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GENERATION OF BIOELECTRICITY FROM SAP OF ORGANIC-ACID-RICH BIOMASS

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Abstract- *This paper focused on the electricity generation from bio-sources like star fruit (Averrhoa Carambola), patharkuchi leaves (Kalanchoe Pinnata), and lemon (Citrus Limonium). The sap of star fruit (Averrhoa Carambola) was selected as electrolyte due to containing higher amount of organic acid and it was rich in citric acid and ascorbic acid. For the preservation of sap, phenol (1%, v/v) was used to reduce the growth of microorganism and addition of phenol did not affect the initial pH value. With increasing of surface area of electrode, reaction rate and pH were amplified but current generation rate remained constant. The fluctuation of voltage drop was reduced by increasing surface area of electrode to acquire continuous and constant current supply. Internal resistance increased rapidly when surface area was lower. Furthermore, internal resistance was significantly influenced by flow-agitation and the resistance values of a system of 16 cells in series were found about 19000 Ω for without agitation and about 9000 Ω for agitation. From this system, maximum power generation was achieved up to 17 mW and no net addition of* CO_2 *to the atmosphere took place.*

Keywords: biomass, electrochemical cell, star fruit, bioelectricity, and acid-rich biomass.

1. INTRODUCTION

Energy is one of the driving forces for the socio-economic development of any country. Bangladesh has been facing a power crisis for about a decade, mainly because of inadequate power generation capacity compared with demand and the ageing infrastructure of many existing power generation facilities. Only 20% of the total populations are connected to grid electricity. Currently, most power plants in Bangladesh (representing 84.5% of the total installed capacity) use natural gas—the main commercial primary energy source, with limited national reserves as a fuel [1]. Figure 1 shows the installed capacity of power plants in Bangladesh [2] according to primary energy source.

We have been completely dependent on conventional energy sources such as natural gas, coal and oil for quite a long time. These two non-replenishable sources of energy contribute to the major part of our energy consumption and we are slowly approaching a stage where these fuels are fast becoming scarce due to the huge increase in the world demand. Biological fuel cells offer a potential solution to all these problems. It uses the available substrates from renewable sources and converts them into harmless by-products with simultaneous production of electricity [3].

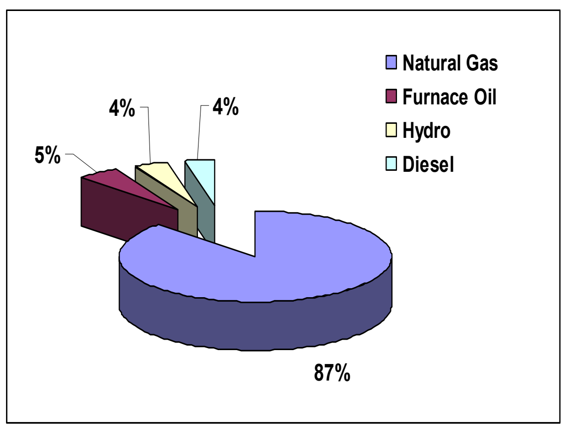

Fig.1: Installed Capacity of power plants in Bangladesh according to primary energy source

Bioelectricity is a new term in the field of bio-energy. The technology of bioelectricity generation in forms of fuel cell is microbial fuel cell. In microbial fuel cell wastewater are managed to convert using microorganism into fuel such as ethanol, methane and hydrogen from organic matter, and these cells are designed with anode and cathode separated by a membrane. These fuel cells are applied where dual activity could significantly reduce the cost associated with the electricity generation and wastewater treatment methods. It produces very low power electricity. Fuel cell stack design with these kinds of cells is very complicated. Suitable substrate for microorganism in wastewater is not always available. This method is applicable where dual activity of wastewater treatment and small scale electricity production are beneficial and major purpose sits on water treatment. Fortunately not having these kinds of limitation another possible source for bioelectricity generation under this study called bio-acid from rotten and inedible fruit and leaf sap, which is renewable. The technology within this study has shown very economical, environmentally safe and possibility of small scale electricity generation. In this study, we focused in the development of a fuel cell to generate electricity from organic acid-rich biomass such as star fruit (*Averrhoa Carambola)* without having any CO_2 emission to the atmosphere.

