


**Research Article**

# Study of High-Efficient Dye-Sensitized Liquid Phase Photogalvanic Cell Composed with Natural Dye Curcumin, Fructose and Tween 80 Chemicals for Solar Power Generation

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**ABSTRACT**

A photogalvanic cell is a device that converts solar energy into electrical energy by coupling a photosensitizer dye with a redox-active medium. Unlike conventional photovoltaic cells using semiconductors, photogalvanic cells rely on light-induced chemical reactions in solution to generate current and voltage. The goal of this research work is to utilize a natural dye-based Curcumin-fructose-tween 80 photogalvanic cell to capture and store solar energy. This chemical mixture demonstrated the ability to generate maximum power, with a storage half-life of 130 minutes under artificial, relatively weak illumination of 10.4 mWcm<sup>-2</sup>. In this experiment, the recorded values for conversion efficiency, fill factor, output at the power point, open-circuit photopotential, and equilibrium photocurrent were 1.16%, 0.1594, 121.43 μW, 1009 mV, and 755 μA, respectively.

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**KEYWORDS:** Curcumin, Fructose, Tween 80, Photogalvanic effect, fill factor, conversion efficiency.

## 1. INTRODUCTION

The combustion of fossil fuels is responsible for more than 75% of greenhouse gas emissions worldwide, leading to global warming and unstable climate conditions. Renewable like solar, wind, hydro and geothermal produce near-zero emissions, providing the clearest path to meeting Paris agreement goals: net-zero by 2050. Solar power is among the most plentiful and renewable energy resources on our planet. It originates from the sun's radiation, which can be captured and utilized through different technologies, including photovoltaic cells, solar thermal devices, and photogalvanic systems. Rising worldwide demand for sustainable energy has accelerated progress in solar technologies, positioning them as a vital tool in lowering greenhouse gas emissions and addressing climate change. Solar energy is not only environmentally friendly but also offers long-term economic benefits due to decreasing costs of installation and maintenance. It plays a crucial role in diversifying energy portfolios and enhancing energy security for both developed and developing countries.<sup>[1]</sup> Solar energy is the energy we get from the sun in the form of sunlight and heat. It is one of the most abundant and sustainable sources of energy available on Earth. Every day, the sun emits vast amounts of energy much more than we currently use globally. By harnessing this energy using various technologies, we can generate electricity, heat water and power homes, businesses and even vehicles. In a photogalvanic cell, light is absorbed by a photosensitive dye present in the electrolyte. When the dye molecules absorb light, they become excited and donate electrons to an electron acceptor. This process initiates a redox cycle that generates a potential difference between two electrodes, known as the photogalvanic effect, which drives the flow of electric current. A photogalvanic cell is an important device for converting solar energy into electricity through this mechanism [2]. The effect was first noticed in the equilibrium system of ferrous–ferric and iodine–iodide, but it was later studied more extensively in the Thionine–Fe system [3-6]. Thionine has also been combined with poly (N-methylolacrylamide) to form a polymer–dye complex. Depending on the ratio of polymer to dye, the absorption spectrum shows a red shift compared to that of free thionine. The efficiency and potential of photogalvanic cells are strongly influenced by this polymer–dye ratio [7]. The photogalvanic effect has been examined using the Methylene blue–EDTA–Sodium lauryl sulphate system, where a photocurrent of 190  $\mu\text{A}$  and a photopotential of 654 mV were recorded [8]. In another study, surfactants such as Sodium lauryl sulphate, Tetradecyl trimethyl ammonium bromide, and Brij-35 were incorporated into a photogalvanic cell employing Azur A as the photosensitizer and glucose as the reductant for solar energy conversion and storage [9]. A dye-sensitized system with Toluidine blue as the photosensitizer, glucose as the reductant, and Tergitol-7 as the surfactant produced a photocurrent of 70  $\mu\text{A}$  and a photopotential of 315 mV [10]. Similarly, the CTAB–glucose–Toluidine blue configuration yielded a photocurrent of 35  $\mu\text{A}$  along with a photopotential of 175 mV. The conversion efficiency, maximum power and storage time were found to be

