

Performance Evaluation of A Photogalvanic Cell for Solar Energy Conversion and Storage Using the Curcumin–Fructose–Brij-35 System

Dr. Rajesh Kumar Lakhera¹, Prof. Veena², Dr. Kewal Singh³

^{1,2}Department of Chemistry, S.N.D.B. Govt. P.G. College, Nohar-335523, Rajasthan, India

³S.G.N. Khalsa P.G. College, Sri Ganganagar-335001, Rajasthan, India

Abstract

Natural dye-sensitized solar cells (NDSSCs) are considered promising third-generation photovoltaic devices due to their potential to produce environmentally friendly energy at relatively low manufacturing costs. Their fabrication process does not require highly sophisticated or expensive equipment, making them economically attractive. This paper presents a review of the design and working mechanism of curcumin-based dye-sensitized solar cells. The primary aim of this study is to capture and store solar energy using a natural dye system composed of curcumin, fructose, and Brij-35 in a photogalvanic cell. When operated in an alkaline medium, the photogalvanic cell demonstrates significant enhancement in both solar energy conversion efficiency and energy storage capability. The chemical system demonstrated a maximum output power of 120.50 μW , with an energy storage capacity lasting up to 100 minutes, measured as the half-discharge time under 10.4 mW cm^{-2} artificial low-intensity illumination. The optimal performance of the cell was recorded with a photopotential of 918 mV and an equilibrium photocurrent of 784 μA . Additionally, the device achieved solar energy conversion efficiency and fill factor 1.15% and 0.1436 respectively.

Keywords: Natural Dye Sensitized solar cell, Curcumin, Fructose, Brij-35, Sustainable development, Photogalvanic effect, fill factor, conversion efficiency.

1. Introduction

The growing demand for sustainable power generation has significantly increased research interest in photogalvanic cells due to their dual capability of converting and storing solar energy efficiently. These cells operate through photochemical reactions in which light absorption triggers the formation of high-energy chemical species. Renewable energy refers to power derived from naturally replenished resources that are virtually unlimited and can be utilized with minimal environmental impact. Among these resources, solar radiation is widely recognized as one of the most promising and practical options for clean energy production. In addition to being eco-friendly, solar power has become increasingly cost-effective as installation and maintenance expenses continue to decline. It contributes substantially to energy diversification and strengthens energy security in both industrialized and developing nations. Solar energy is the radiant energy emitted by the sun, received on Earth primarily as light and heat. Solar energy is among the most plentiful and sustainable energy resources available on Earth. The sun releases an enormous quantity of energy each day, far exceeding the total energy consumption of the global

population. Through appropriate technological systems, this abundant resource can be utilized to produce electricity, provide thermal energy for water heating, and supply power for residential buildings, commercial establishments, and transportation systems. In a photogalvanic cell, a light-sensitive dye dissolved in the electrolyte absorbs incident radiation. Upon absorbing photons, the dye molecules reach an excited state and transfer electrons to a suitable electron acceptor. This electron transfer initiates a redox reaction sequence, leading to the development of an electrical potential between the two electrodes. This phenomenon, referred to as the photogalvanic effect, results in the generation of an electric current.