2. MATERIALS AND METHODS

2.1 Biomass Processing

Star fruit (*Averrhoa Carambola*) was washed by normal water to remove dust from the surface of the fruit and also washed by distilled water for more cleaning. The Star fruit was cut into small pieces (Fig. 2A) and disrupted (Fig. 2B) in a blander to obtain juice. The juice was filtrated with filter paper to remove fibrous portion. The filtrate was treated as electrolyte/ bio-electrolyte. For the preservation of electrolyte, very small percentage of benzoic acid, ascorbic acid, and phenol solution was used in this case.

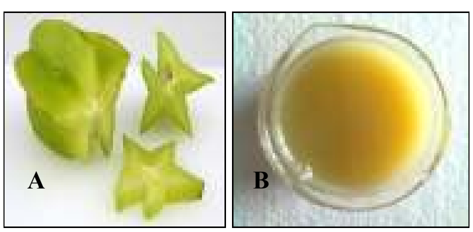

Fig.2: **A**. Pieces of star fruit, and **B**. Juice

2.2 Fuel Cell Design

To prepare low cost cell, empty battery boxes were collected from local market. After washing the boxes, electrodes of copper and zinc (Fig. 3) having dimensions of Height: 10.8 cm, Length: 5.4 cm, Effective height for electrolyte: 9.5 cm, and Weight: 12g were inserted with star fruit juice in boxes. An ammeter was connected for measuring the electricity.

Fig.3: **A** – Zn Plate and **B** – Cu Plate

A box of four compartments was shown in Fig. 4, where each compartment had following dimensions: Width: 4 cm, Length: 8.4 cm, Height: 10.5 cm, and Effective Height: 9 cm.

Fig.4: Cell box with four compartments

For achieving high voltage and high current yield several cell connections has been observed, among these observations following two connections have been found that was capable of producing maximum power. Typical series connection of four cells in series is shown in Fig. 5, where effective height for electrolyte was 9.5 cm.

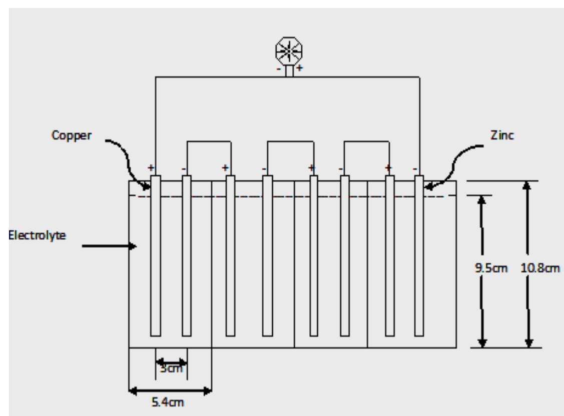

Fig.5: Typical series connection: Four cells in series

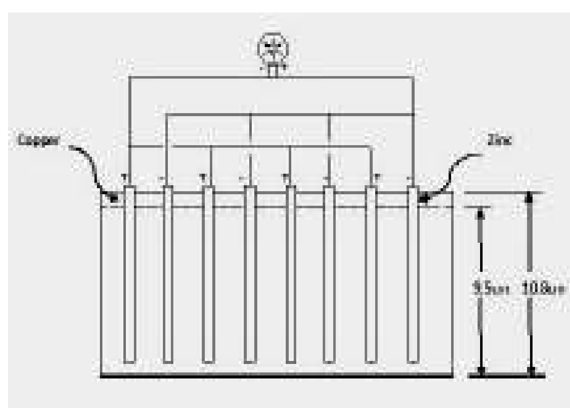

Fig.6: Typical parallel connection: (in a single compartment)

A typical parallel connection (Fig. 6) in single compartment was used in the box to minimize fluctuation of voltage while each compartment was connected in series. This combination of parallel and series connection in the boxes was studied for maximum power yield. Polymeric separator has been used in between anode and cathode that was chemically stable to the electrolyte.

