Solar Energy Conversion With Photosensitizers Toluidine Blue And Malachite Green

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Abstract: Photogalvanic cells with photosensitizer – reductant pair, Toluidine Blue – Arabinose and Malachite Green - Arabinose were developed in presence of anionic surfactant NaLS (Sodium lauryl sulphate). A tentative mechanism has been proposed for the cell reaction. The conversion efficiency and storage capacity of the developed cells were found to be 0.1448% and 123.0 minutes, respectively with Toluidine Blue and 0.0590% and 32.0 minutes, respectively with Malachite Green.

Index Terms - Photosensitizer; Toluidine Blue; Malachite Green; Arabinose; Sodium lauryl sulphate; Conversion efficiency and Storage capacity.

1. Introduction

Solar energy can be converted into electrical energy by means of photogalvanic conversion. The photogalvanic effect was firstly observed by Rideal and Williams [1], later systematically investigated by Rabinowitch [2-3], specially with the reversible redox system thionine / Fe^{2+}. Later Sakata et al. [4], Clark [5], Peter et al. [6] and Anisworth [7] also studied the photogalvanic response of this system and discussed various problems encountered in the development of the photogalvanic cell. Critical survey of literature [8-15] reveals that various effective energy storing photochemical systems made of photosensitizer (dye) and reductant have been experimentally studied, yet there is no photochemical reaction has obtained which can produce an efficient cell with effective conversion efficiency and valuable storage capacity. In this direction, Genwa et al. [16-20] and Gangotri et al. [21-24] reported effective photosensitizer - reductant systems in presence of surfactant. In present work, the photogalvanic effect was studied in Toluidine Blue – Arabinose and Malachite Green – Arabinose (dye - reductant systems) in presence of anionic surfactant NaLS.

2. Experimental

Toluidine Blue (Loba), Malachite Green (Loba), Arabinose (BDH), Sodium lauryl sulphate (S.D.fine) and Sodium hydroxide (Qualigen) were used in the present work. All the stock solutions were prepared in double distilled water. Dye solution was stored in darkened container to protect it from light exposure. NaOH solution of 1N concentration was freshly prepared in every experimental set up by standardization with 1N Oxalic acid. The mixture of appropriate volume of dye, reductant, surfactant and NaOH was made up to 25.0 ml with double distilled water and taken into blackened H-shaped glass container. A platinum foil electrode of 1cm^2 electrode area was immersed into one limb of container which contained a transparent window through which electrode was exposed to light and a saturated calomel electrode (SCE) was immersed into another one. A water filter was used between the cell and light source (200W tungsten lamp) to prevent the reactive system from thermal radiation. The photopotential and photocurrent prod radiation. The photopotential and photocurrent produced by developed photogalvanic cell were measured by digital pH meter (Systronics model 335) and microammeter (MO-65), respectively. A load resistance (log 470 K) was used to apply desired load in microammeter circuit to establish current- voltage characteristics of the

3. Results and Discussion

The representative data for the studied systems Toluidine Blue - Arabinose - NaLS and Malachite Green - Arabinose - NaLS are given in Table 1 which is reflecting the over all outcome of the present studies

3.1 Effect of variation of dye concentration

Effect of variation of dye concentration on electrical output of cell in both the systems was studied and observed that systems worked with efficiency at a particular maximum [Toluidine Blue] = 2 x 10^{-5} M and [Malachite Green] = 2.4 x 10^{-5} M. On increase or decrease in these values, cell's output decreased in both situations [Table 2].

As dye solution in the photogalvanic cell absorbs the light radiation and initiates the cell reaction, its concentration must effects the cell output and this was observed in experimental results. In presence of higher or lower concentration of dye, there should be low availability of dye molecules to excite and to donate electron to the platinum electrode. In presence of higher concentration of dye, density of dye molecules in path of platinum electrode should be large and therefore these absorbs major portion of light. Hence the dye molecules around the electrode will not obtain the desired light intensity. In presence of lower concentration of dye, there should be low availability of dye molecules to excite and donate electrons to the platinum electrode.

3.2 Effect of variation of pH of the systems

Photogalvanic response of the systems with Toluidine Blue and Malachite Green were obtained under the variation of pH of these systems. The photopotential and photocurrent increased with pH and reaches maximum at pH = 12.90 and pH = 12.77, respectively and then decreased with further increase in pH [Table 3]. It was found that optimum electrical output was obtained at particular pH value. It may be due to better availability of reductant's donor form at that pH value.