A photogalvanic cell serves as an effective system for transforming solar radiation into electrical energy through photochemically induced redox reactions [2]. The phenomenon was initially observed in an equilibrium mixture containing ferrous–ferric and iodine–iodide redox couples. Subsequent investigations provided a more detailed understanding of the process, particularly through studies involving the thionine–iron redox system. Furthermore, thionine has been incorporated with poly (N-methylolacrylamide) to develop a polymer–dye complex, enhancing its applicability in photogalvanic systems [3-6]. The optical absorption characteristics of the polymer–dye complex vary with the proportion of polymer to dye. In comparison to pure thionine, the complex exhibits a noticeable red shift in its absorption spectrum, indicating changes in its electronic environment. Moreover, the overall performance, including the electrical output and conversion efficiency of the photogalvanic cell, is significantly affected by the specific polymer-to-dye composition. [7]. The photogalvanic effect has been examined using the Methylene blue–EDTA–Sodium lauryl sulphate system, where a photocurrent of 190 μA 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 μA and a photopotential of 315 mV [10]. Similarly, the CTAB–glucose–Toluidine blue configuration yielded a photocurrent of 35 μA along with a photopotential of 175 mV. The conversion efficiency, maximum power and storage time were found to be 0.0578%, 6.26 μW 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 μA . This system demonstrated a conversion efficiency of 0.5398% with a maximum power output of 81.62 μW , 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 μW 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 μW , 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 μW , 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 μW . 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 μW , 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 μA , a short-circuit current of 590 μA , a power output of 183.3 μW 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 μA , a short-circuit current of 972 μA , and a power output of 244.02 μW 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 μA , 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 xylidine ponceau–Tween 60–ascorbic acid system was examined, where the device generated a maximum power output of 68.77 μW 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 μA , 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 μA , and a power output of 19.84 μW . 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]. Towards this direction, the study of photogalvanic effect in dye sensitized liquid phase solar cell fabricated with natural dye Curcumin, reductant fructose and surfactant Brij 35 in basic medium was planned. Therefore, present work is undertaken and it was planned to carry out systematic investigations under following salient points.

2. Result and discussion

(a) Effect of variation of curcumin, fructose and Brij 35 concentration:

The effect of varying the concentrations of Curcumin, fructose and Brij 35 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. Beyond this concentration, a decline in electrical output was noted. At very low dye concentration, 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, photocurrent and power. On further increasing the concentration of reductant fructose the electrical output decreased. At lower concentration, 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 increases with increasing concentration of surfactant. Further increases in surfactant concentration act as a barrier and excessive surfactant led to photobleaching of some dye molecules, resulting in a decrease in the electrical output.

Concentrations	Photopotential(mV)	Photocurrent (μA)	Power (μW)
[Curcumin]×10⁻⁵ M			
1.4	657.0	604.0	396.82
1.6	823.0	693.0	570.33
1.8	918.0	784.0	719.71
2.0	833.0	683.0	568.93
2.2	667.0	586.0	390.86
[Fructose] x 10⁻³ M			
1.2	654.0	574.0	432.80
1.4	857.0	693.0	593.90
1.6	918.0	784.0	719.71

1.8	844.0	684.0	577.30
2.0	763.0	587.0	447.88
[Brij-35] x 10⁻³ M			
1.5	732.0	613.0	448.72
1.6	847.0	712.0	603.06
1.8	918.0	784.0	719.71
1.9	859.0	701.0	602.16
2.0	741.0	600.0	444.60

(b) Effect of diffusion length:

The impact of variation of diffusion length (it is distance between the two electrodes) on the current parameters of the cell (i_{max} , i_{eq} and initial rate of generation of photocurrent) was studied using H-shaped glass cells of different dimensions. It was observed that in the first few minutes of illuminations there is sharp increase in the photocurrent. As consequences, the maximum photocurrent (i_{max}) increase in diffusion length because path for photochemical reaction was increased, but this is not observed experimently whereas equilibrium photocurrent (i_{eq}) decreased 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 ascorbic acid and its oxidation product act only as electron carriers in the path. The results are given in figure 1.

