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Fabrication of Photogalvanic Cell Composed with Natural and Synthetic Dyes for the Generation and Storage of Solar Power

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Abstract

Objective: To develop PG cells with improved electrical output for solar energy conversion and storage. **Methods:** The current generation was carried out in an H-shaped PG cell system using various solutions of ascorbic acid, aniline blue, curcumin and sodium lauryl sulphate. The following parameters have been measured at light intensity of 10.4 mWcm^{-2}: photopotential, photocurrent, Power at power point, fill factor, conversion efficiency, and cell performance ($t_{1/2}$) on the order of 802.0 mV, 920 μA, 164.70 μW, 0.1825, 1.59%, and 140 minutes, respectively. The cell's current–voltage characteristic was examined. Speculative mechanism for the photocurrent's generation has been put forth. **Findings:** Better current observations for cell performance have been noted. Numerous factors, including the concentration of photosensitizers, reductant, and micelles, as well as changes in pH, light intensity and diffusion length were shown to have an impact. **Novelty:** The combination of natural dye curcumin with synthetic Dye aniline blue in PG cell improves the photoelectrical parameter of cell by providing a wider absorption spectrum. Facts regarding the performance and stability of the PG cell can be found in the present study.

Keywords: Curcumin; Aniline blue; Sodium Lauryl Sulphate; Ascorbic acid; Photogalvanic effect

1 Introduction

A crucial instrument that offers a suitable path for transforming solar energy to electrical energy is a photogalvanic (PG) cell. The utilization of renewable energy with high efficiency has attracted researchers' attention all over the world in terms of enhancing the renewable generation efficiency, the efficient and flexible energy distributions to end-users [1]. Solar-driven technologies offer environment friendly and cost-efficient alternatives for desalination [2]. Photogalvanic cell is one of the various solar cells (photovoltaic, DSSC, Quantum Dot etc.) that converts solar energy into electrical energy with inbuilt storage capacity. Two electrode platinum as working electrode and Saturated calomel electrode as counter electrode dipped in electrolytic solution of mixed photosensitizer with reductant and surfactant, solution was madenewgeo alkaline by adding sodium hydroxide. absorption of solar radiation by dye molecule and their excited forms receive electron from reductant molecule reduced form of dye sacrifices its extra electron at platinum surface which is taken by counter electrode though external circuit results in photogeneration of current. Initially, ferrous ferric iodine iodide was exposed with light then the PG effect was observed. If the electrolyte absorbs light, a photovoltaic potential is created between two electrodes. As a result, the PG cell that is based on certain electrochemical processes that, when excited by a photon, produce high energy products. The PG effect is the process by which this energy product releases energy electrochemically to produce electricity. Genwa and Prasad studied on PG in solar energy transformation and performance analysis: Alizarin Cyanine Green, EDTA, and sodium stearate system [3]. Lal and Gangotri reported on impact of MB photosensitizer with mixed surfactant in PG solar cell for solar power generation and storage [4]. Rathore et al., studied photogalvanic cell with better electrical outputs via photocurrent, photopotential, conversion efficiency, fill factor and cell performance [5]. Further, Rathore et al., studied photogalvanic cell in biodegradable surfactant lauryl glucoside in Tatrazine–fructose system by using photocurrent, photopotential, conversion efficiency, fill factor and cell performance [6]. Lal and Gangotri reported on innovation for prospective energy source through solar cell for better results [7]. Lal and Gangotri studied on innovation in progressive study for prospective energy source through PG system [8]. Lal and Gangotri reported on innovative study in renewable energy source through mixed surfactant system for eco-friendly environment and published in Environmental Science and Pollution Research Journal [9]. Ram et al. worked on innovative study of the PG cell for Solar Energy conversion and storage through Brilliant Yellow + NaLS + Ascorbic Acid System [10]. Gangotri and Meena reported on different PG cell with micelles to increase power output and storage capability of PG cells [11]. Jayshree and Mohan studied on PG effect in cell containing single surfactant as DSS, Tartrazine as a photosensitizer and EDTA as reductant for solar energy conversion and storage [12]. Ascorbic acid in a basic medium under low intensity light has helped in the search for a relatively suitable combination of chemicals, such as photosensitiser, surfactant, and reductant, to further increase these cells efficiency. Photogalvanic cells have the ability to transform solar energy to electric energy by using a variety of photosensitisers, reductants, and surfactants. However, the employment of combining dyes and the other synthetic, aniline blue has received little attention. In order to improve the PG cell's electrical output and performance, a system including a combination of dyes was designed. Therefore, our objective of this work is to enhance the performance of PG cell.

