ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Use of Trypan blue-Arabinose System in Photogalvanic Cell for Solar Energy Conversion and Storage

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Abstract

Photogalvanic effect was studied in the cell containing Trypan blue as photosensitizer in Arabinose-NaOH system. The conversion efficiency of the cell, fill factor and the cell performance were observed 0.80%, 0.23 and 140.0 minutes in dark respectively. The effects of different parameters on the electrical output of the cell were observed and current-voltage (i–V) characteristics of the cell were also studies. The photopotential and photocurrent were observed as 834 mV and 350 μA respectively. The mechanism was proposed for the generation of photocurrent in photogalvanic cell.

Keywords: Fill factor, conversion efficiency, photopotential, photocurrent, storage capacity..

Introductions

The reserve of fossil fuels and wood are depleting very fast, as a results of which energy production is becoming expensive day by day. The search for alternative source of energy has led to rapid strides in the utilization of solar energy [1]. Conversion of solar energy into electrical energy through photogalvanic cell is the most important and desirable route for obtaining electricity. The photogalvanic cell works on photogalvanic effect. This effect was reported by Rideal and Williams [2] but it was systematically investigated by Rabinowitch [3, 4]. Later on many workers studied it from time to time [5-11]. Ameta et al [12-15] reported the photogalvanic cells for solar energy conversion and storage. Use of micelles in photogalvanic cells for solar energy conversion and storage: cetyl trimethyl ammonium bromide-glucose-toluidine blue system studied by Gangotri et al [16]. Comparative Studies in anionic cationic and neutral surfactants in Azur-B – NTA – CPC system in photogalvanic cell was reported by Genwa and Gangotri [17], Role of surfactants in photogalvanic cells for solar energy conversion and storage.

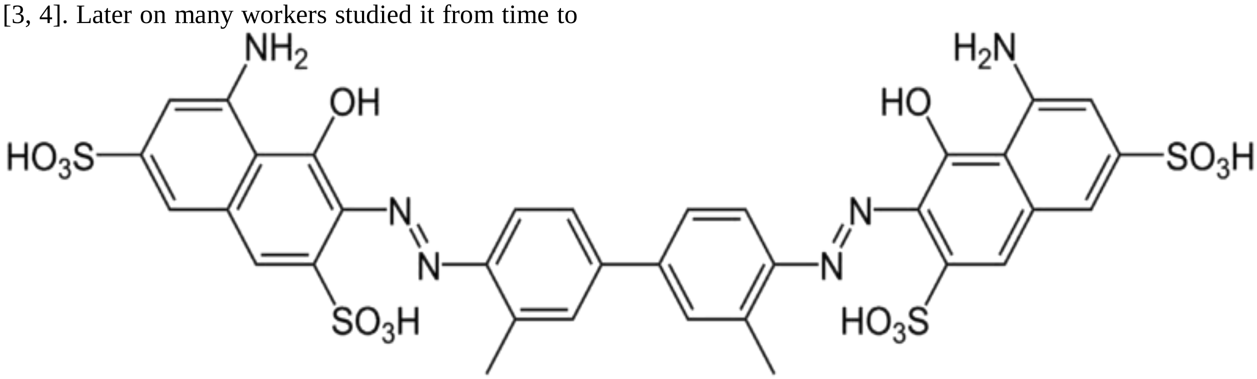

Figure-1 Trypan blue Dye

studied by Gangotri and Bhimwal [18]. Recently, Genwa and sagar [19], Genwa and Chouhan [20], Gunsaria et al [21], Genwa and Khatri [22], Genwa and Singh [23] and Meena et.all [24] reported some new photogalvanic cell systems in view of electrical parameters and solar energy conversion and storage. The present work is an effort to increase the efficiency of photogalvanic cell using Trypan blue-Arabinose-NaOH system in photogalvanic cell for solar energy conversion and storage.

