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Investigation of Ion Transport in Banana Pith Electrolyte Sandwiched Between Mild Steel Electrodes

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ABSTRACT

Improving the bio-battery design specification is a widely researched area in recent years to satisfy the consumer demands. After subsequent studies of investigating the applicability of Sri Lankan banana variety [*musa* AAA group (Cavendish subgroup) 'ambun'] as the electrolyte in bio-batteries with different electrode combinations, the present study was aimed to understand the ion transport in a bio-cell with two mild steel electrodes. Mild steel which is in contact with banana pith oxidizes to Fe^{3+} and complexes with phenolic groups. Average initial current and voltage of bio-cell (4 x 2 cm^2) with two mild steel electrodes of 1 cm separation under a load of 50 Ω was 0.50 mA and 58.0 mV respectively that appeared due to activation polarization (ηa) and concentration polarization (ηc). When the electrodes are connected to a power source for charging, mild steel at the anode further oxidizes to Fe^{3+} while Fe^{3+} complexed with phenolic groups reduce to Fe^{2+} near the cathode. Two colourful layers of dark blue and pale pink were formed near the cathode and anode in this process. Oxidation of Fe^{2+} ions back to Fe^{3+} that complexed with phenolic groups deliver a current after charging the cell. The bio cell delivered average initial voltage and current of 592 mV and 3 mA under a load of 50 Ω after charging. A sudden increment in the voltage (96.1 mV) of the discharge curve was noticed due to the interruption of double layer formed between the mild steel and electrolyte.

1. INTRODUCTION

The consumer demand for energy storage devices such as batteries seems to accelerate with diverse applications in different user niches. Yet, unavoidable and inevitable research challenges are continuously being faced by the researchers when developing such metal and chemical batteries without contaminating the environment. As a result, usage of bio-batteries to harvest sustainable energy have come forward in the recent past as an inexpensive, eco-friendly and alternative energy solution to the existing batteries. Hence, from the initial research work of Galvani [1], bio-batteries have evolved over the past years with variations in the battery design specification. Specifically, usage of new materials as constituents [2-4] and different structural modifications [5, 6] are being introduced to cope the problems associated with bio-batteries.

Except for the usage as a decorative base, banana trunk is just a waste material after fruit harvest in Sri Lankan context. Yet, in the recent past, banana has been a constituent in many research and development projects of different research areas. The inedible banana peels which serve a little economic purpose are now being used as a constituent in super capacitors [7] and rechargeable batteries [8]. Even the efficacy of banana pith as a natural coagulant and as a natural polyelectrolyte in wastewater contaminant removal [9] have been evaluated by researchers whereas banana pith suitability in textile wastewater treatment have been also studied [10]. Another study [11] reported

the discovery of the living banana plant as a long-lasting power source where Cu and Zn electrodes were inserted into the plant to produce electricity. The organic compound in the on-site plant acted as electrolyte.
A specific Sri Lankan banana variety [*Musa* AAA Group (Cavendish Subgroup) 'ambun'] was used in this study as it has not been subjected to research so far by any other local or foreign research group for further investigations as an electrolytic material in bio-batteries. After numerous investigations [12-17] with the same pith of Sri Lankan banana variety which focused to promote stability, safety and usage of less expensive materials, this study was aimed to understand the ion transport in a bio-battery with mild steel electrodes when ambun banana pith was used as the electrolyte.

2. METHODOLOGY

First, the trunk of the *ambun* banana that was used in this investigation was cut into small cubes ($1 \times 1 \times 1$ cm^3) and was mixed in a blender. The blended pith was kept on a hot plate set at 120 ^{0}C for 30 minutes to concentrate its liquid content for the usage as an electrolytic medium of the bio-batteries. Next, banana pith was sandwiched between two mild steel (which contains 0.05% - 0.25% carbon) plates of area (4 x 2) cm^2 with 1 cm of separation. Normal galvanic discharge and the discharge after charging by connecting to a power supply withconstant voltage of 2 V for one hour were monitored for the cells with banana pithfor total eight hours by recording the current and voltage.

3. RESULTS AND DISCUSSION

Figure 1 shows the variation of the circuit voltage with time under discharge of cells accross a 50 Ω resister with and without charging**.** The average initial voltage and current of the cell without charging were about 58.0 mV and 0.50 mA respectively when connected across the load. Thiscell which was not charged, produced the above current and voltage due to activation polarization originates from the electrochemical reactions at the electrode surface (ηa) and concentration polarization arises from concentration differences of charged species between the electrode surface and the bulk electrolyte (ηc) even both the electrodes of mild steel have equal half-cell potentials (E_{cell}) in opposite directions that supposed to be nullified.
Voltage of a cell in general is given by equation 1 where $E_{cell} = 0$ in this case and IR is the ohmic loss.

$$V_{cell} = E_{cell} - \eta a - \eta c - IR \qquad \ldots\ldots (1)$$

Activation polarization (η_a) is also has two components, i.e., the energy involved in transporting ions across the Electric Double Layer (EDL) and activation energy for the oxidation/reduction reaction to occur.
According to the following equation 2, Fe^{2+} ions diffuse to the electrolyte from mild steel electrodes.

$$Fe(s) \qquad Fe^{2+}_{(aq)} + 2e \qquad (E_0 = 0.44\ V) \qquad \ldots\ldots (2)$$