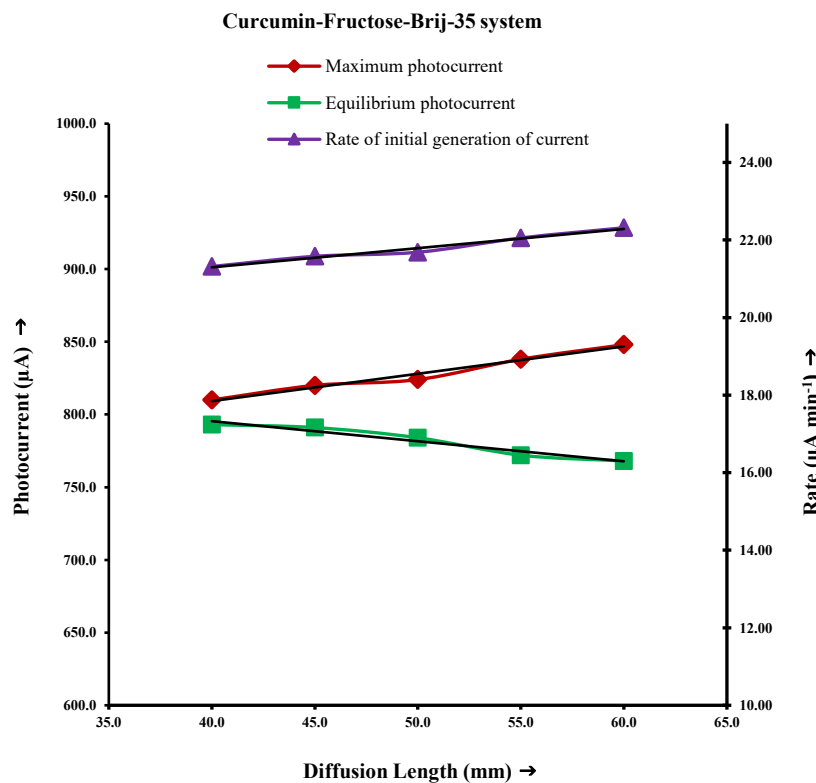


Fig. 1 Variation of current parameters with diffusion length

(c) Effect of temperature:

With an increase in the temperature, the photocurrent of the PG cell was found to increase with a corresponding rapid fall in potential. The effect of temperature on total possible power output in the Curcumin-Fructose-Brij-35 system 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 photopotential. The results are reported in table 2.

Table- 2
Variation of photopotential and photocurrent with temperature

Curcumin-Fructose-Brij-35 System	Temperature (K)				
	298.0	300.0	303.0	310.0	315.0
Photopotential (mV)	930.0	924.0	918.0	907.0	900.0
Photocurrent (µA)	772.0	777.0	784.0	798.0	809.0

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

The short circuit current (i_{sc}) 784 µA and open circuit voltage (V_{oc}) 1070 mV of the photogalvanic cell were measured with the help of a microammeter (keeping the circuit closed) and with a digital pH meter (keeping the circuit open), respectively. The photo current and 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 multimeter, through which an external load was applied. The i-V properties of the photogalvanic cell containing Curcumin, fructose and Brij-35 chemicals are graphically shown in figure 2. It was observed that i-V curve deviated from its regular rectangular shape. A point in the i-V curve, called power at point (pp), was determined where the product of photo current (i_{pp}) 482 µA and potential (v_{pp}) 250 mV was maximum. With the help of i-V curve, the fill-factor was reported 0.1436 by using the formula:

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

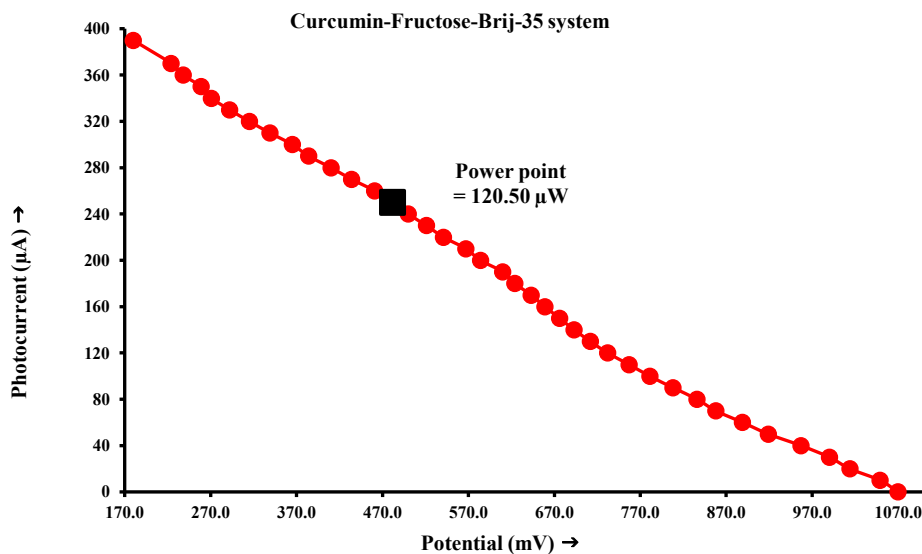


Fig. 2 Current-Voltage (i-V) properties of the cell

(e) 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 terminating the light source as soon as the potential reaches at a constant value. The performance was determined in terms of $t_{1/2}$, i.e., the time required in fall of the power output to its half at power point in dark. It was observed that the cell containing Curcumin-Fructose-Brij-35 system can be used in dark for 100 minutes. With the help of photo current and potential values at power point and the incident power of radiations, the conversion efficiency of the cell was determined as 1.15 % using the formula.

The results are graphically represented in time-power curve (figure 3).

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

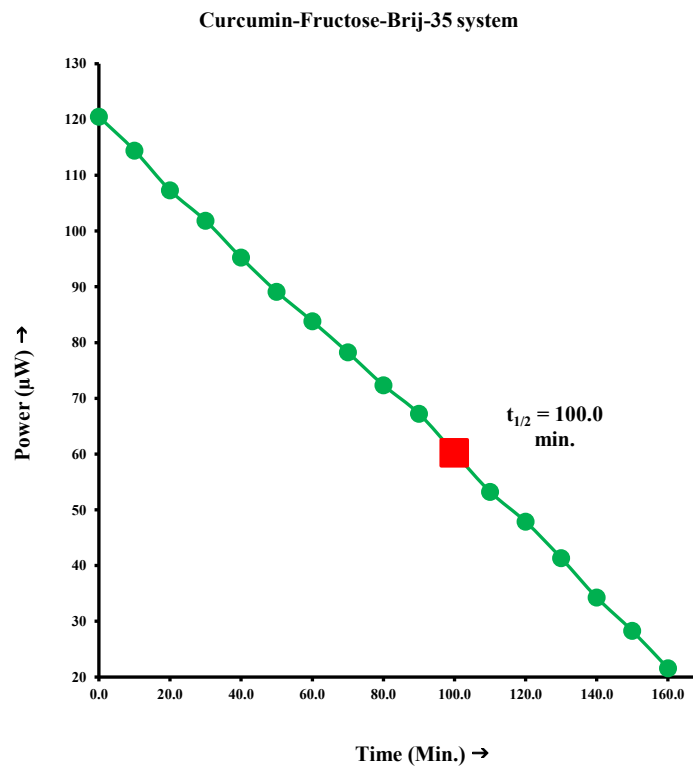


Fig. 3 Time power curve of the photogalvanic cell

3. Mechanism

When the dye molecule is excited by the light in the presence of electron donating substance (Fructose), the dye 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 Photogalvanic cell shown in figure 4.