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Materials and methods

Materials

Trypan blue (98%, Loba Chemical, Mumbai), Arabinose (99.9%, Ases Chemical, Jodhpur) and Sodium hydroxide (96%, RFCL, New Delhi) were used in the present work. Solutions of Arabinose, Trypan blue, and NaOH (1N) were prepared in double distilled water (conductivity 3.5 × 10^{-5} Sm^{-1}) and kept in amber coloured containers to protect them from sun light. Trypan blue dye figure 1 is dark greenish-brown powder, odorless, soluble in water and stable under normal temperatures and pressures. Its molecular formula and molecular weight $C_{34}H_{24}N_6Na_4O_{14}S_4$ and 960.80 respectively. Melting point and λmax of dye measured in laboratory and find about >300 ^{0}C and 607 nm in mathanol, 588 nm in water respectively.

Methods

A mixture of solutions of dye (Trypan blue), reductant (Arabinose) and NaOH was taken in an H–type glass tube which was blackened by black carbon paper to unaffected from sun radiation. A shiny platinum foil electrode (1.0 x 1.0 cm^2) was immersed in one limb of the H–tube and a saturated calomel electrode (SCE) was immersed in the other limb. Platinum electrode act as a working electrode and SCE as a counter electrode the whole system was first placed in the dark till a stable potential was attained, then the limb containing the platinum electrode was exposed to a 200 W tungsten lamp (Philips). A water filter was used to cut off thermal radiation. Photochemical bleaching of the dye was studied potentiometrically. Absorption spectra of dye–surfactant combination were noted by using Spectrophotometer (Systronics 106) with the matched pair of silica cuvetts (path length 1 cm). All spectral measurements were duplicated in a constant temperature water bath maintained with in ±1°C and mean values were processed for data analysis. A digital pH meter (Systronics 335) was used to measure the potential and a microammeter (Nucon) was used to measure the current generated by the system respectively. The current voltage characteristics were studied by applying an external load with the help of a carbon pot resistance (log 470 K) connected in the circuit. Over all experimental set up is shown in Figure 2.