2.3 Measurement of E.M.F., Volt, Current and Internal Resistance

Open circuit voltage $V_{oc,}$ and short circuit current I_{sc} was measured precisely by digital multimeter. After that, for voltage and current measurement, a 1950 KΩ resistance was connected in parallel and series respectively. E.M.F. was measured by multimeter in open circuit.

2.4 Agitation System

Agitation system has been designed by circulation of electrolyte through cell boxes using potential energy difference (Fig. 7). Stair was made by wood from local furniture shop and boxes for battery were bought from local market. Diaphragms pump was used for organic solvent handling and cells were connected with plastic pipes for the circulation of electrolyte. A regulator was connected through diaphragms pump to control flow rate of electrolyte, and a 12 DCV LED bulb was also connected in series.

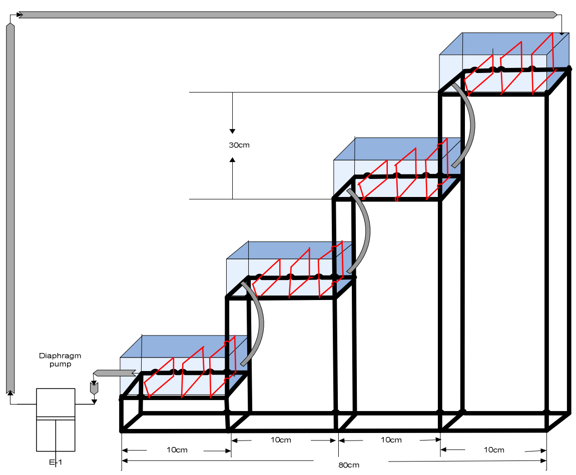

Fig.7: Flow agitation of electrolyte through cell boxes

3. RESULTS AND DISCUSSIONS

3.1 Electrolyte Analysis

Any kind of fruit or leaf juice can be used, if there is evidence of significant percentage of acids present in juice with suitable pKa value. First, pH measurement (Table 1) showed the results either extracted juice was suitable for producing sufficient voltage difference in a cell or not. It was observed that lower value of pH showed higher voltage difference. The pH and pKa values were most important factor in case of voltage difference and amount of current generation.

Another most important parameter on selection of feasible fruit or leaf juice was compositions of extracted juice. Composition of juice had an impact on electric resistance on cell when it was used as electrolyte.

Table 1: pH of bio-electrolytes

Juice with no additives	*Averrhoa Carambola*	*Kalanchoe Pinnata*	*Citrus Limonium*
pH	2.8	4.6	2.1

There are some acid which have higher pKa value that means high dissociation in aqueous solution which refers high reactive affinity to metal (electrode). Presence of some component resists proton transport through electrolyte causing internal resistance in that. Some acids which react with anode to produce complex salts of used metal anode forming a black or white layer on the inserted surface of the anode. Conductivity is another important parameter of electrolyte. The Conductivity of star fruit juice was found 5.67 µS.

In this study, star fruit had been used as electrolyte to inspect electricity production capability in the electrolytic cells those were connected in series and parallel combination for acquiring desired electrical energy. Chemical compositions of green Star Fruit per 100g [4] of eligible portion are given in Table 2.