3.3 Current - voltage characteristics of the cells

Under the continuous illumination of light, open circuit voltage (V_{oc}) and short circuit current (i_{sc}) of the cells were obtained by a digital pH meter (keeping the circuit open) and a microammeter (keeping the circuit close), respectively. The cell's i-V characteristics is shown between the current and potential values measured between the V_{oc} and i_{sc} by applying external load in microammeter circuit. The i-V curve for Toluidine Blue and Malachite Green systems is shown in Fig. 1 and Fig. 2, respectively.

3.4 Storage capacity, Conversion efficiency and Fill factor of the cells

By i- V curves, a point was obtained where product of current and potential found maximum called power point. Performance of the cell i.e., storage capacity denoted by $t_{1/2}$ were observed 123.0 minutes and 32.0 minutes in Toluidine Blue - Arabinose - NaLS and Malachite Green - Arabinose - NaLS, respectively , by keeping the cells at power point stage in dark and noted down the time required in fall of power output to its half value.

The conversion efficiency and fill factors of the cells (with platinum foil electrode of 1 cm^2 electrode area) were determined 0.1448% and 0.259, respectively, with Toluidine Blue system and 0.0590% and 0.0239, respectively, with Malachite Green system by following formula:

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{10.4\text{mW/cm}^2} \times 100\% \qquad \ldots (1)$$

$$\text{Fill factor} = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}} \qquad \ldots (2)$$

where V_{pp} and i_{pp} represents the value of potential and current at power point, respectively.

4. Mechanism

According to photochemistry of dyes in solution, chemically reactive species are the triplet state of dye. Specially, when certain dyes are excited by light in the presence of electron donating substances, the dyes are rapidly changed into colourless ("reduced") form. The dye is now a powerful reducing agent and will donate electron to other substances, with dye being returned to its oxidized state[25].

On the basis of above studies, a tentative mechanism for the cell reaction has been proposed as follows:

Illuminated Compartment

$$\underset{\text{(Ground state)}}{\text{Dye}} \xrightarrow{h\nu} \underset{\text{(First excited state)}}{\text{Dye}^*} \longrightarrow \underset{\text{(Triplet state)}}{\text{Dye}'} \qquad \ldots (1)$$

$$\text{Dye}' + \text{R} \longrightarrow \underset{\text{(semi or leuco form of dye)}}{\text{Dye}^-} + \text{R}^+ \qquad \ldots (2)$$

At platinum electrode:

$$\text{Dye}^- \longrightarrow \text{Dye} + e^- \qquad \ldots (3)$$

Dark Compartment

At SCE:

$$\text{Dye} + e^- \longrightarrow \text{Dye}^- \;\text{(semi or leuco form of dye)} \qquad \ldots (4)$$

$$\text{Dye}^- + \text{R}^+ \longrightarrow \text{Dye} + \text{R} \qquad \ldots (5)$$

where Dye, Dye^-, R and R^+ represents the Dye, reduced form of dye, reductant and oxidized form of reductant, respectively.

5. Conclusion

The photogalvanic power generation by new photogalvanic systems, Toluidine Blue - Arabinose - NaLS and Malachite Green - Arabinose - NaLS in photogalvanic cell were studied and analyzed. The developed cell with photosensitizer Toluidine Blue appeared efficient from storage capacity point of view.

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Table 1

Measured parameters of studied systems

S. No.	Parameters	Observed Values: Toluidine Blue-Arabinose- NaLS System	Observed Values: Malachite Green - Arabinose-NaLS System
1.	Open Circuit Voltage, V_{oc} (mV)	966.0	836.0
2.	Short Circuit Current, i_{sc} (μA)	60.0	36.0
3.	Potential at Power Point, V_{pp} (mV)	502.0	341.0
4.	Current at Power Point, i_{pp} (μA)	30.0	18.0
5.	Fill factor, F_f	0.259	0.2039
6.	Conversion efficiency, η (%)	0.1448	0.0590
7.	$t_{½}$ (minutes)	123.0	32.0

Table 2

Effect of Variation of Dye concentration (at 303 K Temperature ; 10.4 mW cm^{-2} Light Intensity)

Concn. of dye (x 10^{-5})	Photopotential (mV)	Photocurrent (μA)
[Toluidine Blue][a]		
1.23	605.0	29.0
1.50	650.0	40.0
2.00	813.0	60.0
2.70	735.0	48.0
3.00	680.0	44.0
3.25	602.0	40.0
[Malachite Green][b]		
1.32	285.0	25.0
1.68	306.0	30.0
2.40	348.0	36.0
2.80	311.0	31.0
3.40	292.0	25.0
4.00	272.0	21.0

