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RESEARCH ARTICLE

Innovative Study for Prospective Energy Source Through EDTA+TB+NaLS for Photogalvanic System

K M Gangotri[1], **Jagrati Meena**[2]*

1 Professor, Solar research energy Laboratory, Department of Chemistry, faculty of Science, New Campus, Jai Narain Vyas University, Jodhpur, 342001, Rajasthan, India
2 Assistant Professor, Solar research energy Laboratory, Department of Chemistry, faculty of Science, New Campus, Jai Narain Vyas University, Jodhpur, 342001, Rajasthan, India

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* **Corresponding author**.

photochemistrylabjnvu@gmail.com

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Abstract

Objective: Photogalvanic (PG) cells are based on solar storage concepts. Hence, the objective of the research work is to enhance the solar energy conversion into electricity and store through PG cells for better electrical output. **Methods:** The PG cell setup consists of two electrode, digital pH meter, resistance key, carbon pot, and micro -ammeter. The specially designed H shaped PG cell was studied for better electrical having EDTA+TB+NaLS system. The significant impact of solar energy was studied by varying the various parameters in PG cell. The 25 ml solution of surfactant (07 ml), reductant (04 ml) and dye (13 ml) and distilled water with alkali were used for the PG cell. The designed PG cell is experimentally proved to be an efficient system with reference to enhanced electrical outcomes of renewable energy. **Findings:** For EDTA+TB+NaLS PG cell, the observed maximum photopotential and maximum photocurrent were 1065.00 mVand150.00 mA, respectively. The PG cell performance and efficacy were found 24.00 minutes and 0.2630%, respectively. **Novelty:** A proposed photochemical mechanism for solar radiation energy transformation in PG cells enhances significant electrical output by using of EDTA+TB+NaLS PG cell system.

Keywords: Electrical Output; Toluidine Blue; Fuel Cell; Conversion Efficiency; Sodium

1 Introduction

Among alternative sources, solar energy cells are the most suitable pathway. Among solar cells, photogalvanic (PG) cells are best studied for significant results. In this way, the dye-based storage capacity of photogalvanic are good over photovoltaic cells and due to this reason, D-R-S (Dye-Reductant–Surfactant) system is comparatively good in field of photogalvanics[(1)]. The reaction kinetic of photodegradation of dyes was followed by the first-order kinetic model and the photodegradation mechanism of dyes was proposed[(2)]. Jayshree and Mohan (2018) studied on PG cells by using DSS + Tartrazine + EDTA for solar energy conversion and storage[(3)]. Koli (2021) studied on sudan-fructose based PG cells for electrochemical solar energy conversion

and storage at low and artificial sun intensity[4]. Koli et al. (2021) reported formic acid -Sodium Lauryl Sulphate Surfactant (SLSS) with enhanced PG effect of indigo carmine dye sensitizer for simultaneous solar energy conversion and storage[5]. Koli et al. also studied on modified and simplified PG cells for solar energy harvesting using bromo cresol green (BCB) dye with different electrodes and cell dimensions[6]. The PG cells were studied using different electrical outputs via photocurrent, photopotential, conversion efficiency, fill factor and cell performance[7]. Electrical output of the cell has also been observed for tartrazine, D-Fructose and lauryl glucoside systems. The power point potential (PPP), open circuit potential (OCP), power point of cell (pp) and short circuit current (SCC) were obtained with values 1133 mV, 1523 mV, 435.321 and 544μA, respectively [8]. Various parameters were studied in a photogalvanic having D-Xylose+MB+Brij-35+NaLS PG cell for solar cell conversion and storage [9]. The mixed surfactants (Brij-35+NaLS) in PGS have experimentally proved the efficient system as the desired object of the research with special reference to enhanced electrical out and storage of solar energy [10]. They have used different surfactant-dye- reductants (SDR) in the solar system but none paid attention to use of toluidine Blue (TB) to enhance the electrical output. Therefore, the present work (EDTA+TB+NaLS system) PG cell was undertaken.

2 Methodology

2.1 Laboratory work for solution preparations

For the experiment work, all solutions (sodium hydroxide, oxalic acid, EDTA, toluidine blue, NaLS), were prepared by using distilled water (DW) for significant results. The prepared solution of NaOH was standardized by using oxalic acid in all sets of experiments. All the solutions are kept in an amber color flask to protect them from sunlight [11].