Table 2: Chemical compositions of green Star Fruit

Parameter	Percent in (gram)
Moisture	90.65
Protein	0.39
Lipid	0.31
Crude fiber	0.92
Reducing sugars	2.80
Total sugars (as g reducing sugars)	2.91
Pectin	1.64
Starch	1.92
Titratable acidity (as gm anhydrous citric acid)	0.98
Ascorbic acid	.0252
Tannin	0.0028

3.2 Reaction Mechanism of Cell

The principle of electricity generation using bio-acid is same as simple electric cell (Fig. 8) which converts chemical energy into electrical energy. The difference in the present study with electric-cell-theory is only with utilization of organic acid (citric acid, iso-citric acid, oxalic acid including other weak organic acid etc) found in fruits and leafs as electrolyte which we named as bio-acid. This is renewable source for producing energy. In case of citric acid, the organic juice contained about 90 to 95% water. The weak organic acids dissociated in this aqueous solution, consequently H^+ ions were increased. In the mean time *Zn* plate dissolved in the organic electrolyte as Zn^{2+} ion sacrificing two electrons. Electrons pass through the external circuit and salt of *Zn* is produced. On the other hand, H^+ ions are adsorbed on the surface of *Cu* plate and receiving electron those evolved as H_2 gas [4].

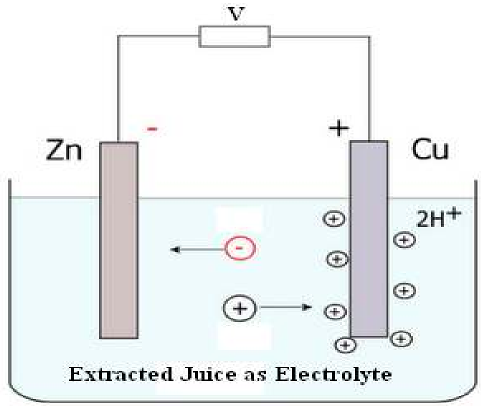

Fig.8: Simple electric Cell

Bio-electrolyte has been prepared in such a way that blended fruits contain pest and water with proportion 8:1. After pouring such mixture into a cell, copper and zinc plates were to be merged into the mixture, and then and there, a chemical reaction was taken place, which in turn, created positive and negative potentiality. As a result, the conduction of electricity was started. Citric acid reacts with *Zn* to produce zinc citrate and releases Hydrogen ions.

$$HOOC\text{-}CH_2\text{-}C(OH)(COOH)\text{-}CH_2\text{-}COOH(aq) \rightarrow HOOC\text{-}CH_2\text{-}C(OH)(COOH)\text{-}CH_2\text{-}COO^- + H^+$$

$$Zn^{2+} + 2HOOC\text{-}CH_2\text{-}C(OH)(COOH)\text{-}CH_2\text{-}COO^- \rightarrow [HOOC\text{-}CH_2\text{-}C(OH)(COOH)\text{-}CH_2\text{-}COO^-]_2Zn$$

In this way, *Zn* plate became negatively charged and H^+ contact with *Cu* plate and became positively charged. As, these two plates were connected by wire, current flew from *Cu* to *Zn* through outer circuit and from *Zn* to *Cu* through mixture sap. Therefore, the circular path of current generated DC electricity. By applying inverter, DC was converted into AC [5].

At anode, two electrons were then released from each zinc atom, giving the Zn^{2+} ion.

$$Zn(s) \quad 2e \rightarrow Zn^{2+}(aq)$$

At cathode, the other reaction is called reduction, focused on the positively charged hydrogen atoms, or hydrogen ions, in the citric acid near the screw.

$$H^+(aq) + 2e \rightarrow H_2(g)$$

3.3 Effects of pH

Generation of current depends on the initial pH of the electrolyte. The change of pH is shown in the following graphical representations.

From Fig. 9, 10 and 11, it was observed that the rate of change of pH increased with addition of the surface area of electrode. In case of single pair electrode, pH change was very slight but current generation was remained constant for long time. On the other hand, current generation trend was almost same for double and triple pair electrodes. Further study is going on to optimize the condition to generate maximum electricity with parameters surface area and pH.