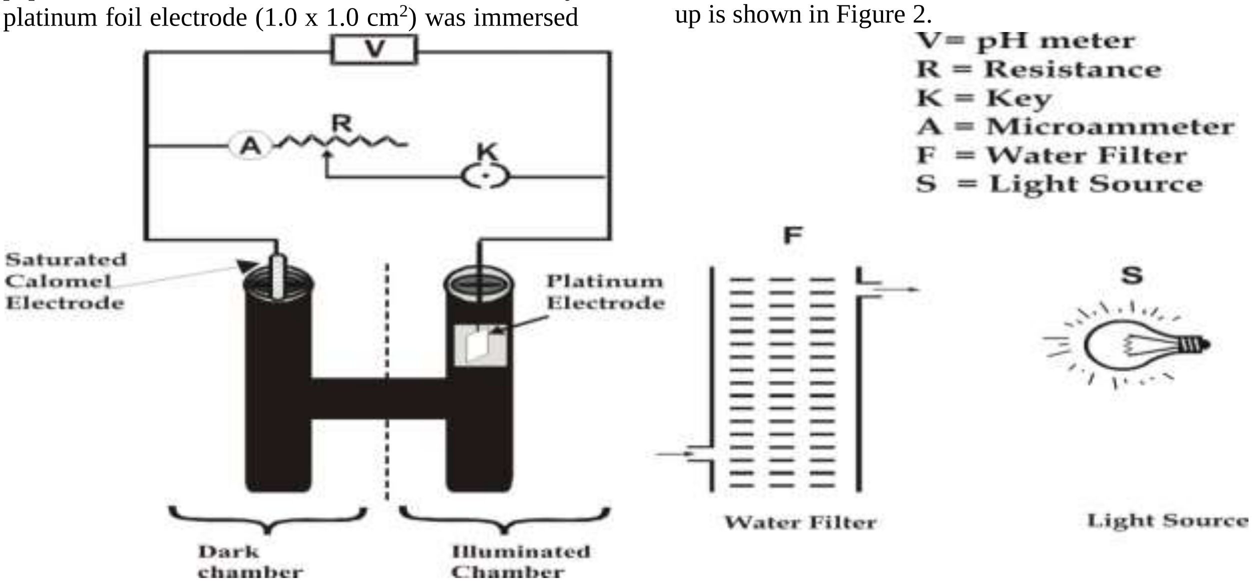

Figure-2 Photogalvanic cell set-up

Results and discussion

Effect of Variation of Trypan blue, Arabinose and NaOH Concentration

The results showing the effect of variation of Trypan blue, Arabinose and NaOH concentration are summarize in Table 1.Variation of dye concentration studied by using solution of Trypan blue of different concentrations. It was observed that the photopotential and photocurrent increased with increase in concentration of the dye [Trypan blue]. A maxima (at 834 mV and 350 μA) was obtained for a particular value of dye concentration (1.6 x 10^{-5} M), above which a decrease in electrical output of the cell was observed. Low electrical output observed at the lower concentration range of dye due to limited number of dye molecules to absorb the major portion of the light in the path, while higher concentration of dye again resulted in a decrease in electrical output because intensity of light reaching the molecule near the electrode decrease due to absorption of the major portion of the light by the dye molecules present in the path, therefore corresponding fall in the electric output of the cell. Reductant concentration also

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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affects the cell output. With the increase in concentration of the reductant [Arabinose], the photopotential and photocurent was found to increase till it reaches a maximum value at 1.1 x 10^{-3} M. These values are 834 mV and 350 µA respectively. On further increase in concentration of Arabinose, a decrease in the electrical output of the cell was observed. The fall in power output was also resulted with decrease in concentration of reductant due to less number of molecules available for electron donation to the cationic form of dye. On the other hand, the movement of dye molecules hindered by the higher concentration of reductant to reach the electrode in the desired time limit and it will also result into a decrease in electrical output. The electrical output of the cell was increased on increasing the concentration of sodium hydroxide [NaOH]. A maximum (834 mV and 350 µA) result was obtained at a certain value (1.2 x 10^{-3} M) of concentration of NaOH. On further increasing the sodium hydroxide concentration it react as a barrier and major portion of the surfactant photobleach the less number of dye molecules so that a down fall in electrical output was observed.

Table-1:- Effect the variation of Trypan blue-Arabinose and NaOH Concentrations.

Light Intensity = 10.4 $mWcm^{-2}$

Temperature = 303 K

Concentrations	**Photopotential (mV)**	**Photocurrent (µA)**
[Trypan blue] x 10^{-5} M		
0.8	732.0	288.0
1.2	785.0	318.0
1.6	834.0	350.0
1.9	795.0	308.0
2.4	698.0	242.0
[Arabinose] x 10^{-3} M		
0.7	738.0	278.0
0.9	785.0	312.0
1.1	834.0	350.0
1.4	776.0	306.0.
1.6	702.0	262.0
[NaOH] x 10^{-3} M		
0.8	712.0	285.0
1.0	768.0	323.0
1.2	834.0	350.0
1.4	778.0	318.0
1.7	723.0	276.0

Effect of pH

Photogalvanic cell containing Trypan blue-Arabinose-NaOH system was found to be quite sensitive to pH of the solution. It was observed that the increase in photopotential and photocurrent of the cell with increase in pH value (in alkaline range). At pH 11.60 a maxima (834 mV and 350 µA) was achieved. On further increase in pH, there was a decrease photopotential and photocurrent. The 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. The results showing the effect of pH are summarized in Table 1.

Effect of Diffusion Length and Electrode Area

Effect of variation of diffusion length (distance between the two electrodes) on the current parameter of the cell (i_{max}) was studied by using H-shaped cells of different dimensions. It was observed that in the first few minutes of illuminations there is sharp increase in the photocurrent. As a consequence, the maximum photocurrent (i_{max}) increases with increase in diffusion length because path for photochemical reaction was increased, but this is not observed experimentally. Where as the equilibrium photocurrent (i_{eq}) decrease linearly. Therefore, it may be concluded that the main electroactive species are the leuco or semi form of dye (photosensitizer) in the illuminated and dark chamber respectively. The reductant and its oxidation product act only as electron carriers in the path. The results are summarized in Table 1. The effect of electrode area on the current parameters of the cell was also studied. It was observed that with the increase in the electrode area the value of maximum photocurrent (i_{max}) is found to increase. The results are summarized in Table 1.