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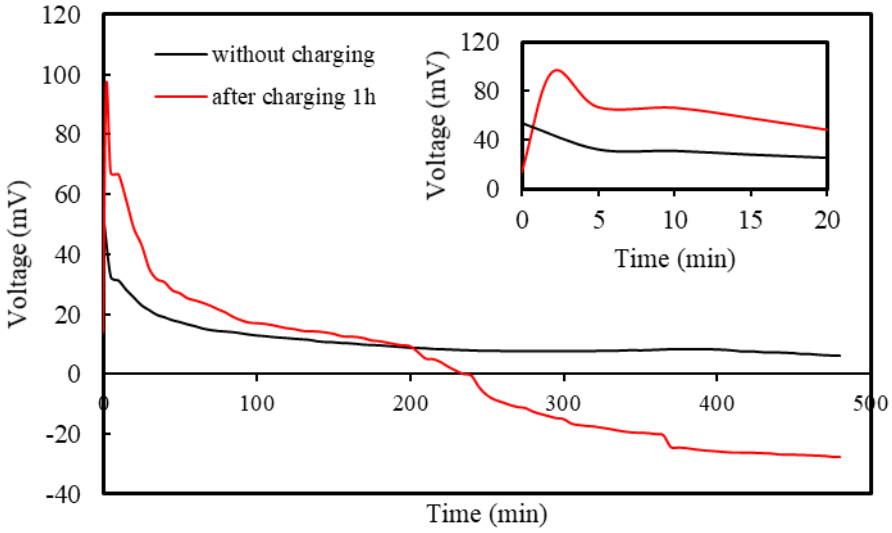

Figure 1: Discharged circuit voltage variation of the bio-cell with and without charging after connected to a 2 V power supply for one hour

These Fe^{2+} ions further oxidized to Fe^{3+} ions in an acidic media and complex with phenolic groups in the electrolyte as given in Figure 2.

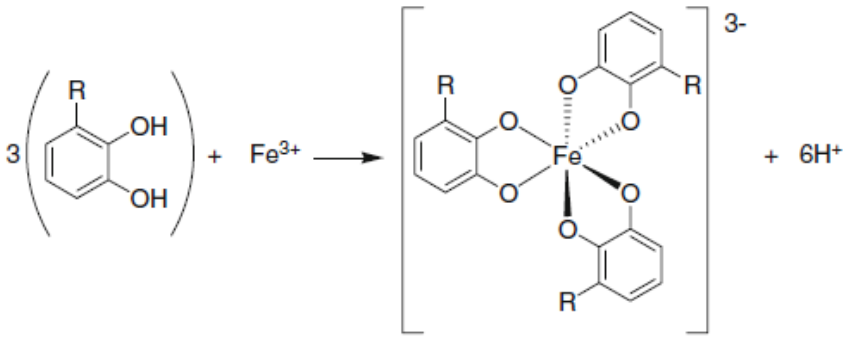

Figure 2: Fe^{3+} ions complexation with phenolic groups [18]

The cathode and anode of the cell is determined arbitrarily by activation energy for the oxidation/reduction reaction that occur and concentration differences of charged species between the electrode surface and the bulk electrolyte etc. When an electric current is passed during the charging connecting anode to positive terminal and cathode to negative terminal of the power source, mild steel at the anode oxidized to Fe^{2+} and further to Fe^{3+} while Fe^{3+} complexed with phenolic groups reduces to Fe^{2+} near the cathode.

Two specific colour changes could be observed within one hour indicating the complexation of Fe^{3+} ions with phenolic groups by turning the banana pith into black blue colour and reduction to Fe^{2+}, turn the banana pith into pale pink colour (Figure 3). The oxidation of Fe^{2+} ions to Fe^{3+} that complexed with phenolic groups deliver a current after charging the cell.

Figure 3: Colour changes observed in the cell with mild steel electrodes

The voltage discharge curve of the bio-cell after charging for one hour showed a sudden increment in the second minute (Figure 1 inset). Recorded voltage increment of this bio-cell was 96.1 mV which caused by interruption of the double layer. When the sudden increment of voltage was noted, the recorded current was 1.85 mA.
The formed double layer was interrupted due to the high current delivery by the cell. As a result, the voltage was increased initially. Again, the stability of the double layer dropped the voltage, when the circuit current was decreased. Later, there was an exponential decay of current where this cell discharged after four hours.Afterwards current and voltage become negative in the cell .Again, this negative voltage is caused l which reaches zero volts at long by activation and concentration polarization of the cel run. [3]It is negative now because charging the cell altered the Fe^{+}ion concentration at the two electrodes complimentary to the initial sate.

4. CONCLUSION

The functionality of the bio-cell made from two mild steel electrodes and banana pith electrolyte with phenolic groups is based on the equilibrium between Fe^{2+} and Fe^{3+} ions in the redox mediator. This phenomenon was used to demonstrate a rechargeable bio cell while studying the ion transport in banana pith electrolyte. The cell initially had an average current and voltage of 0.50 mA and 58.0 mV respectively under a load of 50 Ω without charging. This was due to the activation polarization originates from the electrochemical reactions at the electrode surface (ηa) and concentration polarization arises from concentration differences of charged species between the electrode surface and the bulk electrolyte (ηc). The bio cell delivered an average initial voltage and current of 592 mV and 3 mA under a load of 50 Ω after charging. Therefore, this concept can be further investigated to develop rechargeable bio-cells with high charge density.

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