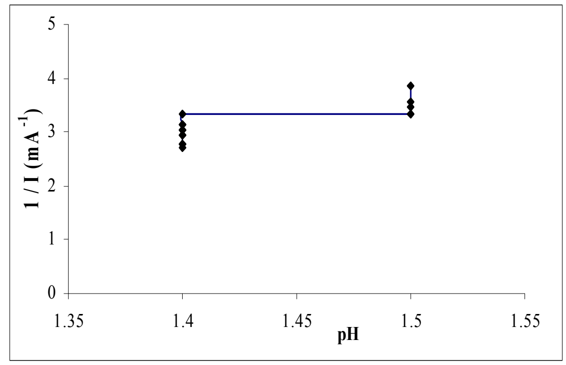

Fig.9: pH vs. 1/I for single pair electrode with juice as electrolyte

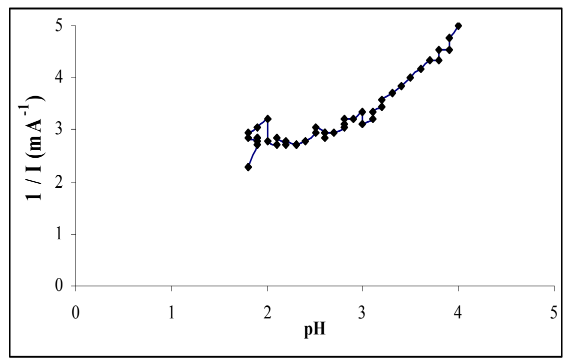

Fig.10: pH vs. 1/I for double pair electrode with star fruit juice electrolyte

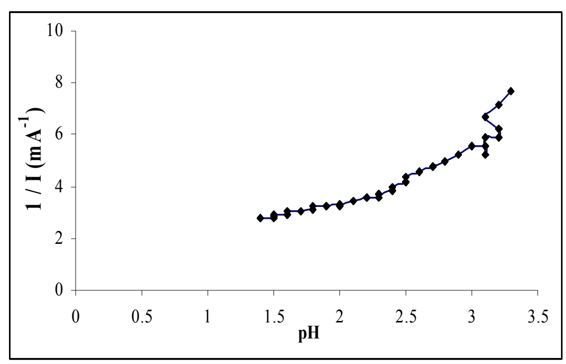

Fig.11: pH vs. 1/I for three pair electrode with star fruit juice as electrolyte

3.4 Effects of Surface Area of Electrode

The major problem of any kind of electrochemical cell is increase of internal resistance within the electrolyte. Electrolyte resistance causes regular voltage drop between electrodes with change of time. So, electrolyte resistance plays an important role in case of electrolyte selection. The lower electrolyte resistance enhances the better performance of the cell. For this reason, effect of electrolyte resistance was observed precisely and a fixed resistor (2kΩ) was connected in parallel and series with the cell while voltage and current were measured respectively. Figure 12 illustrates that internal resistance was initially relatively high for the single pair of electrode and the rate of increase in internal resistance was slow with time. But with the triple pair of electrode, internal resistance was increased almost constantly from a very low initial value. It was also reasonable for double pair of electrode. So, it may conclude, less surface area and due to slow reaction rate, internal resistance was high. On the other hand, due to more surface area and faster reaction rate, internal resistance increased gradually.

