Comparative Study of Photogalvanic Cells: A Detailed Analysis of Erythrosine-Tween -80 Based Photogalvanic Systems for Solar Energy Harvesting

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Abstract: ***Photogalvanic cells employ a reversible photochemical redox process to store electricity reliably. It is crucial to differentiate between photovoltaic and photogalvanic cells. While photovoltaic cells generate electricity by directly exciting an electron with a photon, photogalvanic cells involve the excitation of a molecule by a photon, triggering a chemical reaction that produces high-energy products. These high-energy products can subsequently release their energy electrochemically, functioning similarly to a conventional battery. Photogalvanic cells harness light using the relatively narrow absorption bands of specific molecules. In this study, erythrosine was used as a photosensitizer, D-xylose as a reductant, and Tween-80 as a surfactant for solar energy harvesting. The system achieved a maximum photocurrent of 440.00 µA, a photopotential of 820.00 mV, and a power output of 287 µW. The conversion efficiency of the system was 2.92%, with an energy storage capacity of 75.0 minutes in the dark. The present study investigated various factors influencing the performance of photogalvanic cells, including the concentrations of reductant and surfactant, pH, diffusion length, electrode area, temperature, and light intensity. Higher concentrations of reductant generally increase photocurrent, although this may lead to reduced efficiency due to stability issues. Increasing surfactant concentration lowers surface tension and enhances emulsification, but it may also introduce toxicity and environmental concerns. The pH has a positive effect on electrical output within a specific range, while diffusion length impacts charge carrier mobility, current density, and the cell's sensitivity to light intensity.***

Keywords: Photogalvanic cells, Solar Energy; Conversion Efficiency

I. Introduction

Solar energy conversion and storage are accomplished through the employment of photovoltaic and photogalvanic technologies. Although Rabinowitch (1940) conducted a thorough investigation on the photogalvanic effect in an endergonic photochemical reaction between iron and thionine, Rideal and Willians (1925) made the initial observation of it.. The potential of photogalvanic cell was studied by Albery and Archer (2019) and they observed that the conversion efficiency of the photogalvanic cell could be as large as 18% that all the requirements can be fulfilled is improbable. A more reliable estimate of the maximum power conversion efficiency that could be achieved from a photogalvanic cell is between 5% and 9%. Pan et al (2020)., Dixit and Mackay (2023), Hamdi and Aliwis (2023), Bayer et al (2022), and Jinting et al. (2022) have reported the various systems in photogalvanic cell for solar energy conversion and storage. The variation of the power output with the concentrations of the reductant, surfactant, Sodium hydroxide and variation of diffusion length and other parameters of the cell is found. The photogalvanic effects were observed for solar energy conversion and storage in various systems by Dube and Sharma (2022), Lal et al (2013), Gangotri and Pramila (2007), Pramila and Gangotri (2009), Genwa and Genwa (2004), Kumari et al. (2018) Genwa and Khatri (2009) Genwa et al. (2006), Gangotri and Gangotri (2001), and Gangotri and Bhimwal (2010). The photogalvanic behavior of [Cr_2 O_2 S2(1-Pipdtc)2] in aqueous DMF was studied by Pokhrel and Nagaraja (2009).

Groenen et al. (2016) observed micelles effect in the ferrous/thionine photogalvanic cell for solar energy conversion. Gangotri and Pramila (2007), and Ghosh and Bhattacharya (2022) observed anionic micelles effect in photogalvanic cells for solar energy conversion and storage. The correct measurement of the efficiency of solar cells as a basis for their comparative techno-economic analysis was study by Koltune (2020). The stability of photochemical mechanism for photogalvanic cells was observed by Dung and Kozakis (2021). The cells included phenosafranin-EDTA and various redox couples. The photogalvanic effect with potassium naphthalenidein-tetrahydrofuran solution was also studied by Miyashita (2022). Memming (2022) suggested the process of solar energy conversion by photoelectrochemical process. The transient process in photogalvanic cells was studied by Daul et al (2023). On the basis of observed results, the Congo red- D-Xylose, Tween-80 system is the best with all the respects followed by Rose Bengal-D-Xylose ,Tween-80 system and Rhodamine-B,- D-Xylose- Tween-80 system and Erythrosine,- D-Xylose-Tween-80 system. According to observed results the order is all right but the overall performance of photogalvanic cells is also most equal ie, the difference of overall output is equal. It is very important to observe that the selection of the substrates is very much near to absolute values with respect to the type of substrates used. Further, it is the most encouraging observing that selected systems have the remarkable electrical output, conversion efficiency and storage capacity of the Photogalvanic cells so developed.