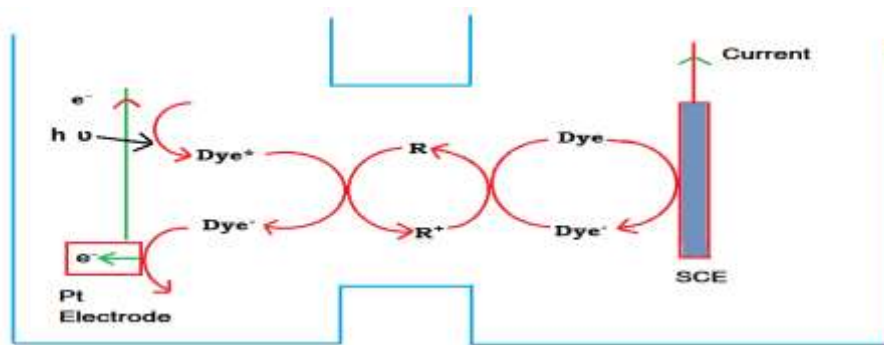


Fig. 4 Scheme of mechanism

SCE = Saturated calomel electrode
R = Reductant

D = Dye (Photosensitizer)
D = Semi & Leuco form

4. Materials and methods

Curcumin, Fructose, Brij-35 and NaOH of Loba Chemie were used in the present work. Solutions of Fructose, Curcumin, Brij-35 and NaOH (1N) were prepared in double distilled water (conductivity $3.5 \times 10^{-5} \text{ Sm}^{-1}$) and kept in coloured container to protect them from sun light. A shiny Pt foil electrode ($1.0 \times 1.0 \text{ cm}^2$) was immersed in one limb of the H-tube and a saturated calomel electrode was immersed in the other limb. Pt-electrode acts as a working electrode and saturated calomel electrode as a counter electrode. The whole system was first placed in the dark till a stable potential was attained, then the limb containing the Pt-electrode was exposed to a 200 W tungsten lamp (Philips). A water filter was used to cut off thermal radiation. A digital multimeter was used to measure the photo potential and current generated by the system respectively. The i-V characteristics were studied by applying an external load with the help of Carbon pot (log 470 K) connected in the circuit the photogalvanic cell set-up is shown in figure 5.

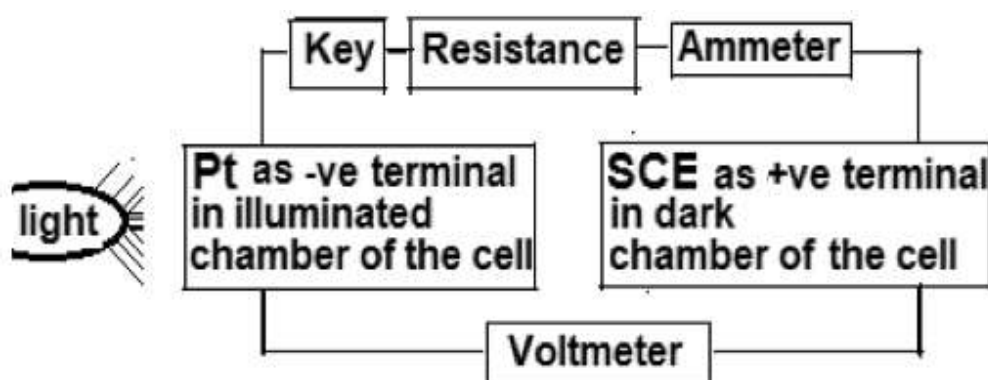
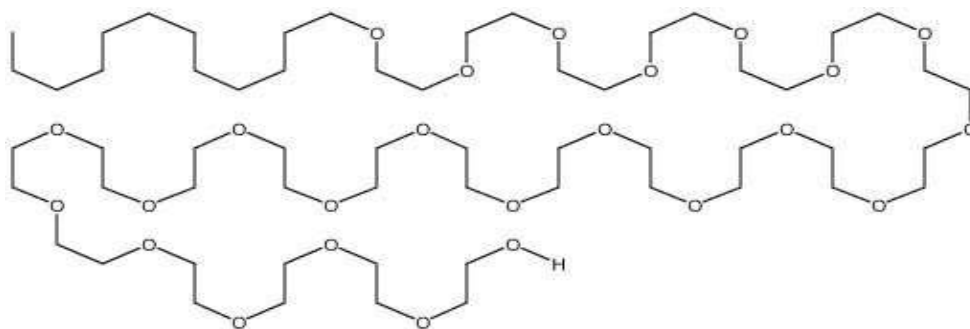
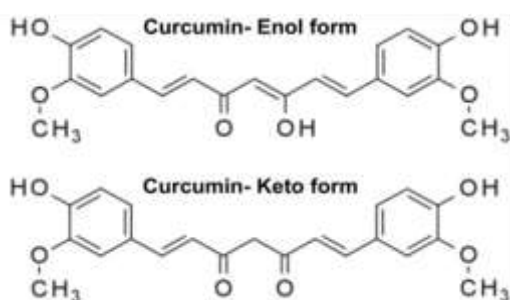
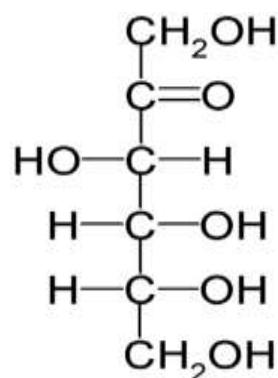