Effect of Light Intensity

The intensity of light was also affects the electrical output of the cell. It was observed that photocurrent shows a linear increasing behavior with the increase in light intensity whereas photopotential increased in logarithmic manner. This increasing behavior of electrical output due to increase in number of photons with increase in light intensity. The effect of variation of light intensity on the photopotential and photocurrent is graphically represented in Figure 3.

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Scientific Journal Impact Factor: 3.449
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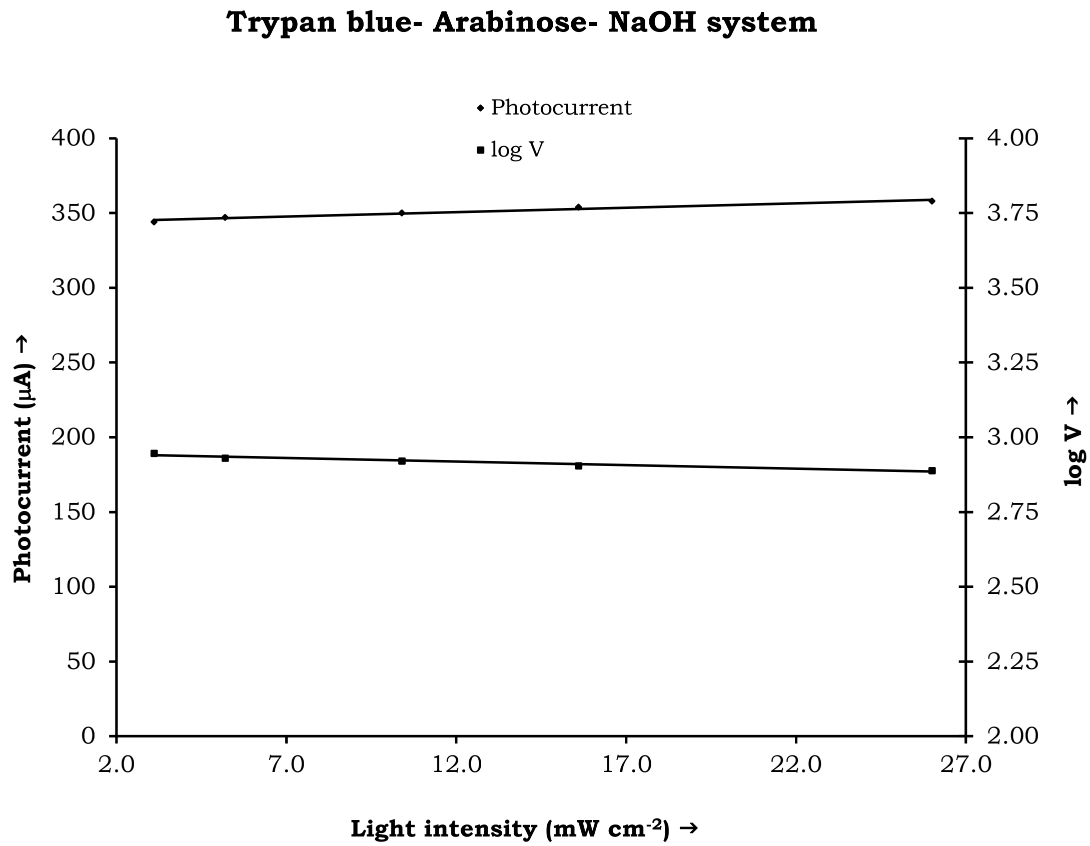