0.0578%, 6.26  $\mu\text{W}$  and 6 minutes respectively [11]. In another investigation, a photogalvanic cell comprising EDTA with a mixed photosensitizer system of methylene blue and toluidine blue produced a photopotential of 742.0 mV and a photocurrent of 110.0  $\mu\text{A}$ . This system demonstrated a conversion efficiency of 0.5398% with a maximum power output of 81.62  $\mu\text{W}$ , and it was capable of operating for 34.0 minutes in the absence of light [12]. Further, Gangotri and Lal examined the photogalvanic effect in a cell containing methylene blue and Azur B as photosensitizers. Their study reported a conversion efficiency of 0.1165% and a maximum power output of 51.24  $\mu\text{W}$  at the power point [13]. The photogalvanic effect was investigated in a cell using ascorbic acid as the reductant and eosin as the photosensitizer, where the conversion efficiency, maximum power, and storage capacity were reported as 0.4474%, 46.5  $\mu\text{W}$ , and 36.0 minutes, respectively [14]. Another study explored a system containing nitrilotriacetic acid with Azur B, along with different surfactants—sodium lauryl sulphate, cetyl pyridinium chloride, and Tween 80—for solar energy conversion. The conversion efficiencies observed for the anionic, cationic, and nonionic surfactants above their critical micelle concentrations were 0.4053%, 0.1386%, and 0.2177%, with storage capacities of 105, 31, and 74 minutes, respectively [15]. In addition, a dye-sensitized photogalvanic cell employing EDTA with methylene blue and thionine showed a conversion efficiency of 0.43%, delivering a maximum power output of 67.68  $\mu\text{W}$ , and sustaining operation for 30 minutes in the dark [16]. A dye-sensitized photogalvanic cell utilizing the dioctylsulfosuccinate–mannitol–safranin system has been employed for solar energy conversion into electricity. Analysis of its current–voltage characteristics revealed a conversion efficiency of 0.7603%, a fill factor of 0.50, and a storage capacity of 40.0 minutes [17]. In another study, the photogalvanic effect was examined in a Tween-80–EDTA–Safranin-O system. This configuration exhibited a conversion efficiency of 0.9769%, a fill factor of 0.34, and a maximum power output of 235.50  $\mu\text{W}$ . The initial current generation rate was 80.0  $\mu\text{A min}^{-1}$ , and the cell retained functionality for 60.0 minutes under dark conditions [18]. Gangotri and Bhimwal investigated a photogalvanic cell employing eosin as the photosensitizer and arabinose as the reductant for solar energy conversion. The system exhibited a conversion efficiency of 0.7026% and a fill factor of 0.2856 at the power point. After 140 minutes of irradiation, the cell was capable of operating for 85.0 minutes in the absence of light [19]. In another study, Gangotri and Indora utilized a mixed reductant system consisting of dextrose and EDTA, along with Azur A as the photosensitizer, to develop a photogalvanic cell aimed at reducing construction costs for commercial feasibility. This configuration yielded a maximum power output of 10.87  $\mu\text{W}$ , a conversion efficiency of 0.1045%, and a fill factor of 0.1942 [20]. The photogalvanic behavior of Brilliant cresyl blue with fructose in an alkaline medium has been investigated to improve the efficiency and storage capacity of solar energy conversion. The system demonstrated a maximum potential of 1115 mV, a maximum photocurrent of 785  $\mu\text{A}$ , a short-circuit