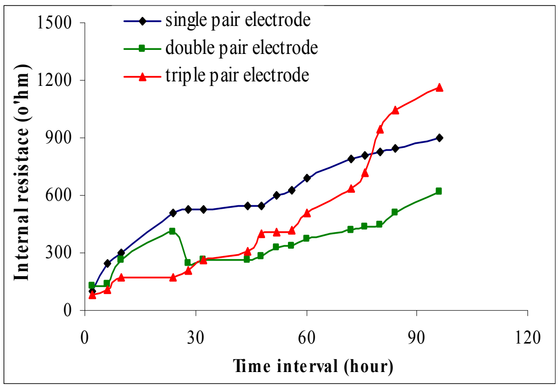

Fig.12: Internal resistance vs. Time interval for different surface area of electrode with Star Fruit electrolyte

3.5 Effects of Agitation

Since, only fruit juice was used as bio-electrolyte, the stagnancy might interrupt the ionic movement, anodic-cathodic reactions, voltage drop and occur precipitation. The conversion of current is high with increasing the agitation rate [6]. Therefore, a flow type agitation system was developed for the present electrolytic cell. In the Figure 13, the effect of agitation is shown on current generation. With the same pH range (2.4-2.6), current generation was always high when the system was under agitation. With influence of agitation, it might have happened that H^+ were distributed and contacted with the electrode uniformly.

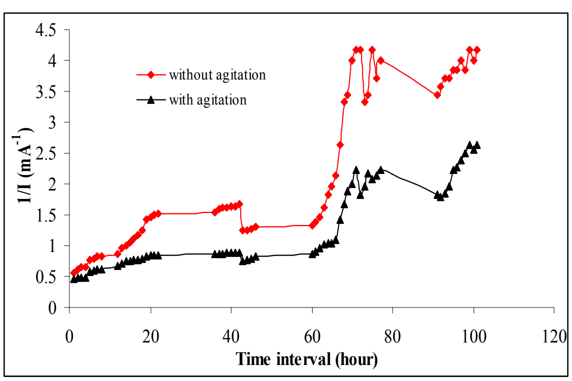

Fig.13: Effect of agitation on current generation for 16 cells in series

For better function of electrochemical cell, internal resistance is one of the important factors. In the present study, internal resistance was increased rapidly and reached to a quite higher value around 19000Ω when no agitation was conducted. But this value was remarkably reduced to around 9000Ω when the system was agitated (Fig. 14). So, agitation had a fruitful effect on current generation, fluctuation and internal resistance.

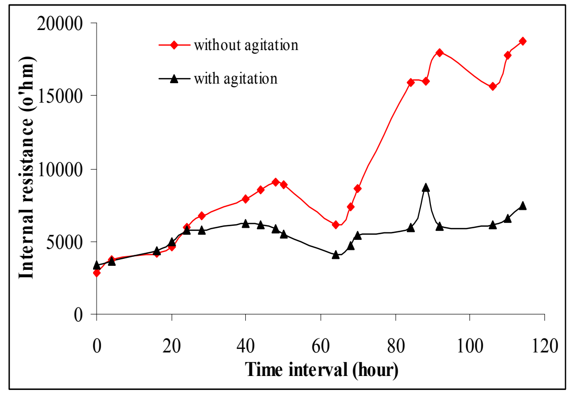

Fig.14: Internal resistance vs. time interval for 16 cells in series with star fruit juice electrolyte

4. CONCLUSION

Though Solar and wind energy are also promising renewable sources in Bangladesh but these are characterized by high investment cost, seasonal and site dependency. However, biomass is a major energy source in Bangladesh, which can be used for decentralized electricity generation. Worldwide, biomass-to-electricity generation has gained importance due to employment opportunity, reduction in reliance on fossil fuels and positive environmental benefits. The change of surface area, initial pH of electrolyte and stair-flow agitation significantly influenced the generation of electricity. Much more R & D is essential to evaluate the optimum condition of the effect of change in parameters for large scale electricity generation. It can be concluded, applying the same process, small- to medium-scale biomass-based electricity generation systems can provide a good prospect for supplying electricity economically. Electrification with this technology to the remote areas usually leads to low investment and less power losses associated with transmission and distribution networks and minimize the environmental pollution. This will make a significant contribution towards the achievement of the government target of total electrification of the country by the year 2021.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
I	Current	(A)
V	Voltage	(Volt)
E.M.F.	Electro Motive Force	(Volt)