Mall et al., reported on photoelectrochemical and spectrophotometric study of dye surfactant combination in PG cell [13]. Lal and Gangotri studied on PG effect in PG cell containing mixed surfactant (NaLS+ Tween-80), MB as a photosensitizer and xylose as reductant [14]. In the present study, aniline blue, ascorbic acid, curcumin, NaLS, and NaOH were used. Double-distilled water was used to make solutions of aniline blue, curcumin, SLS, ascorbic acid, and NaOH (1N). To shield them from the sun, these solutions were later kept in amber-coloured containers. Better results with sudan dye and fructose chemicals-based PG cells for electrochemical solar energy conversion and storage at low and artificial sun intensity [15]. Dye, surfactant, reductant, and NaOH mixture was placed inside H-shaped glass tube [16]. The resulting photoelectrochemical process in photogalvanics leads to energy conversion for sustainable development in the field of solar energy [17]. This study investigated the photochemical bleaching of dye using potentiometric method.

2 Methodology

In this system, a mixture of dye, reductant, and surfactant was employed. All solutions were prepared using double-distilled water and stored in amber-colored glass bottles to prevent photochemical deterioration. This mixture was put into an H-shaped PG cell for current voltage study (Figure 1. Experimental setup). One leg of H-tube was filled with glossy platinum foil electrode, while other limb was filled with saturated calomel electrode (SCE). The active electrode is platinum, whereas SCE is the counter electrode. The current and potential values of the system were checked using a digital multimetre. In order to analyse current-voltage characteristics, an external load was provided using carbon pot which was connected to the circuit. The PP and PC produced by the system were observed using a digital pH meter and a micro ammeter, respectively.

3 Results and Discussion

3.1 Impact of Dye, ascorbic acid, & SLS concentration variations

Table 1 shows the effects of varying the dye combination [Aniline blue + Curcumin], ascorbic acid, and SLS concentration. Using solutions with varying dye concentrations, the variation in the mixture's concentration was investigated. It was found that when the concentration of combined dyes [Aniline blue + Curcumin] increased, so did the photopotential, photocurrent, and power. At 802 mV, 920μA, and 737.84 μW, a maximum was achieved for specific dye concentration (1.9×10^{-5}M); beyond this, the cell's electrical output dropped. Reason being, the route's dye molecules weren't large enough to absorb most of the light, inadequate electrical output was seen at the lowest dye concentration level. Higher dye concentrations, on the other hand, also