current of 590  $\mu\text{A}$ , a power output of 183.3  $\mu\text{W}$  at the power point, and an overall conversion efficiency of 1.9586% [21]. In another study, a photogalvanic cell based on the Safranin–sodium lauryl sulphate–D-xylose system was explored to enhance the electrical performance and output of the device. A conversion efficiency of 0.68% and a fill factor of 0.32 were recorded at the power point of the photogalvanic cell [22]. In another investigation, Rhodamine B with fructose in an alkaline medium was employed to improve the electrical performance of the system. The measured parameters included a maximum potential of 1071 mV, a maximum photocurrent of 1049  $\mu\text{A}$ , a short-circuit current of 972  $\mu\text{A}$ , and a power output of 244.02  $\mu\text{W}$  at the power point. This configuration achieved a conversion efficiency of 7.58% and demonstrated a storage capacity of 3.6 hours [23]. A photogalvanic cell employing Tergitol-7, EDTA, and Azur B for solar energy conversion and storage produced a photopotential of 778.0 mV and a photocurrent of 45.0  $\mu\text{A}$ , corresponding to a conversion efficiency of 0.14% and a fill factor of 0.3169. The cell-maintained performance for 40.0 minutes in the absence of light [24]. In another study, the photogalvanic response of the xylydine ponceau–Tween 60–ascorbic acid system was examined, where the device generated a maximum power output of 68.77  $\mu\text{W}$  under optimal conditions. Conversion efficiency in this case was calculated from the observed photopotential and photocurrent at the power point. Additionally, Nile Blue, in combination with arabinose, was utilized as a photosensitizer–reductant pair in a photogalvanic cell. This system exhibited a conversion efficiency of 0.6095% with a fill factor of 0.2566, demonstrating suitability for enhanced energy conversion and storage [25–26]. The photogalvanic effect was examined in a cell containing Tween-80 as a non-ionic surfactant, Toluidine Blue as the photosensitizer, and EDTA as the reductant. The system produced a photopotential of 430 mV, a photocurrent of 50  $\mu\text{A}$ , and a storage capacity of 60 minutes. Conversion efficiency and fill factor were also evaluated for this configuration [27]. In a separate investigation, Yadav and Sharma [28] reported the photogalvanic activity of a cell employing Azur C with nitrilotriacetic acid in alkaline medium. The device delivered a maximum photopotential of 347 mV, a photocurrent of 70  $\mu\text{A}$ , and a power output of 19.84  $\mu\text{W}$ . The corresponding conversion efficiency was 0.19%, and the storage capacity in dark conditions was 38 minutes. Yadav and co-workers have reported a series of studies demonstrating effective electrical performance of photogalvanic cells employing different dyes as photosensitizers. Their research also examined the role of

surfactants in enhancing cell efficiency and investigated innovative photogalvanic cell configurations, with particular emphasis on electrical characteristics, solar energy conversion, and storage capabilities [29–32]. Although various photosensitizers, surfactants, and reductants have been employed in photogalvanic cells for solar energy conversion, limited attention has been given to the use of natural dye curcumin in combination with fructose and Tween-80 as active materials to enhance electrical output and overall cell performance. Therefore, the present study aims to investigate this system to achieve improved efficiency and explore the potential for commercial viability of photogalvanic cells.

## 2. RESULT AND DISCUSSION

### (a) Effect of variation of curcumin, fructose and tween 80 concentration:

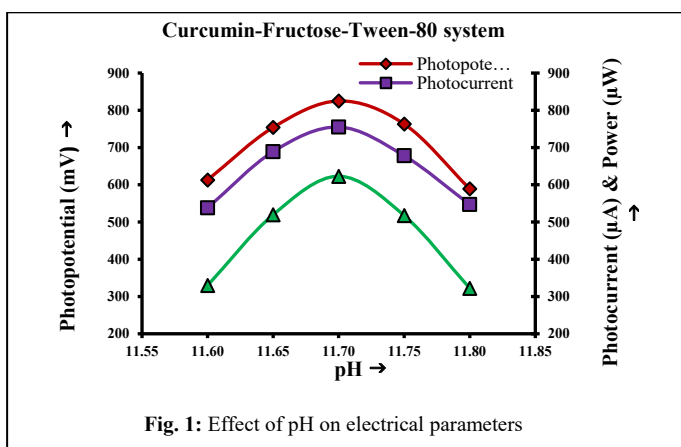
The effect of varying the concentrations of Curcumin, fructose, and Tween-80 on the photogalvanic cell performance is summarized in Table 1. The influence of dye concentration was investigated using Curcumin solutions at different molarities. It was observed that the photopotential, photocurrent, and power output increased with rising Curcumin concentration, reaching maximum values at  $2.2 \times 10^{-5}$  M. Beyond this concentration, a decline in electrical output was noted. At very low dye concentrations, the limited number of Curcumin molecules was insufficient to absorb most of the incident light, resulting in lower electrical output. Conversely, at higher concentrations, excessive light absorption by molecules farther from the electrode reduced the light intensity reaching molecules near the electrode, thereby decreasing the cell's electrical output. Similarly, increasing the concentration of fructose led to enhanced photopotential, current, and power, attaining maximum values of 825.0 mV, 755.0  $\mu\text{A}$ , and 622.88  $\mu\text{W}$  at  $1.4 \times 10^{-3}$  M. Beyond this point, the electrical output decreased. At lower concentrations, insufficient fructose molecules were available to efficiently donate electrons to the Curcumin dye. At higher concentrations, the mobility of dye molecules was hindered, limiting their ability to reach the electrode in the desired time frame, which further reduced electrical output. The electrical performance of the cell also improved with increasing Tween-80 concentration, reaching a maximum (825.0 mV, 755.0  $\mu\text{A}$ , and 622.88  $\mu\text{W}$ ) at  $1.8 \times 10^{-3}$  M. Further increases in surfactant concentration acted as a barrier, and excessive Tween-80 led to photobleaching of some dye molecules, resulting in a decrease in the electrical output.