2.2 Set –up for EDTA+TB+NaLS

A specially designed H-shaped glass tubes were designed for PG cell. The photocatalytic activity of mushroom was assessed for the degradation of Congo red dye, fast green dye, and brilliant blue dye[12]. The H tube was completely blackened except the one window to absorb electromagnetic radiation [13]. The 25 ml solutions of surfactants (NaLS, 07 ml), reductant (EDTA, 04 ml), photosensitizer (toluidine blue, 14 ml), and sodium hydroxide (01 ml) were filled in H tube (Fig. 1). During the experiment, both ends of electrodes were connected through the carbon pot, resistance key, micro-ammeter, 200 W electric bulb (W filament containing), and digital pH meter for completion of solar circuit. The water filter was used for light sources and to cut off IR radiations for experiment setup [14]. On illumination, the maximum photopotential (PP_{max}), maximum photocurrent (PC_{max}), photocurrent (PC), and Maximum power (P_{max}) were measured [15]. The electrical results in terms of the PP_{max} (1065.00 mV), PC_{max} (150.00 mA), PP (70.00 mA), and P_{max} (27.36mW), were measured for PG cells. The percentage purity (90% - 94%) and nature of material used were uncertain of the experiment. The scientific instruments handling (errors) and calibration factors were related to uncertainty of meters (i.e., microammeter and p^H meter). A much-diluted solution of dye (TB = 4.00 $\times$ 10^{-5} M), reductant (EDTA = 2.40 $\times$ 10^{-3} M), and surfactant (NaLS = 6.00 $\times 10^{-3}$ M) were used for cell configuration that was the condition of the experiment. The cell illumination time was 220.00 minutes and ambient temperature was 303 K. The experimental work for EDTA+TB+NaLS cells is given in Figure 1.

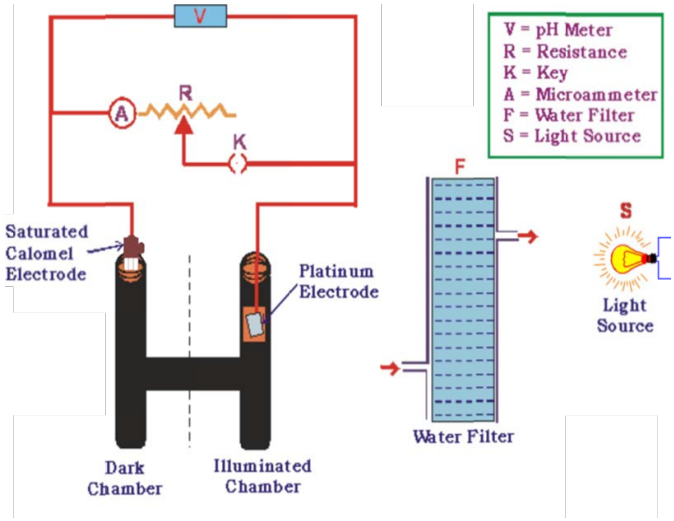

Fig 1. Methodology set up of cell

3 Results and Discussion

3.1 Variation of toluidine blue (TB) on the PG system

In the present study, variation of dye concentration has been studied for EDTA+TB+NaLS. On increase of TB concentration, the electrical results are increased and attains maximum value at 4.00×10^{-5} M, and then decreases in EDTA+TB+NaLS system. The comparative minimum number of toluidine blue molecules (TB < 4.00×10^{-5} M), acts as lower nature of TB for the absorption of the light due to hydrophobic nature, so the electrical output is comparatively low. Whereas, at a higher concentration range of TB molecules (TB > 4.00×10^{-5} M), there are a large number of TB molecules present that overload the surface of absorbent [16]. At the intermediate range of TB concentration (TB = 4.00×10^{-5} M), there are optimum molecules present that the optimum light source does reach the molecule near the electrode for photochemical changes. The PP_{max}, PC_{max} and P_{max} are recorded for variation of toluidine blue (TB) on the PG system and obtained values are 1065.00 mV, 150.00 mA, and 52.01 μW, respectively. all observed results are reported in Tables 1, 2 and 3 and Figures 2, 3 and 4.

Table 1. Variation of TB, EDTA, NaLS and P^H

	Light Intensity = 10.4 mWcm^{-2}	**Temperature = 303 K**	
Parameters	**Photopotential (mV)**	**Photocurrent (mA)**	**Power (μW)**
[TB] $\times 10^{-5}$ M			
3.00	708.00	52.00	22.82
4.00	743.00	70.00	52.01
5.00	612.00	45.00	25.46
[EDTA] $\times 10^{-3}$ M			
0.95	638.00	214.00	136.53
2.40	743.00	70.00	52.01
3.05	635.00	48.00	32.08
[NaLS] $\times 10^{-3}$ M			
5.90	638.00	46.00	37.81
6.00	743.00	70.00	52.01
7.00	642.00	52.00	36.10
p^H			
12.50	622.00	42.00	31.86
12.60	743.00	70.00	52.01
12.70	617.00	56.00	27.10

Table 2. Effect of Diffusion Length on the System

Diffusion length (mm)	Maximum photocurrenti$_{max}$ (mA)	Equilibrium photocurrent i$_{eq}$ (mA)	Rate of initial generation of photocurrent (mA min^{-1})
35.00	143.00	76.00	15.0
40.00	146.00	73.00	15.8
45.00	150.00	70.00	16.6
50.00	154.00	67.00	17.4
55.00	158.00	63.00	18.2