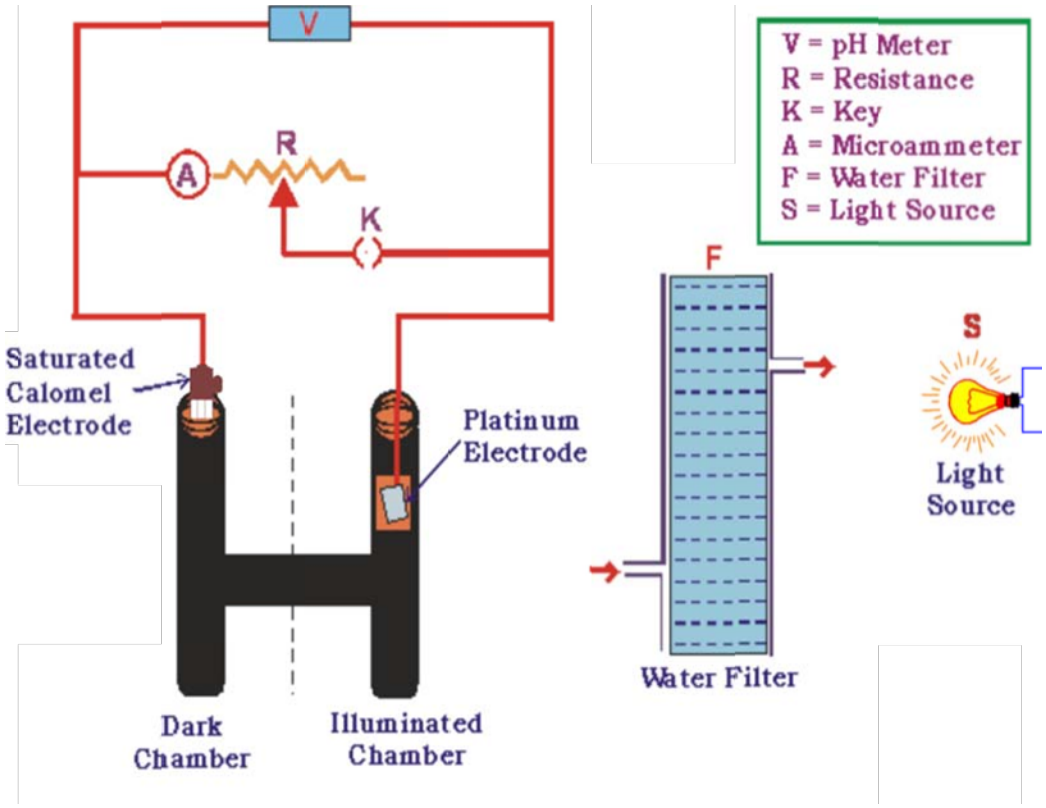

Fig 1. Set-Up of Photogalvanic Cell

caused a drop in electrical output as the dye molecules along the route absorbed most of the light, lowering the amount of light that reached the molecule near the electrode. As a result, electric output decreases proportionately. The photopotential, photocurrent, and power were observed to rise as the reductant [ascorbic acid] concentration increased, reaching maximum value on 1.7×10^{-3} M. The electrical output will be reduced due to the increased reductant concentration and the fact that dye molecules will not be able to migrate to electrode within given time. As the surfactant [SLS] concentration increases, cell's electrical output increased as well. At a certain concentration of SLS (1.6×10^{-3}M), the best outcome was achieved. A decline in electrical output was seen as a result of the surfactant's barrier effect at higher concentrations; this is because most surfactants photobleached fewer dye molecules.

[pH = 11.35] [Temperature = 303 K] [Light Intensity = 10.4 mW cm^{-2}]

3.2 Impact of pH variation

This was found that PG cell using the [Aniline Blue + Curcumin]–Ascorbic acid–SLS system was very sensitive to the solution's pH. This was found that when pH value (in alkaline range) increased, the system's photopotential, photocurrent, and power increased as well. A maximum was reached at pH 11.35. Photocurrent, photopotential, and power all decreased as pH increased more. A certain pH value produced the best electrical output. It could be because reductants are more readily available in donor form at that pH level. Table 2 reported a summary of findings demonstrating the impact of pH.

[Aniline Blue + Curcumin] $= 1.9 \times 10^{-5}$ M, [Ascorbic acid] $= 1.7 \times 10^{-3}$ M, [SLS] $= 1.6 \times 10^{-3}$ M, Temperature = 303 K, Light Intensity = 10.4 mW cm^{-2}

3.3 Impact of diffusion length

By varying diffusion length, impact on cell's current properties, including i_{eq}, i_{max}, and initial photocurrent generation rate, was studied using H-shaped cells of varied sizes. The photocurrent was found to rise sharply during the first few minutes of illumination. Due to the extended channel for the photochemical process, the maximum photocurrent (i_{max}) grew with diffusion length; however, this was not seen experimentally. On the other hand, at equilibrium (i_{eq}), the photocurrent

Table 1. Impact of Dye [Aniline Blue + Curcumin], ascorbic acid, & SLS concentration variations