II. Used Chemical Materials, Instruments and Method

2.1 **Used Chemical Materials:** In the present work Erythrosine was used as photosensitizers with D-Xylose as reductant and Tween- 80 as nonionic surfactant in alkaline media**.** All used chemicals are listed in Table 1.

Table 1: Used Chemical Materials

S.No.	Used Chemical	Molecular Weight	Manufacturer/ Brand
1.	Erythrosine	879.86 g/mol	ASES Chemicals , Jodhpur
2.	D-Xylose	150.13 g/mol	CDH fine Chemicals
3.	Tween 80	1310.00 g/mol	RANKEM
4	NaOH	39.997 g/mol	RANKEM

2.2 Instruments: Various instruments are used in solar energy harvesting by photogalvanic cells. All used instruments are listed in Table 2.

Table 2.Used Instruments

S.No.	Name of Instrument	Manufacturer/Brand
1	UV-Visible Spectrophotometer	Systronics Model -119
2	Microammeter	R.Simpson
3	Voltammeter	R.Simpson
4	Digital pH Meter	Systronics model-335
5	Electric Balance	Wenser
6	Resistance	carbon pot log 470 K
7	H cell	Borasil Glass

2.3 Experimental Method

A mixture of very dilute solutions of photosensitizer, surfactant, reductant, and sodium hydroxide was taken in an H-type glass tube blackened except for a window. One limb of the H-tube containing a window was immersed in a platinum electrode (area of 0.2 mm) and the other limb was immersed in a saturated calomel electrode (SCE). A stable potential was first established by placing the cell in the dark, then exposing the limb containing the platinum electrode to sunlight/artificial light emitted from the tungsten filament based incandescent light bulb of 200 watt.

In preliminary, the circuit is kept open in dark till it attains a stable photopotential. Then, Pt electrode is exposed to diffused light radiations. On illumination, the potential (v) and current (i) are generated by the photogalvanic system. The maximum photopotential (Vmax), open-circuit potential (Voc), maximum current (imax), and equilibrium current (ieq) of the PG cell are measured after it has been charged.The generated photo potential and photocurrent of the systems were measured with the help of the digital pH meter (Systronics model-335) and microammeter (R.Simpson), respectively. The microammeter was also connected to a key to close one circuit and open the other. Using a resistance (a carbon pot log 470 K) connected to a circuit; we have studied the current-voltage characteristics of photogalvanic cells. After the illumination was turned off and the potential reached a constant value, an external load (required to have current at power point) was applied to test the storage capacity of photogalvanic cell's. The time it takes for the electrical output (power) to decrease by half at the power point in the absence of light, or $t_{1/2}$, was used to compute the storage capacity.

Conversion efficiency of a systems containing Erythrosine as photosensitizer (dye), D-xylose as reductant, and Tween 80 as nonionic surfactant in alkaline medium was calculated using the electrical output at power point and the power of incident radiation by using a 0.2 cm^2 area of Pt electrode.