Fig.5 Photogalvanic Cell Set-up


Brij-35

Curcumin

Fructose

Structures of chemicals

5. Conclusions

The Curcumin is a water soluble dye having good photo-sensitizer property. These characteristics of the dye make it a good light absorbing candidate for the use in dye sensitized photogalvanic cell. In present study, this dye has responded favorably to the use of good reductant fructose in the presence of small Pt working electrode, combination electrode as counter electrode and Brij-35 as surfactant at very high pH to show abruptly enhanced photogalvanics (current 784 μA , power 120.50 μW). This study revalidates efficacies of the small Pt working electrode, combination electrode, surfactant, and high pH for having the increased solar power generation and storage from any dye sensitizer through the photogalvanic cell. Therefore, the Curcumin, fructose and Brij-35 chemicals combination with small Pt electrode will be an option for construction of highly efficient photogalvanic solar cells.

References:

1. International Energy Agency (IEA), Solar Energy: Tracking Report, 2023. <https://www.iea.org/reports/solar-energy>
2. Bard A. J, Memming R. and Miller B., Terminology in semiconductor electrochemistry and photoelectrochemical energy conversion, Pure and Appl. Chem. 1991; 63, 569.
3. Kamat P.V., Karkhanawala M. D. and Moorthy P. N., Study of Ferrous- Thionine System Part II- Power Output in Homogeneous and Heterogeneous Type Photogalvanic Cells, Indian J. Chem. 1979; 18A, 210.

4. Rabinowitch E., The Photogalvanic Effect I: The Photochemical Properties of the Thionine-Iron System, *J. Chem. Phys.* 1940; 8, 551.
5. Rabinowitch E., The Photogalvanic Effect II: The Photogalvanic Properties of Thionine-Iron System, *J. Chem. Phys.* 1940; 8, 560.
6. Rideal E. K. and Williams E. G. The Action of Light on the Ferrous Iodine Iodide Equilibrium, *J. Chem. Soc. Trans.* 1925; 127, 258.
7. Tamilarasan R. and Natrajan P. Photogalvanic Cell: Iron (II) - Poly (N-acrylamidomethyl thionine) System, *Indian J. Chem.* 1981; 20A, 213.
8. Ameta S. C., Khamesra S., Chittora A. K. and Gangotri K. M. Use of Sodium Lauryl Sulphate in a Photogalvanic Cell for Solar Energy Conversion and Storage: Methylene Blue- EDTA System. *International journal of energy research.* 1989; 13 (6): 643.
9. Khamesra S., Ameta R., Bala M. and Ameta S. C. Use of micelles in photogalvanic cell for solar energy conversion and storage: Azur A-glucose system. *International journal of energy research.* 1990; 14 (2): 163.
10. Gangotri K. M., Regar O. P., Lal C., Kalla P., Genwa K. R. and Meena R. Use of tergitol-7 in photogalvanic cell for solar energy conversion and storage: Toluidine blue-glucose system. *International journal of energy research.* 1996; (20): 581.
11. Gangotri K. M., Meena R. C. and Meena R. Use of micelles in photogalvanic cells for solar energy conversion and storage: cetyl trimethyl ammonium bromide-glucose-toluidine blue system. *Journal of Photochemistry and Photobiology A: Chemistry.* 1999; 123 (1-3): 93.
12. Gangotri K. M. and Lal C. Studies in photogalvanic effect and mixed dyes system: EDTA-methylene blue + toluidine blue system. *International journal of energy research.* 2000; (24): 365.
13. Gangotri K. M. and Lal C. Use of mixed dyes in photogalvanic cell for solar energy conversion and storage: EDTA methylene Blue and Azur-B system. *Energy Sources part A.* 2001; 23 (3): 267.
14. Gangotri K. M. and Meena R. C. Role of reductant and photosensitizer in solar energy conversion and storage: Ascorbic Acid-Eiosin system. *Journal of the Indian Chemical Society.* 2004; 81 (7): 576.
15. Gangotri K. M. and Genwa K. R. Comparative studies in anionic, cationic and nonionic surfactants in photogalvanic cells from solar energy conversion and storage point of view: NTA-Azur B system. *Journal of the Indian Chemical Society.* 2004; (7): 81.
16. Gangotri K. M. and Lal C. Use of mixed dyes in photogalvanic cells for solar energy conversion and storage: EDTA-methylene blue and thionine system. Part A: *Journal of Power and Energy.* 2005; 219 (5): 315.
17. Pramila S. and Gangotri K. M. Use of anionic micelles in photogalvanic cells for solar energy conversion and storage dioctylsulfosuccinate-mannitol-safranin system. *Energy Sources Part A.* 2007; 29 (13): 1253.
18. Gangotri P. and Gangotri K. M. Studies of the micellar effect on photogalvanics: Solar energy conversion and storage in EDTA-Safranin O-Tween-80 system. *Energy and Fuels.* 2009; 23 (5): 2767.
19. Gangotri K. M. and Bhimwal M. K. The photochemical conversion of solar energy into electrical energy: Eosin-arabinose system. *International Journal of Electrical Power and Energy Systems.* 2010; 32 (10): 1106.
20. Gangotri K. M. and Indora V. Studies in the photogalvanic effect in mixed reductants system for solar energy conversion and storage: Dextrose and Ethylenediaminetetraacetic acid-Azur A system. *Solar Energy.* 2010; 84 (2): 271.
21. Sharma U., Koli P. and Gangotri K. M. Brilliant Cresyl Blue-Fructose for enhancement of solar energy conversion and storage capacity of photogalvanic solar cells. *Fuel.* 2011; 90 (11): 3336.
22. Solanki P.P. and Gangotri K. M. Studies of the anionic micelles effect on photogalvanic cells for solar energy conversion and storage in Sodium lauryl sulphate-Safranin-D-Xylose system. *World Renewable Energy congress 2011- Sweden.*