[a][Arabinose] = 2.0 x 10^{-3} M; [NaLS] = 5.6 x 10^{-3} M; pH = 12.90

[b][Arabinose] = 2.4 x 10^{-3} M; [NaLS] = 6.4 x 10^{-3} M; pH = 12.77

Table 3

Effect of Variation of pH (at 303 K Temperature; 10.4 mW cm^{-2} Light Intensity)

pH	Photopotential (mV)	Photocurrent (μA)
Toluidine Blue system [a]		
12.50	435.0	39.0
12.70	685.0	45.0
12.90	813.0	60.0
13.10	698.0	53.0
13.30	495.0	49.0
Malachite Green system [b]		
12.57	246.0	18.0
12.64	299.0	29.0
12.77	348.0	36.0
12.84	306.0	33.5
12.87	286.0	29.5

[a][Toluidine Blue] = 2.0 x 10^{-5} M; [Arabinose] = 2.0 x 10^{-3} M; [NaLS] = 5.6 x 10^{-3} M

[b][Malachite Green] = 2.4 x 10^{-5} M; [Arabinose] = 2.4 x 10^{-3} M; [NaLS] = 6.4 x 10^{-3} M

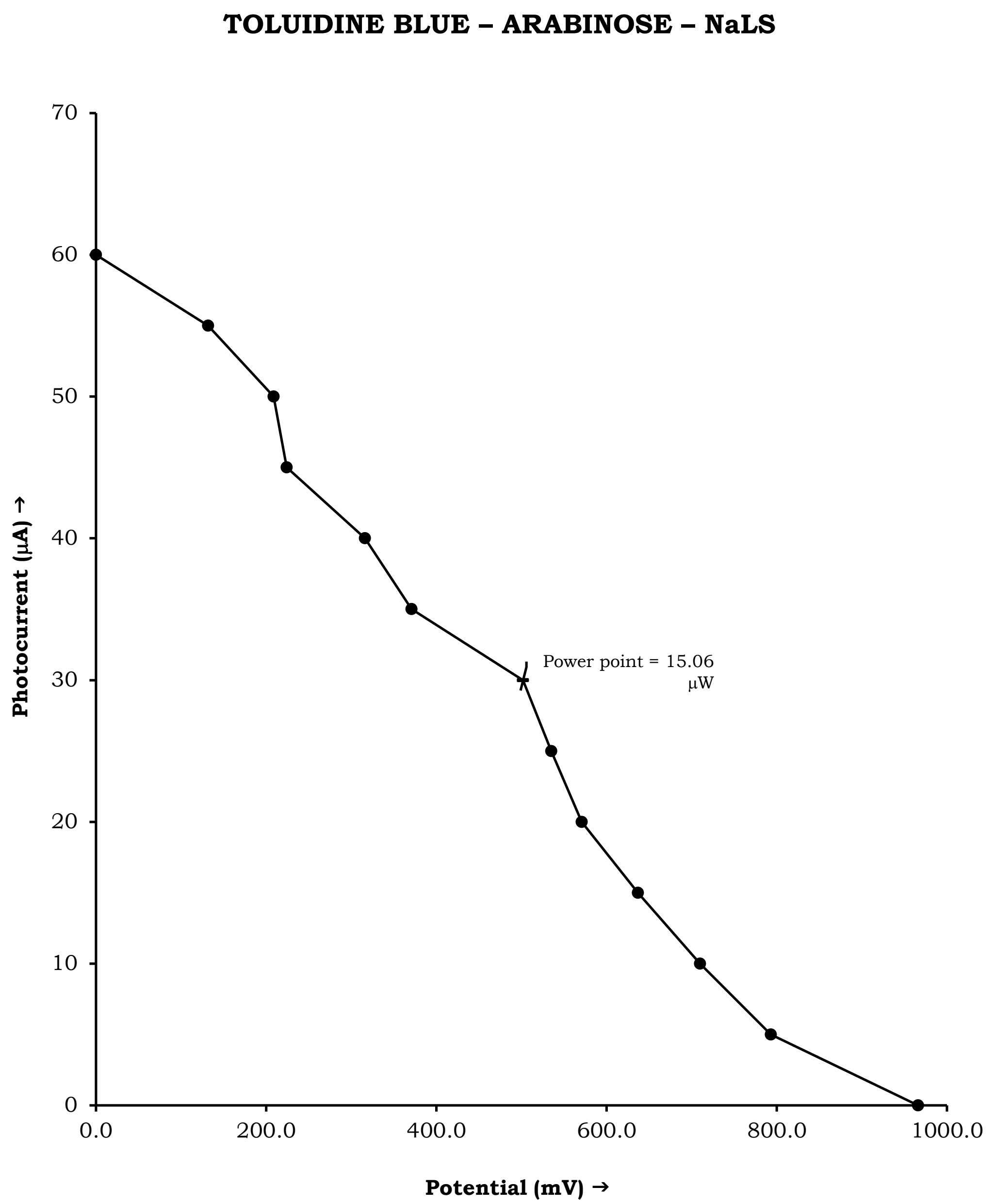

Fig. 1 CURRENT-VOLTAGE (i-V) CURVE OF THE CELL

MALACHITE GREEN – ARABINOSE – NaLS

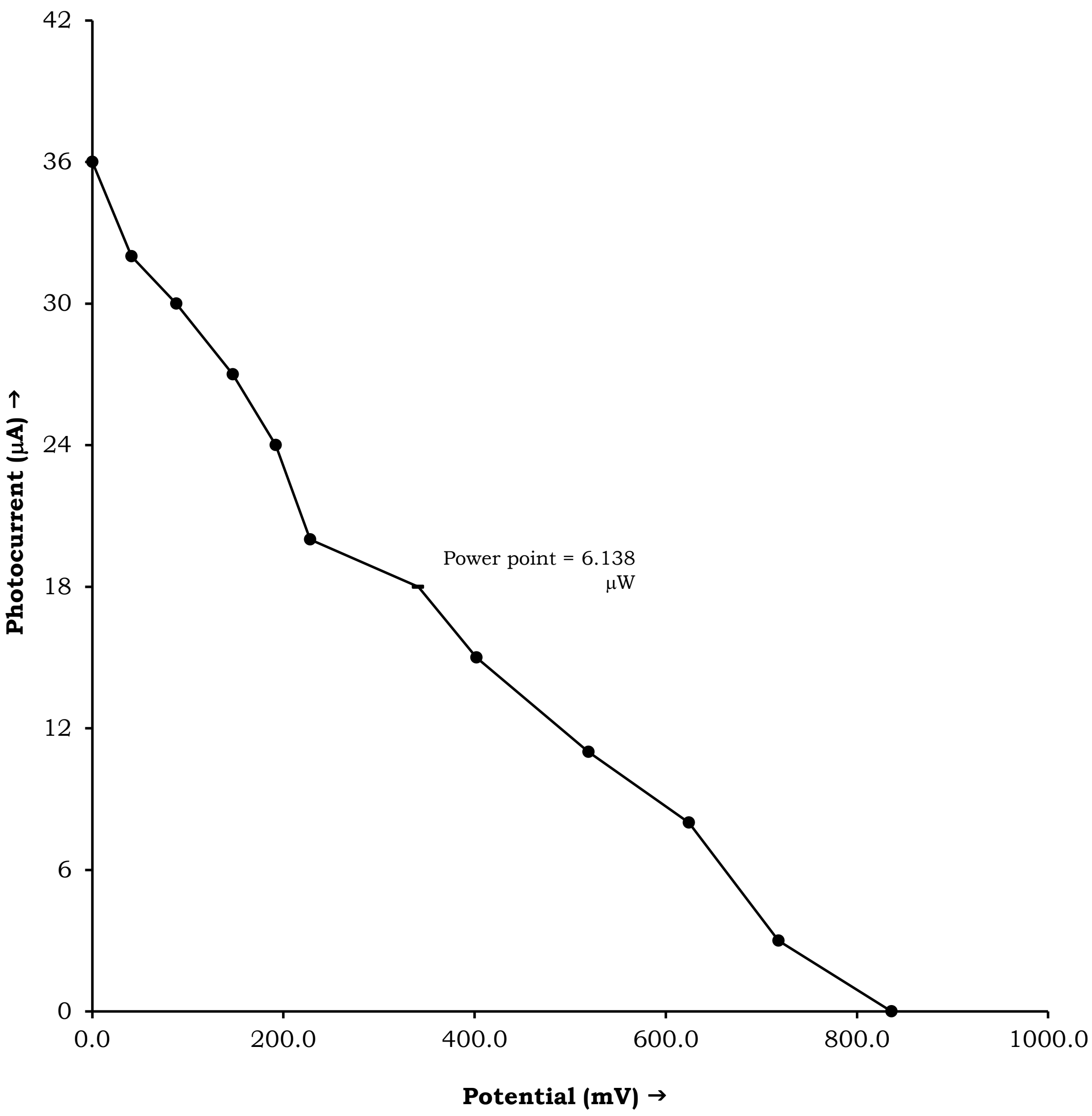

Fig. 2 CURRENT-VOLTAGE (i-V) CURVE OF THE CELL