Concentrations **[Aniline blue + Curcumin]** $\times 10^{-5}$ **M**	**Photopotential (mV)**	**Photocurrent** (μ**A**)	**Power** (μ**W**)
1.3	594	675	400.95
1.6	718	790	567.22
1.9	802	920	737.84
2.0	730	835	609.55
2.2	610	698	425.78
[Ascorbic acid] $\times 10^{-3}$ **M**			
1.2	605	645	390.23
1.4	685	752	515.12
1.7	802	920	737.84
1.8	644	753	484.93
1.9	534	591	315.59
[SLS] $\times 10^{-3}$ **M**			
1.3	691	724	500.28
1.5	795	854	678.93
1.6	802	920	737.84
1.7	754	864	651.46
1.9	668	758	506.34

Table 2. Impact of pH Variation

pH	**Photopotential (mV)**	**Photocurrent** (μ**A**)	**Power** (μ**W**)
11.15	671	700	469.70
11.25	751	800	600.80
11.35	802	920	737.84
11.40	740	875	647.50
11.45	651	790	514.29

dropped linearly. Consequently, one major electroactive species may be leuco or semi form of dye in light and dark chambers, correspondingly. During this whole process, the only thing the reductant and its oxidised product do is move electrons. Table 3 gives a summary of the findings. Furthermore, the impact of electrode area on cell's current characteristics was studied. The highest photocurrent (i_{max}) value was shown to increase with increasing electrode area. Table 4 summarises the findings.

Table 3. Impact of Diffusion Length

Diffusion Length (mm)	**Photocurrent (Maximum)** i_{max} (μ**A**)	**Photocurrent at Equilibrium** i_{eq} (μ**A**)	**Rate of initial Current Generation** (μ**A min**$^{-1}$)
35	942	924	24.79
40	945	922	24.87
45	948	920	24.95
50	951	917	25.03
55	954	915	25.11

3.4 Impact of light intensity

To investigate impact of light intensity, researchers used a Solarimeter model-501 intensity meter. Photocurrent grows in a linear manner with increasing intensity of light, but photopotential grows in logarithmic manner. The number of photons rises

Table 4. Impact of Electrode Area

Electrode Area (cm^2)	Photocurrent (Maximum) i_{max} (μA)	Photocurrent at Equilibrium i_{eq} (μA)
0.7	942	925
0.8	945	922
1.0	948	920
1.1	951	916
1.3	954	914

with the intensity of the light. Figure 2 shows a graphical illustration of how variations of light intensity affect photocurrent and photopotential.

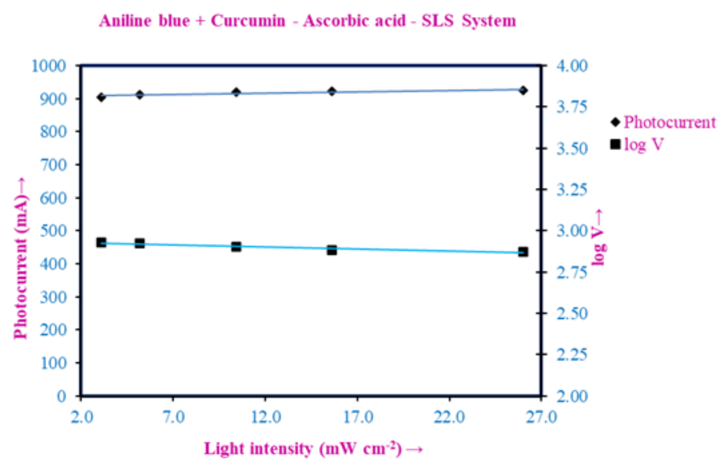

Fig 2. Change in Photocurrent & log V with Light Intensity

3.5 Current-Voltage (i-V) characteristics of cell

A microammeter was used in PG cell to extent open circuit voltage (V_{oc}), which was 981 mV, and short circuit current (i_{sc}), which was 920 μA. Using digital pH meter, the voltage was measured while the circuit was open. Between these two ends, the mustimeter's circuit and an external load were used to monitor the current and potential levels in a carbon pot (log 470 K).