**Table 1:** Effect of variation of Curcumin, fructose, and tween 80 system concentrationsLight Intensity =  $10.4 \text{ mW cm}^{-2}$ , Temperature = 303 K, pH = 11.70

| Concentrations<br>[Curcumin] $\times 10^{-5} \text{ M}$ | Photopotential (mV) | Photocurrent ( $\mu\text{A}$ ) | Power ( $\mu\text{W}$ ) |
|---------------------------------------------------------|---------------------|--------------------------------|-------------------------|
| 1.8                                                     | 678.0               | 606.0                          | 410.86                  |
| 2.0                                                     | 722.0               | 689.0                          | 497.45                  |
| 2.2                                                     | 825.0               | 755.0                          | 622.87                  |
| 2.4                                                     | 772.0               | 687.0                          | 530.36                  |
| 2.6                                                     | 661.0               | 584.0                          | 386.02                  |
| [Fructose] $\times 10^{-3} \text{ M}$                   |                     |                                |                         |
| 1.0                                                     | 659.0               | 557.0                          | 367.06                  |
| 1.2                                                     | 767.0               | 663.0                          | 508.52                  |
| 1.4                                                     | 825.0               | 755.0                          | 622.88                  |
| 1.6                                                     | 774.0               | 651.0                          | 503.87                  |
| 1.8                                                     | 673.0               | 547.0                          | 368.13                  |
| [Tween 80] $\times 10^{-3} \text{ M}$                   |                     |                                |                         |
| 1.4                                                     | 634.0               | 547.0                          | 346.80                  |
| 1.6                                                     | 757.0               | 662.0                          | 501.13                  |
| 1.8                                                     | 825.0               | 755.0                          | 622.88                  |
| 2.0                                                     | 767.0               | 757.0                          | 503.92                  |
| 2.2                                                     | 631.0               | 533.0                          | 336.32                  |

**(b) Effect of variation of pH**

The photogalvanic cell containing the Curcumin–fructose–Tween 80 system was found to be highly sensitive to the pH of the solution. It was observed that increasing the pH led to an enhancement in electrical output. Maximum values of photopotential, photocurrent, and power—825.0 mV, 755.0  $\mu\text{A}$ , and 622.88  $\mu\text{W}$ , respectively—were achieved at pH 11.70. Further increases in pH resulted in a decline in electrical performance. The optimum output at this specific pH is likely due to the improved availability of fructose molecules in their electron-donating form. The effect of pH on the system is illustrated in Figure 1.

**Fig. 1:** Effect of pH on electrical parameters**(c) Impact of diffusion length**

The effect of diffusion length—the distance between the two electrodes—on the current parameters of the photogalvanic cell ( $i_{\text{max}}$ ,  $i_{\text{eq}}$ , and the initial rate of photocurrent generation) was investigated using H-shaped glass cells of

varying dimensions. During the initial minutes of illumination, a sharp rise in photocurrent was observed. With increasing diffusion length, the maximum photocurrent ( $i_{\text{max}}$ ) was expected to increase due to the extended path for the photochemical reaction; however, this trend was not observed experimentally. In contrast, the equilibrium photocurrent ( $i_{\text{eq}}$ ) showed a linear decrease with increasing diffusion length. These observations suggest that the primary electroactive species are the leuco or semi-reduced forms of the dye (photosensitizer) present in the illuminated and dark compartments, respectively. Ascorbic acid and its oxidation products serve mainly as electron carriers within the system. The experimental data supporting these findings are presented in Table 2.