Figure -3 Variation of photocurrent and log v with light intensity

i–V Characteristics

The open circuit voltage (V_{oc}) and short circuit current (i_{sc}) of the photogalvanic cell were measured under the continuous illumination of light, with the help of digital pH meter (keeping the circuit open) and a microammeter (keeping the circuit closed) respectively. The potential and current in between these two extreme values (V_{pp} and i_{pp}) were recorded with the help of a carbon pot resistance (log 470 K) connected in the circuit of microammeter through which an external load applied. i-V characteristics of the cell containing Trypan blue-Arabinose-NaOH system is shown in current-potential curve (Figure 4). It was observed that i-V curve deviated from its regular rectangular shape. A point in the i-V curve, called power point (pp), was determined where the product of curve of current and potential was maximum. With the help of i–V curve, the fill-factor was calculated as 0.23 using the formula:

$$\text{Fill factor}(\eta) = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}} \quad (1)$$

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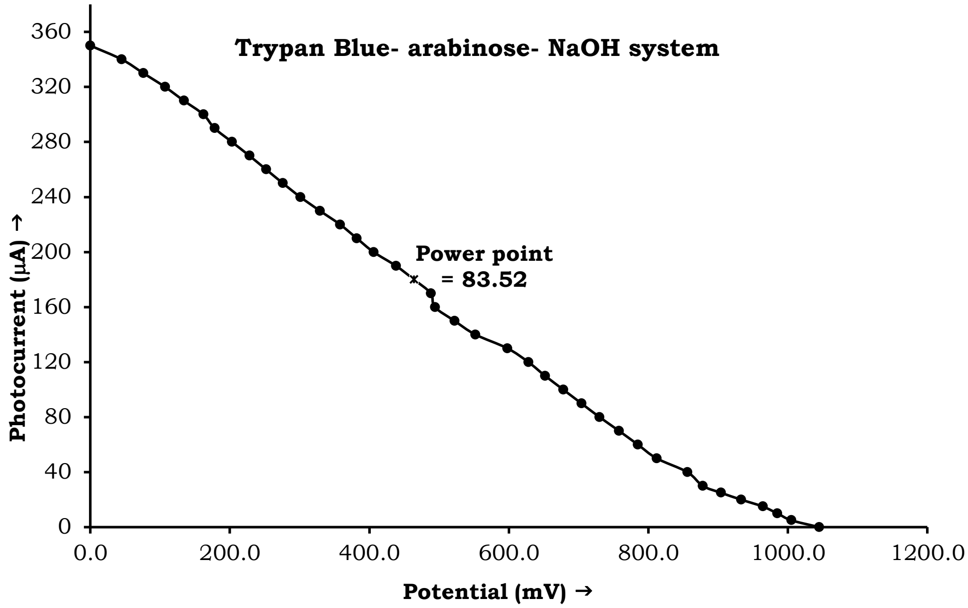

Figure -4 Current-potential (i-v) curve of the cell

Cell Performance and Conversion Efficiency

The performance of the photogalvanic cell was observed by applying an external load (necessary to have current at power point) after termination the illumination as soon as the potential reaches a constant value. The performance was determined in terms of $t_{1/2}$, i.e., the time required in fall of the output (power) to its half at power point in dark. It was observed that the cell can be used in dark for 140.0 minutes. Performance of the cell is graphically shown in figure 5. Conversion efficiency of the cell was determined as 0.80%, using the formula:

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{A \times 10.4 mWcm^{-2}} \times 100\% \qquad (2)$$