Table 5 provides a summary of results and also seen in Figure 3, which employ the [Aniline Blue + Curcumin]-Ascorbic acid-SLS system to illustrate i-V properties of PG cells. The i-V curve was found to have strayed from its typical rectangular form. Power point (pp) of i-V curve was found to be the point where product of the current (i_{pp}) of 323 μA and the voltage (v_{pp}) of 510 mV was at its highest. The fill-factor was determined to be 0.1825 using i-V curve and the following calculation:

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

3.6 Conversion efficiency & Cell performance

Researchers were able to test the PG cell's functionality by stopping the illumination and adding an external load—the two things needed to keep the current at power point. Time required for output to drop to half at dark power point ($t_{1/2}$) was used to measure performance. The cell having [Aniline Blue + Curcumin]-Ascorbic acid-SLS system could function for 140.0 minutes in dark. Using the calculation that took into account the incoming radiation power, current, potential values at power

Table 5. i-V characteristics of cell

Potential (mV)	**Photocurrent (μA)**
981	0
980	5
978	10
972	15
968	20
961	25
955	30
898	40
875	50
840	60
798	75
774	95
754	105
741	115
698	125
679	135
651	155
628	170
622	180
618	210
580	270
567	280
568	285
519	315
510	**323**
489	330
470	340
419	375
404	388
347	430
339	440
319	465
308	480
292	505
250	580
236	610
230	620
108	720
0	750
Fill factor (η) = 0.1825	

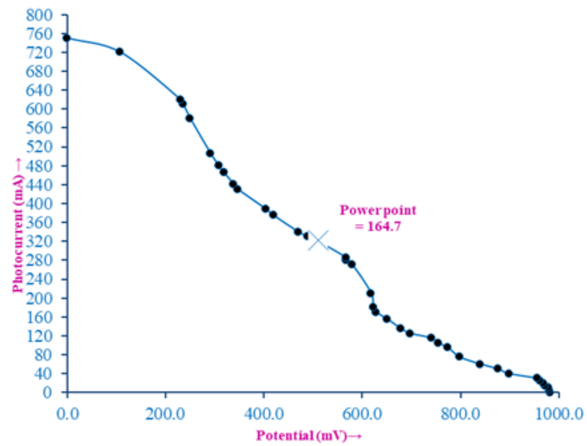

Fig 3. Current Voltage Curve

point, conversion efficiency was 1.59%. The findings may be seen visually in Figure 4, which displays the time-power curve.

$$Conversion\ efficiency = \frac{Vpp \times ipp}{A \times 10.4mW\,cm-2} \times 100\%$$

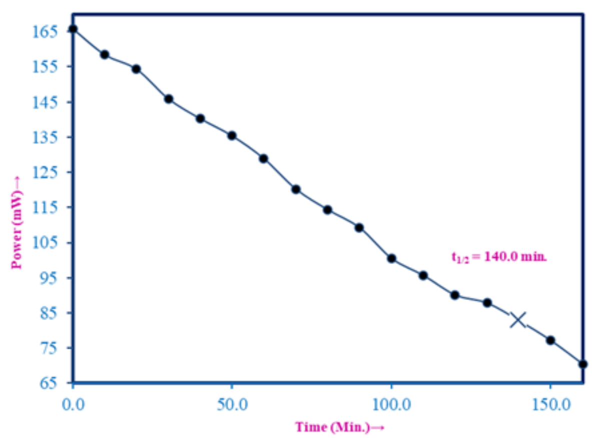

Fig 4. Time-Power Curve

3.7 Mechanism

Based on prior studies, the following is a description of the suggested mechanism in a PG cell. **Illuminated chamber:** Dye molecules gain energy when they are exposed to radiation. The oxidised state of the reductant is achieved by converting the excited dye molecules into their semi- or leuco form by absorbing one electron from the reductant. **At platinum electrode:** After losing an electron, the dye's semi-or leuco form reverts to its original molecular form. Ultimately, the original dye and reductant molecule is obtained when the oxidised form of reductant and the leuco/semi dye in photochemical process. This mechanism's cycle is repeatedly carried out, resulting in generation of current. Figure 5 displays the scheme of mechanism.