23. Koli P, Sharma U. and Gangotri K. M. Solar energy conversion and storage: Rhodamine B-Fructose photogalvanic cell. *Renewable energy*. 2012; 37 (1): 250.
24. Gangotri K. M., Aseri P., and Bhimwal M. K. The use of tergitol-7 in photogalvanic cells for solar energy conversion and storage: An EDTA–Azur B system. *Energy Sources Part A: Recovery Utilization and Environmental Effects*. 2013; 35 (4): 312.
25. Genwa K. R. and Sagar C. P. Xylidine ponceau dye based photogalvanic cell: Energy conversion for sustainable development. *European Chemical Bulletin*. 2014; (3): 76.
26. Lal M and Gangotri K. M. The optimum conversion efficiency in Nile blue arabinose system by photogalvanic cell. *Advances in Energy Research*. 2015; 3 (3): 143.
27. Meena J. and Gangotri K. M. Use of Toluidine Blue-EDTA- Tween-80 system in photogalvanic cell for solar energy conversion and storage. *JETIR*. 2019; 6(6): ISSN-2349-5162.
28. Yadav S. K. and Sharma S. Use of Azur-C-NTA as a new sensitizer-Reductant system for enhanced simultaneous solar power conversion and storage by Photogalvanic cell. *Int. J. Res. Bio. Agri. Tech*. 2021; 17.
29. Yadav S. K. Dye Sensitized Solar Cell Based on A New Class Of Doubly Concerted Companion Dyes. *Int. J. Adv. Res. E.E. Ins.Eng*. 2022; 11 (11): 3572-3579.
30. Prakash O. and Yadav S. K. Study of Photogalvanic Effect by Using of Natural Dye as Photosensitizer for Solar Energy Conversion and Storage. *Cent. Asia. J. Theo. App. Scie*. 2022; 3 (7): 78-83.
31. Prakash O., Sonel A. and Yadav S. K. Conversion of Solar Radiation into Electrical Energy by Using Solar Cell. *Cent. Asia. J. Theo. App. Scie*. 2022; 3 (7): 104-107.
32. Vikram pal and Yadav S. K. Study of Photogalvanic Effect in Natural Dye (Punica granatum extract)-Glucose- Brij 35 system for solar power generation and storage.
33. Paripex – *Indian Journal of Research*. 2024; 13 (11).