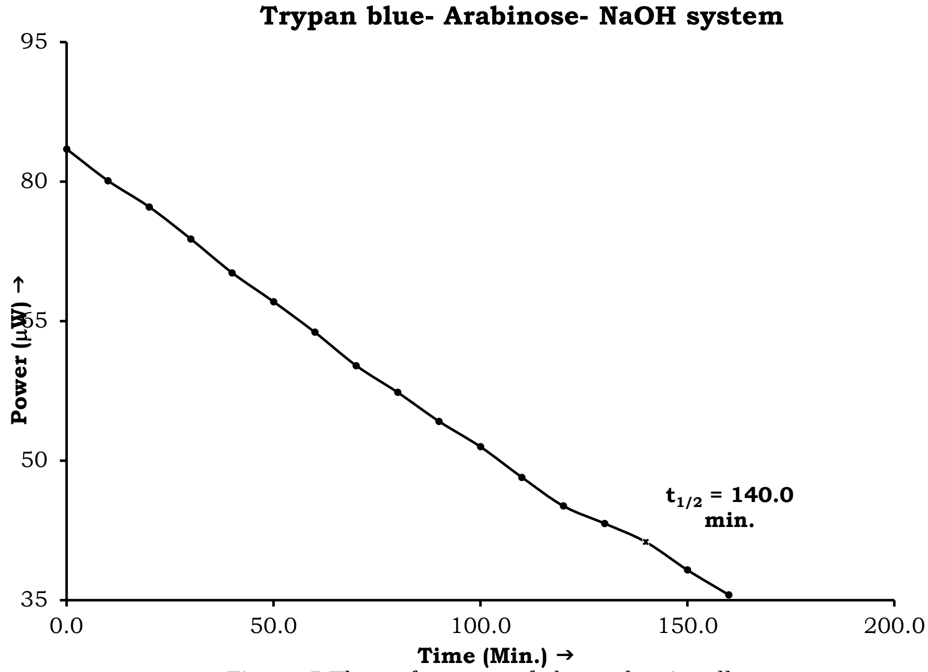

Figure -5 The performance of photogalvanic cell

Mechanisms

When certain dyes are excited by the light in the presence of electron donating substance (reductant), the dyes are rapidly changed into colorless form. The dye now acts as a powerful reducing agent and can donate electron to other substance and reconverted to its oxidized state. On the basis of earlier studies a tentative mechanism in the photogalvanic cell may be proposed as follows:

Illumination Chamber

On irradiation, dye molecule get excited:

$$\text{Dye} \xrightarrow{h\upsilon} \text{Dye}^* \quad \ldots \text{(i)}$$

The excited dye molecule accepts an electron from reductant and converted into semi or leuco form of dye and the reductant into its excited state:

$$\text{Dye}^* + R \longrightarrow \text{Dye}^- \text{(semi or leuco)} + R^- \quad \ldots \text{(ii)}$$

At Platinum Electrode

The semi or leuco form of dye loses an electron and converted into original dye molecule:

$$\text{Dye}^- \longrightarrow \text{Dye} + e^- \quad \ldots \text{(iii)}$$

Dark Chamber

At Counter Electrode

$$\text{Dye} + e^- \longrightarrow \text{Dye}^- \text{(semi or leuco)} \quad \ldots \text{(iv)}$$

Finaly semi/leuco form of dye and oxidized form of reductant combine to give original dye and reductant molecule and the cycle will go on:

$$\text{Dye}^- + R^+ \longrightarrow \text{Dye} + R \quad \ldots \text{(v)}$$

Here Dye, Dye*, Dye^-, R and R^+ are the dye, its excited form, leuco form, reductant and its oxidized form, respectively.

Conclusions

The photogalvanic conversion of solar energy has attracted attention of scientists towards solar energy conversion and storage. This cell undergoes cyclical charging and discharging process. The charging of cell occurs only in presence of illuminating source. The discharging of cell takes place only when we apply the external circuit for electron transfer. As long as there is no external circuit, the cell will keep light energy stored. The photogalvanic cell have inbuilt storage capacity and stored energy can be used in absence of light whereas photovoltaic cells needs extra hardware as batteries for energy storage, photogalvanic cells are economic than photovoltaic cells because low cost materials are used in these cells. The Conversion efficiency, storage capacity and fill factor are recorded as 0.80%,

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$t_{1/2}$ 140.0 min. and 0.23 respectively in Trypan blue-Arabinose-NaOH system.

Acknowledgements

Authors are thankful to Professor MRK Sherwani, Head, Department of Chemistry, Jai Narain Vyas University, Jodhpur, Rajasthan-342001 (India) for providing all the necessary facilities. One of the auther (Mohan Siwanchawat) is also thankful to UGC New Delhi for providing financial assistance.

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ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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