**Table 2:** Effect of Diffusion Length

| Diffusion Length $D_L$ (mm)                                     | 40.00 | 45.00 | 50.00 | 55.00 | 60.00 |
|-----------------------------------------------------------------|-------|-------|-------|-------|-------|
| Max <sup>m</sup> Photocurrent in $\mu\text{A}$                  | 786.0 | 791.0 | 798.0 | 805.0 | 811.0 |
| Equilibrium Photocurrent in $\mu\text{A}$                       | 766.0 | 762.0 | 755.0 | 744.0 | 739.0 |
| Rate of initial Generation of Current in $\mu\text{A min}^{-1}$ | 20.68 | 20.82 | 21.00 | 21.18 | 21.34 |

**(c) Effect of electrode area**

By using Pt-electrodes with varying surface areas, it was possible to conduct more extensive investigations on the effect of electrode area on cell parameters. Elevations in  $i_{\text{max}}$  were shown to be correlated with larger electrode areas, but  $i_{\text{eq}}$  was found to be mostly unaffected by this variation (in fact, it was affected in the opposite way). The effect of changing the electrode area on the  $i_{\text{max}}$  and  $i_{\text{eq}}$  illustrated in figure 2.

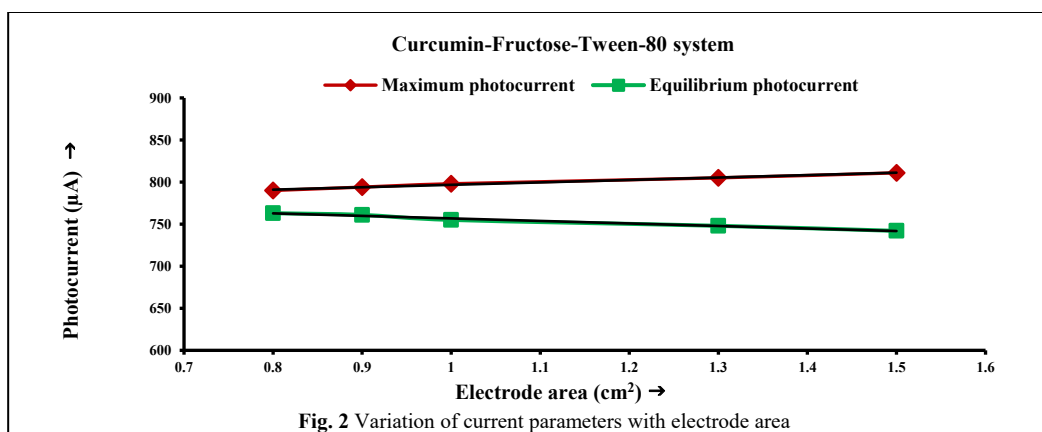


Fig. 2 Variation of current parameters with electrode area

#### (d) Current-Voltage (i-V) properties of the cell

The short-circuit current ( $I_{sc} = 755 \mu A$ ) and open-circuit voltage ( $V_{oc} = 1009 \text{ mV}$ ) of the photogalvanic cell were measured using a microammeter under closed-circuit conditions and a digital pH meter under open-circuit conditions, respectively. Intermediate values of photocurrent and photopotential were obtained by applying an external load through a carbon potentiometer (log 470 K) connected to a multimeter. The current-voltage (i-V) characteristics of the Curcumin-fructose-Tween 80 system are presented in Figure 3.

The i-V curve was found to deviate from the typical rectangular profile. The point of maximum power output, referred to as the power point (pp), was identified at a photocurrent ( $i_{pp}$ ) of  $220 \mu A$  and a corresponding potential ( $v_{pp}$ ) of  $552 \text{ mV}$ . From the i-V curve, the fill factor was calculated to be 0.1594 using the relation:

