used by the people is air tight to minimize the oxidation for maintaining the pH value, voltage and current level. It is shown that the higher current needs to increase the area and number of electrodes. As a result the area of the electrochemical cell and quantity of the PKL sap/juice will be increased. It is shown that the value of the pH of the PKL sap/juice was increased in presence of air. For this reason the traditional battery is always sealed cover. It is shown that PKL plant does not require any extra labor but other PKL need to grow with extra labor. The PKL grow rapidly in the rainy season than the other season. The cost of the PKL electrochemical cell is less than the solar photovoltaic system. The important observation between PKL electrochemical cell and solar photovoltaic system was found that the electrochemical cell can be used in the rainy season because PKL can grow well in the rainy season whereas Solar Photovoltaic system gives low output in the rainy season. So the user of the PKL electrochemical cell will be more beneficial than the Solar Home System in the rainy season. It is also shown that methane gas, Hydrogen gas and bio-fertilizer are produced as a bi-product during PKL electricity generation whereas there is no bi-product in solar photovoltaic system. In addition, during electricity generation the concentration of the product ion increases while reactant ion decreases. Moreover, it is also shown that during electricity generation the pH of the PKL sap increases that indicates that hydrogen gas is produced there. The waste of the PKL after extraction electricity can be used for land filling.

4 Conclusion

The implementation of a new invention is very much important in the light of economic and commercial viability. If there is no usability of our new technology then it will go in vain. Since the production of electricity from vegetative and fruits are relatively new invention, therefore the measurement of its performance was a vital thing. However, it is also tried to identify the strengths, weaknesses, opportunities and threats of the vegetative and fruits electricity system. In this study it is tried to indicate the performance comparing the cell and battery performance. Considering all the performance parameters such as load voltage, load Current, load power, open circuit voltage, short circuit current and maximum power with the variation of time for both 2:1 and 1:1 Zn/Cu based electrochemical cells, we can infer that PKL electrochemical cell would be a more sustainable renewable energy source in comparison with other vegetative and fruits electrochemical cells. From the analysis of heat treatment it can be concluded that at 50 °C the optimum performance would be attained for all the electrochemical cells.

In the secondary salt effect the performance for adding NaCl as a secondary salt was not significant. To stabilize the output voltage and getting more current copper sulphate can be used as a secondary salt in this Zn/Cu based electrochemical cell.

Considering all the necessary surrounding including easier cultivation and cost effectiveness, PKL electrochemical cell is more favorable than the other AVL, tomato and lemon electrochemical cells to generate electricity for practical utilization as dc appliances in the off grid rural areas of not only in Bangladesh but also all over the world. The residue from this technique contains Zinc, which can also be used as Zinc based bio-fertilizer.

For getting enough current it should be increased the number or areas of plates as electrodes in the electrochemical cell to fulfill the requirement of the electricity for off grid areas. It will be cost effective better than the solar photovoltaic (SPV) system.

In the rainy season, the PKL plant and other PKL grows quickly than any other season. This type of PKL based battery will cost much less than a solar PV based system particularly known as solar home system (SHS) that are available in off grid areas. Moreover, PKL juice/extract/sap based batteries will be able to supply power in the rainy season as well when the output from a SHS will very low.

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References

Al-Baghdadi MARS, Al-Janabi HAKS (2007) Parametric and optimization study of a PEM fuel cell performance using three-dimensional computational fluid dynamics model. Renewable Energy 32(7):1077–1101

Blum U, Shafer SR (1988) Microbial populations and phenolic acids in soil. Soil Biol Biochem 20(6):793–800

Chaurasia PBL, Ando Y, Tanaka T (2007) Investigation on proton exchange membrane fuel cell for solar power generation. Int J Sustain Energy 26(2):107–119

Cindrella L, Fu H-Z, Ho Y-S (2014) Globalthrust on fuel cells and their sustainability–an assessment of research trends by bibliometric analysis. Int J Sustain Energy 33(1):125–140

Fontana MG, Greene ND (1978) Corrosion engineering, materials science and engineering, 3rd edn. MG-Hill Series

Gupta VK, Gupta B, Rastogi A, Agarwal S, Nayak A (2011) Pesticides removal from waste water by activated carbon prepared from waste rubber tire. Water Res 45(13):4047–4055