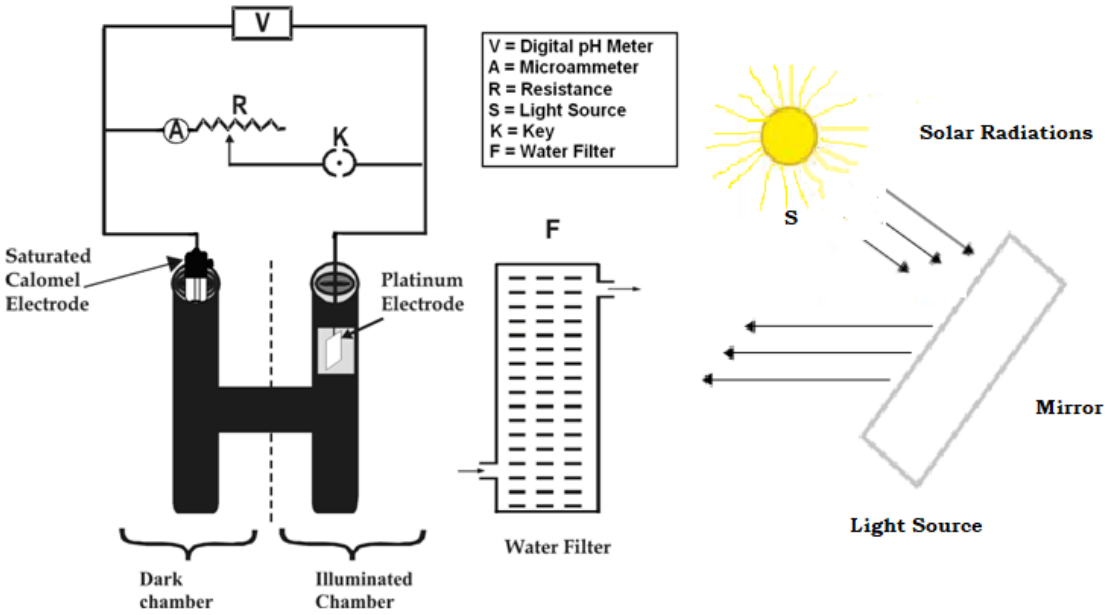

Figure 2.3.1.Experimental set-up of Photogalvanic Cell

The platinum (Pt) electrode has high electro catalytic activity but suffers from the problems of high cost and poor stability in desensitized solar cells. The conversion efficiency of the photogalvanic cell was obtained as 2.32 % by using the following formula:

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{10.4 mWcm^{-2} \times Electrode\ area\left(cm^2\right)} \times 100\% \quad \text{.....(1)}$$

Where $v_{pp,}$ and i_{pp} are photopotential at power point, current at power point. An electrode area was 0.5cm^2 (Thickness of 0.2 mm), and average sunlight intensity (10.4mW cm^{-2} for artificial light source), respectively. Light intensity refers to the strength or amount of light produced by source of light. An external load was provided to a carbon pot (log 470 K) that was coupled in a microampere circuit to measure the current and potential values between these two extremes. A point in the i-V curve, called the power point (pp), was determined where the product of current and potential was maximum, and the fill-factor was calculated using the following formula:

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

….(2)

The value of fill factor (η) of all the systems was obtained and the power points of cells (pp) were determined on the system.

III. Result and Discussion:

The photogalvanic cell was first of all placed in dark till it attained a stable solar photo-potential and then the platinum electrode was exposed to light source and other part of the cell was kept in dark. The photo-potential of the cell can be impacted by several factors, including dust, pollutants, and shade, which can alter the cell's exposure to light. It was observed that solar photo-potential changes on illumination and it reached a constant value after a certain period. When the light source was removed, the direction of change in solar photo-potential was again obtained after sometime. Photo-potential production is strongly influenced by the quantity of light that strikes the cell. Due to variations in sunlight intensity, the current generated by the cell undergoes fluctuations throughout the day. The electrodes in a photogalvanic cell play a crucial role in converting light energy into electrical energy. The composition of the electrolyte or solution in the cell can influence its performance with time. Changes in the concentration or properties of the electrolyte can lead to variations in the photo-potential generated. Components of photogalvanic cells can degrade over time due to prolonged exposure to light, chemical reactions within the cell, or other environmental factors. This degradation can lead to a decrease in the cell's efficiency and photo-potential output.

3.1 Variation Of Solar Photocurrent With Time

It was observed that there was arapid rise in solar photocurrent of Erythrosine-D-Xylose-Tween-80 system in photogalvanic cell when it was illuminated and it reaches a maximum value within few minutes.This value is denoted by i_{max} (Maximum Solar photocurrent).Then the solar photocurrent was found to decrease gradually with the period of illumination finally reaching a constant value at equilibrium. This value is represented as i_{eq} (Solar photocurrent at equilibrium).The solar photocurrent was found to decrease on removing the source of light.

3.2 Effect of Variation of Dye (Erythrosine) Concentration

It was observed that the solar photo-potential and solar photocurrent was increased with the increase in concentration of the dye (Erythrosine) in photogalvanic cell containing D-Xylose, Tween-80 and NaOH solutions. A maximum was obtained for a particular value of Erythrosine concentration, above which there was decrease in the electrical output of the cell.

3.3 Effect of Variation of Reductant (D-Xylose) Concentration

With the increase in concentration of the reductant (D-Xylose) in the photogalvanic cell containing Erythrosine, Tween-80 and NaOH solutions, the solar photo-potential was found to increase till it reached maxima. The electrical output of the cell was seen to decrease when the reductant (D-Xylose) concentration increased.

3.4 Effect of Variation of Surfactant (Tween-80 System) Concentration

The effect of variation of Tween-80 concentration was investigated in Erythrosine –D-Xylose-Tween-80systems in photogalvanic cell. It was observed that electrical output of the cell was found to increase on increasing the concentration of surfactant reaching a maximum value. On further increase in their concentrations, a fall in solar photo-potential, solar photocurrent and power of the photogalvanic cell was observed.