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

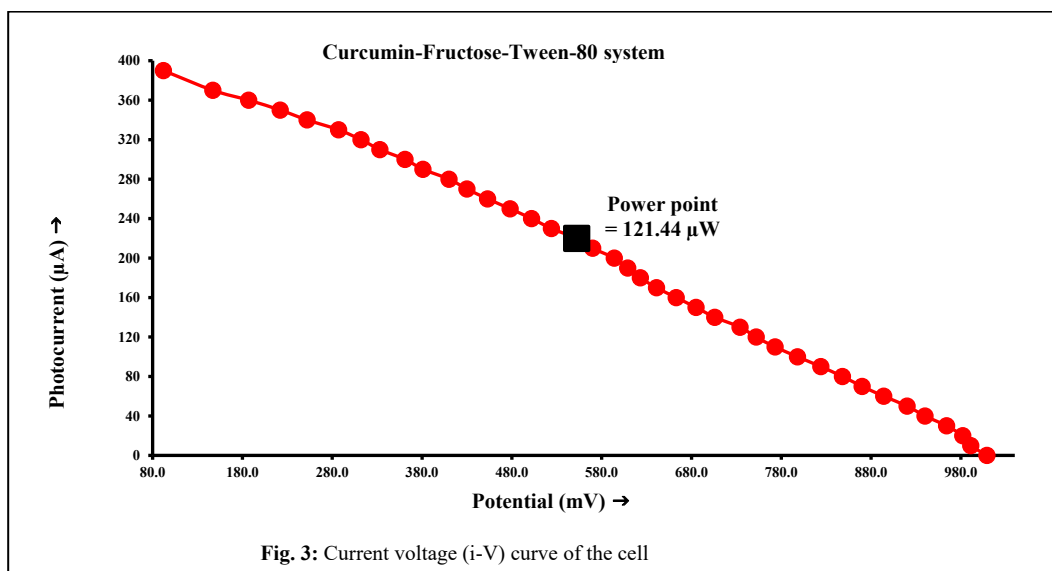


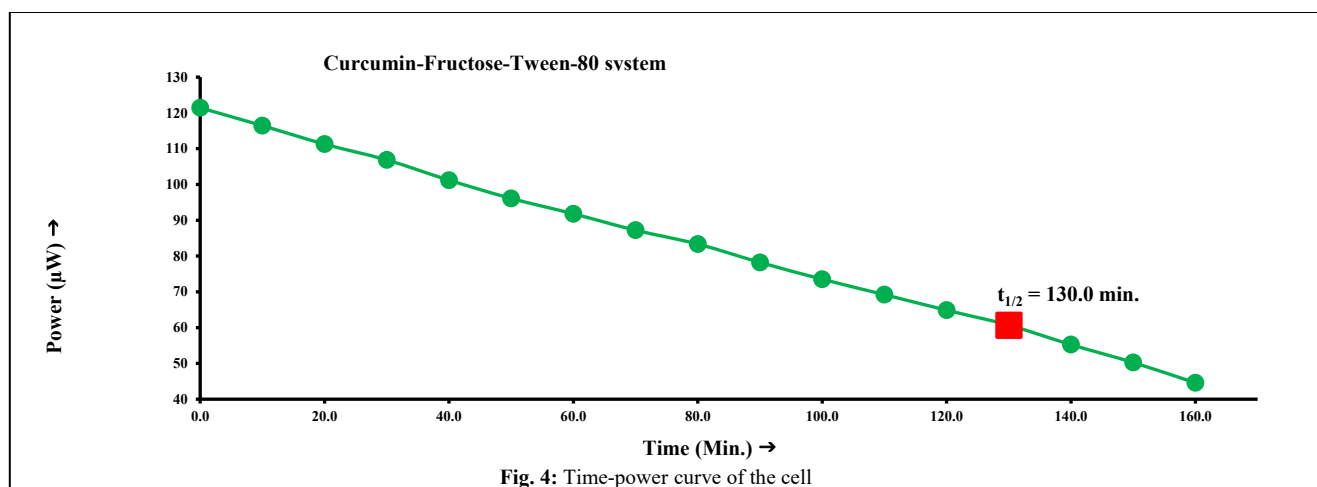
Fig. 3: Current voltage (i-V) curve of the cell

#### (e) Cell performance and conversion efficiency

The performance of the photogalvanic cell was evaluated by applying an external load—essential for obtaining current at the power point—after switching off the light source once the potential had stabilized. The performance was quantified in terms of  $t_{1/2}$ , defined as the time required for the power output at the power point to fall to half of its initial value under dark conditions. The Curcumin-fructose-Tween 80

system demonstrated a storage capacity of approximately two hours in the absence of illumination. Using the photocurrent and photopotential values at the power point, along with the incident light power, the overall conversion efficiency of the cell was calculated as 1.16% according to the standard relation. The variation of power output with time is depicted in the time-power curve (Figure 4).