Halder PK, Paul N, Beg MRA (2014) Assessment of biomass energy resources and related technologies practice in Bangladesh. Renew Sustain Energy Rev 39:444–460

Halder PK, Paul N, Joardder MUH, Sarker M (2015) Energy scarcity and potential of renewable energy in Bangladesh. Renew Sustain Energy Rev 51:1636–1649

Hasan M, Khan KA (2016) Bryophyllum pinnatum leaf fueled cell: an alternate way of supplying electricity at the off-grid areas in Bangladesh. In: Proceedings of 4th international conference on the developments in renewable energy technology [ICDRET 2016], P. 01. https://doi.org/10.1109/icdret.2016.7421522

Hasan MM, Khan MKA, Khan MNR, Islam MZ (2016) Sustainable electricity generation at the coastal areas and the islands of bangladesh using biomass resources. City Univ J 02(01):09–13

Hasan M, Khan KA, Mamun MA (2017) An estimation of the extractable electrical energy from bryophyllum pinnatum leaf. Am Int J Res Sci Technol Eng Math (AIJRSTEM) 01(19):100–106

Hossain AK, Badr O (2007) Prospects of renewable energy utilization for electricity generation in Bangladesh. Sustain Energy Rev 11(8):617–1649 **(Renewable 146–152)**

Huda ASN, Mekhilef S, Ahsan A (2014) Biomass energy in Bangladesh: current status and prospects. Renew Sustain Energy Rev 30:504–517

Kahn KA, Bakshi MH, Mahmud AA (2014) PKL Pinnatum leaf (BPL) is an eternal source of renewable electrical energy for future world. Am J Phys Chem 3(5):77–83. https://doi.org/10.11648/j.ajpc.20140305.15

Khan KA (2009) Electricity Generation form Pathor Kuchi Leaf (*Bryophyllum pinnatum*). Int J Sustain Agril Tech 5(4):146–152

Khan KA, Alam MM (2010) Performance of PKL (pathor kuchi leaf) electricity and its uses in Bangladesh. Int J Soc Dev Inf Syst 1(1):15–20

Khan KA, Arafat ME (2010) Development of portable PKL (pathor kuchi leaf) lantern. Int J Soc Dev Inf Syst 1(1):15–20

Khan KA, Bosu R (2010) Performance study on PKL electricity for using DC fan. Int J Soc Dev Inf Syst 1(1):27–30

Khan KA, Hossain MI (2010) PKL electricity for switching on the television and radio. Int J Soc Dev Inf Syst 1(1):31–36

Khan KA, Rahman A, Rahman MS, Tahsin A, Jubyer KM, Paul S (2016a) Performance analysis of electrical parameters of PKL electricity (an experimental analysis on discharge rates, capacity & discharge time, pulse performance and cycle life & deep discharge of pathor kuchi leaf (PKL) electricity cell). In: Innovative smart grid technologies-Asia (ISGT-Asia), IEEE: 540–544

Khan KA, Paul S, Rahman MS, Kundu RRK, Hasan MM, Moniruzzaman M, Mamun MA (2016b) A study of performance analysis of PKL electricity generation parameters: (an experimental analysis on voltage regulation, capacity and energy efficiency of pathor kuchi leaf (PKL) electricity cell). In: Power India International Conference (PIICON), IEEE 7: 1–6

Kuiters AT, Denneman CAJ (1987) Water-soluble phenolic substances in soils underseveral coniferous and deciduous tree species. Soil Biol Biochem 19(6):765–769

Ono S, Saito M, Asoh H (2005) Self-ordering of anodic porous alumina formed in organic acid electrolytes. Electrochim Acta 51(5):827–833

Paul S, Khan KA, Islam KA, Islam B, Reza MA (2012) Modeling of a biomass energy based (BPL) generating power plant and its features in comparison with other generating plants. IPCBEE 44(3):12–16. https://doi.org/10.7763/IPCBEE.2012.V44.3

Strik DPBTB, Snel JFH, Buisman CJN (2008) Green electricity production with living plants and bacteria in a fuel cell. Int J Energy Res 32(9):870–876