3.5 Effect of Variation Of pH

Photogalvanic cell containing Erythrosine--D-Xylose-Tween-80 system was found to be quite sensitive to the pH of the solution. It was observed that there was an increase in the solar photo-potential of this system with the increase in pH value (in the alkaline range) at **pH =12.60** a maxima wereobtained. Onfurther increase in pH, there was a decrease in solar photo-potential in system.

3.6 Effect of Diffusion Length

The effect of variation of diffusion length (distance between the two electrodes) on the current parameters of the cell ($i_{max,}$ i_{eq}) and initial rate of generation of solar photocurrent) was studied using H-shaped cell of different dimensions.It was observed that with an increase in diffusion length. So virtually, it may be considered as unaffected by the changes in diffusion length.

3.7 Effect of Electrode Area

It was also investigated how the electrode area affected the cell's current characteristics. It was found that the maximum solar photocurrent (imax) value was practically independent of this fluctuation when the electrode area was increased (in fact, it was impacted in the opposite way).

3.8 EFFECT OF TEMPERATURE

With an increase in the temperature, the solar photocurrent of the photogalvanic cell was found to increase with a corresponding rapid fall in solar photo-potential.The effect of temperature on total possible power output in the Erythrosine–D-Xylose –Tween-80system was also studied and it was observed that with the increase in temperature (temperature range under observation) the power output of the cell increase slowly irrespective of the rapid fall in solar photo-potential.

3.9 Current- Voltage (i-V) Characteristics of The Cell

The short circuit current (i_{sc}) and open circuit voltage (V_{OC}) of the photogalvanic cells were measured with the help of a micro ammeter (keeping the circuit closed) and with a digital pH meter (keeping the other circuit open), respectively. The solar photocurrent and solar photo-potential values in between these two extreme values were recorded with the help of a carbon pot (log 470 K) connected in the circuit of micro ammeter, through which an external load was applied. It was observed that Current-Voltage (i-V) curve deviated from their regular rectangular shapes. The value of fill factor (η) =0.41905 was obtained at power point and power point of cell (pp)=196.10 μW was determined on the system.

3.10 Storage Capacity of the Photogalvanic Cell

The storage capacity of the photogalvanic cell was observed by applying an external load (necessary to have current at power point) after terminating the illumination as soon as the potential reached a constant value. The storage capacity was determined in terms of $t_{1/2}$ i.e., the time required in fall of the electrical output (power) to its half at power point in dark. It was observed that the photogalvanic cell can be used in dark for **75.0 minutes**.

3.11 Conversion Efficiency of the Photogalvanic Cell

With the help of current and potential values at power point (pp) and the incident power of radiations, the conversion efficiency of the cell was determined as **2.92%** in the Erythrosine –D-Xylose –Tween-80 systems

3.12 The Performance of Photogalvanic Cell

The overall performance of the photogalvanic cell was observed and reached to remarkable level in the performance of photogalvanic cells with respect to electrical output, initial generation of solar photocurrent, conversion efficiency and storage capacity of the photogalvanic cell. The results so obtained in the Erythrosine –D-Xylose –Tween-80system are summarized in **table 3**

TABLE 3
THE PERFORMANCE OF PHOTOGALVANIC CELL

(Erythrosine) 6.56×10^{-5} M — Light Intensity=10.4 Mw cm^{-2}
(D-Xylose)=3.04×10^{-3} M — Temperature=299 K
(Tween-80 System)=2.56×10^{-3} M — pH=12.60

S. N.	Parameters	Observed Results
1	Dark Potential	**215.0 min.**
2	Open Circuit Voltage (Voc)	**1035**
3	Solar Photopotential	**820**
4	Equilibrium Photocurrent (ieq)	**350**

5	Maximum Photocurrent (imax)	**440**
6	Initial Generation of Photocurrent	**50.74**
7	Storage Capacity(t1/2)	**75.0min.**
8	Photopotential at power point (Vpp)	**690**
9	Photocurrent at power point (Ipp)	**220**
10	Conversion Efficiency	**2.92%**
11	Fill Factor	**0.41905**

Conclusions:

In conclusion, the system explores the dynamics of light absorption in photogalvanic cells, focusing on variations in photopotential, photocurrent, and electrical output concerning changes in photosensitive material, light intensity, photochemical reaction rates, electrolyte dynamics, and cell configuration. The results so obtained are higher in comparison to previous work and suitable for initial stage of commercialization.

Acknowledgement: Authors are thankful for the Head, Department of Chemistry for provide lab facility to complete the research work.

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