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{A \times 10.4 \text{ mW cm}^{-2}} \times 100\%$$



### 3. Mechanism

When the dye molecules are photo excited in the presence of the electron donor ascorbic acid, they are rapidly reduced to their colorless form. In this reduced state, the dye acts as a strong reducing agent, capable of transferring electrons to other

species before being reconverted to its oxidized state. Based on previous studies, a tentative reaction mechanism for the operation of the photogalvanic cell is proposed and illustrated in Figure 5.

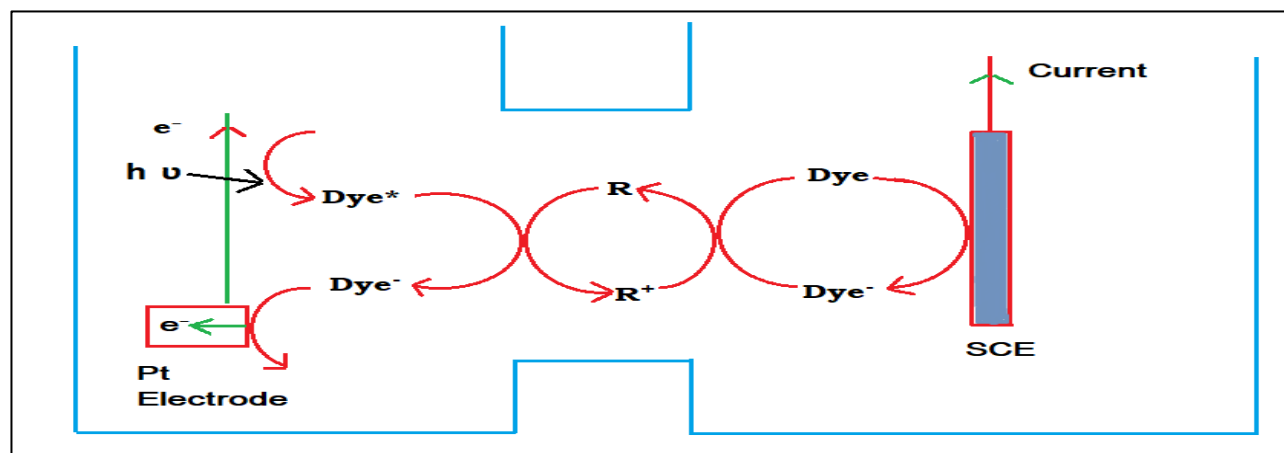


Fig. 5: Scheme of the mechanism

SCE = Saturated calomel electrode, D = Dye (Photosensitizer)  
R = Reductant, D = Semi & Leuco form

### 4. MATERIALS AND METHODS

Tween 80, curcumin, fructose (Figure 7a–c), and NaOH (Loba Chemie) were employed in the present study. Stock solutions of curcumin, fructose, Tween 80 and NaOH (1 N) were prepared in double-distilled water (conductivity:  $3.5 \times 10^{-5} \text{ Sm}^{-1}$ ) and stored in colored containers to prevent exposure to sunlight. A mixture of curcumin, fructose, Tween 80 and NaOH was transferred into an H-shaped glass cell, the outer walls of which were blackened with carbon paper to avoid unwanted light exposure. A platinum foil electrode ( $1.0 \times 1.0 \text{ cm}^2$ ) was inserted into one compartment of the H-cell, while a saturated calomel electrode (SCE) was placed in the opposite

limb. The Pt electrode functioned as the working electrode, whereas the SCE served as the counter electrode. The system was initially kept in the dark until a stable potential was reached. Thereafter, the compartment containing the Pt electrode was illuminated with a 200 W tungsten lamp (Philips). To eliminate thermal effects, a water filter was employed. The photopotential and photocurrent were measured using a digital multimeter (HAOYUE DT830D). The *i*–*V* characteristics of the photogalvanic cell were studied by connecting an external load through a carbon potentiometer (log 470 K). The complete experimental setup of the photogalvanic cell is shown in Figure 6.