$$\begin{aligned}&\text{Dye} \xrightarrow{hv} \text{Dye}^{*}\\&\text{Dye}^{*} + \text{R} \longrightarrow \text{Dye}^{-} + \text{R}^{+}\\&\text{Dye}^{-} \longrightarrow \text{Dye} + e^{-}\\&\text{Dye} + e^{-} \longrightarrow \text{Dye}^{-}\\&\text{Dye}^{-} + \text{R}^{+} \longrightarrow \text{Dye} + \text{R}\end{aligned}$$

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

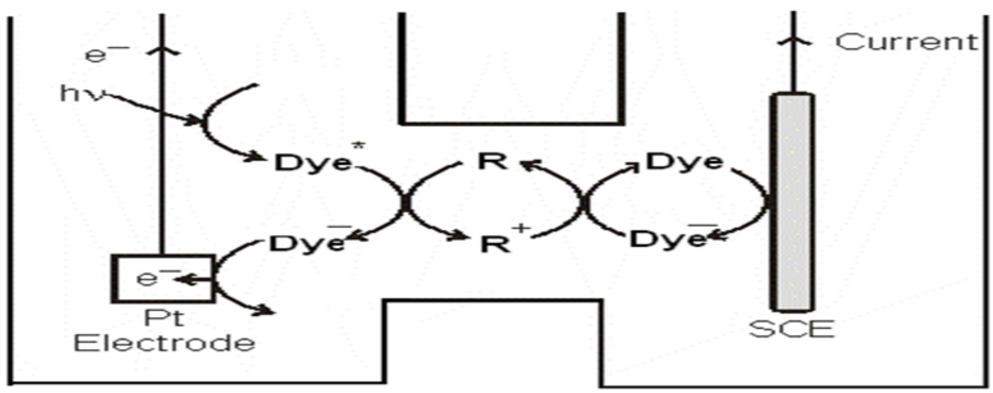

Fig 5. Mechanism Scheme

Opposed to photovoltaic cells, which rely on external hardware like batteries to store energy, PG cells having an internal storage capacity. This stored energy can use even in dark. Compared to photovoltaic solar cells, PG cells are better since they use less costly components. PG cells result i.e. photocurrent, photopotential, conversion efficiency, fill factor and cell performance Potential at power point, Potential at open circuit, power point of cell (pp) and current at short circuit were as follows: 388.0 μA, 1141.0 mV, 0.7995%, 0.5389, 129.0 minutes [6]. The maximum photopotential, photocurrent, time performance and conversion efficiency were observed at 690.00 mV, 235.00 μA, 120.00 minutes and 0.2812% respectively [8]. A sunlight-induced PG cell as key point and the observed V_{OC}, SPP, SPC, SP, and SCE is of the order of 1120 mV, 867 mV 238.00 μA, 206.34 μW, and 1.3012 %, respectively [17]. Additionally, the higher water solubility and photo-stability of PG system also make it suitable than **previously published works** [6], [8], [17].

4 Conclusions

For this PG system, fill factor of 0.1825, power at power point of 164.70 μW, storage capacity $t_{1/2}$ of 140.0 min, and conversion efficiency of 1.59% were recorded in the Aniline Blue + Curcumin + Ascorbic acid +SLS system. The following parameters have been measured at light intensity of 10.4 $mWcm^{-2}$: photopotential, photocurrent, power, fill factor, conversion efficiency, and cell performance ($t_{1/2}$) on the order of 802.0 mV, 920 μA, 164.70 μW, 0.1825, 1.59%, and 140 minutes were obtained respectively. Aniline Blue + Curcumin + Ascorbic acid +SLS based PG system offer potential advantages over previously reported results, including potential and cost factor. This system also has the ability to operate under varying light conditions. These features make them attractive for various applications like solar energy conversion and storage.

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