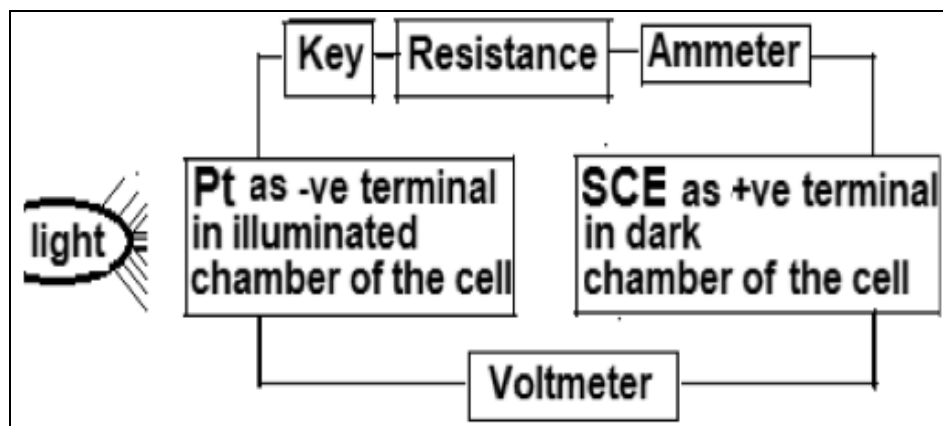


Fig. 6: Photogalvanic cell set-up

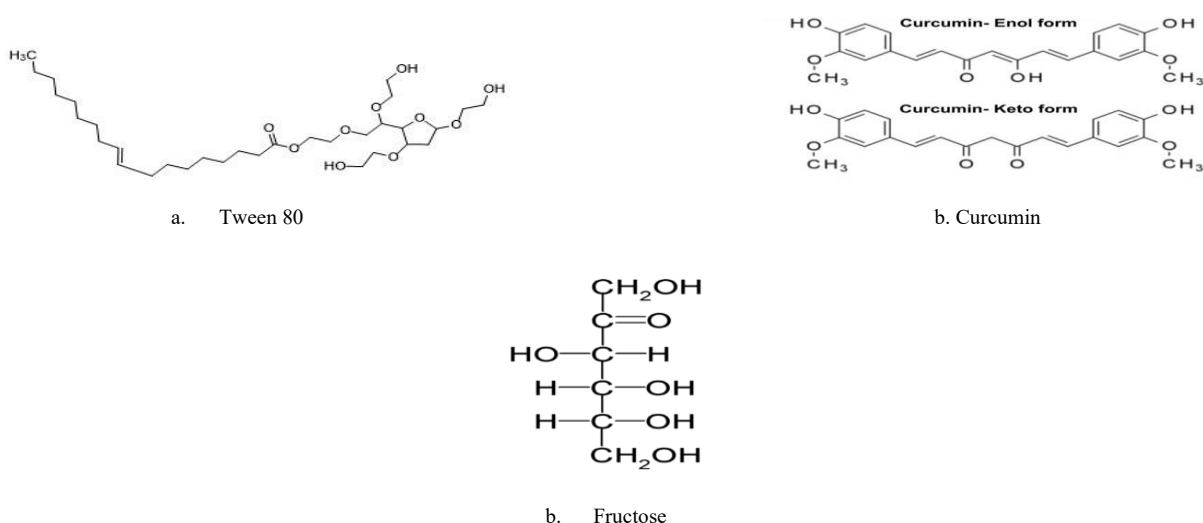


Fig.7: Structures of chemicals

## 5. CONCLUSIONS

The photogalvanic (PG) cell exhibits an inherent storage capability, enabling the utilization of stored energy even in the absence of light. In contrast, photovoltaic cells require additional hardware, such as external batteries, for energy storage. The PG cell is further advantageous due to its use of low-cost materials, making it a promising alternative for solar energy conversion. In the curcumin–fructose–Tween 80 system, the cell demonstrated a conversion efficiency of 1.16%, a storage capacity of 130 minutes, a maximum power at the power point of 121.44  $\mu\text{W}$ , and a fill factor of 0.1594. These results highlight the potential of this system for practical and cost-effective solar energy applications.

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