Table 3. Effect of Electrode Area on the System

EDTA+TB+NaLS	Electrode Area (cm^2)				
	0.36	0.64	1.00	1.21	1.44
Maximum photocurrent i$_{max}$ (mA)	143.0	146.0	150.0	152.0	156.0
Equilibrium photocurrent i$_{eq}$ (mA)	83.0	78.0	70.0	66.0	61.0

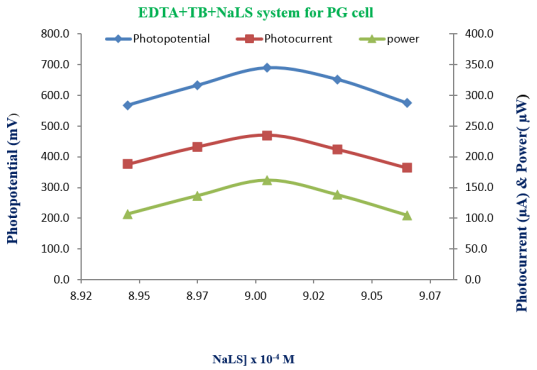

Fig 2. Variation of photopotential, photocurrent and power

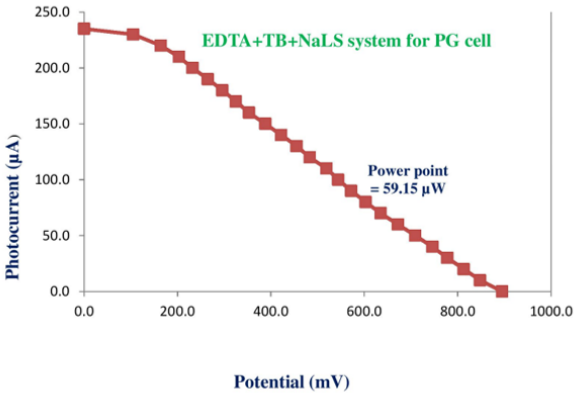

Fig 3. Current voltage (i-V) curve of cell

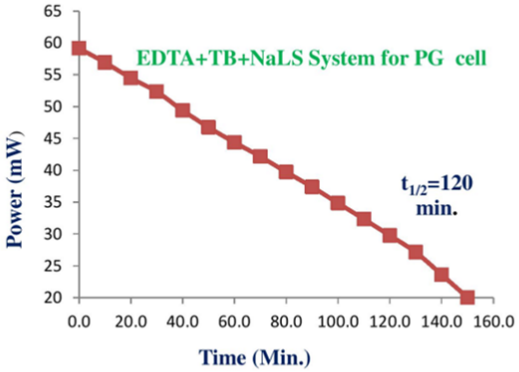

Fig 4. Performance of the PG cell

3.2 Variation of EDTA on the PG system

In the present study, variation of EDTA concentration has been studied for EDTA+TB+NaLS. On increase of EDTA concentration, the observed results are increased. On increase of the concentration of EDTA, the electrical output also increases gradually and attains maximum value at 2.40×10^{-3} M, and then decreases in EDTA+TB+NaLS system. On a lower concentration of D-xylose, (Xylose < 2.40×10^{-3} M), comparatively lesser amounts of reductant EDTA are available for electron donation to TB to form the ionic nature. Whereas, at much more concentration of ethylene dimethyl tetraacetic acid (EDTA > 2.40×10^{-3} M) there are a higher amount of EDTA molecules being available for photophysical change to TB to form the cationic form which hinders the TB molecules. The 2.40×10^{-3} M is an intermediate range of reductant concentration where good results are obtained [17]. The reason behind is, there are optimum numbers of reductant molecules present that form favorable pathways for semi or leuco form of dye TB molecules. The results showed that the current consumption in deep sleep mode was only 10 mA, which is in general much lower than the current consumption of system [18]. The PP_{max}, PC_{max} and P_{max} are recorded for variation of EDTA on the PG system and obtained values are 1065.00 mV, 150.00 mA, and 52.01 μW, respectively. all observed results are reported in Tables 1, 2 and 3 and Figures 2, 3 and 4.

3.3 Variation of NaLS on the PG system

The photo reactivity of NaLS with electric power of the PG cell with EDTA+TB+NaLS system was studied. It was seen that if increased concentration of NaLS, the result is increased up to particular limits and therafetr decreased. At lower concentration range of NaLS (surfactants < 6.00×10^{-5} M), less solubilized the molecules for photophysical process in surface area. Whereas, at a higher concentration range of surfactants (NaLS > 6.00×10^{-5} M), there are a lot of surfactant molecules available for photophysical processes in hydrophobic interaction which may reduce electron carrier. The 6.00×10^{-5} M NaLS is an intermediate range of surfactant concentration where significant electrical output was obtained. The good precipitation may occur in surfactant mixture over individually precipitate of single surfactant in PG cells [19]. This is due to surfactant interaction of the micelles interface. The PP_{max}, PC_{max} and P_{max} are recorded for variation of NaLS on the PG system and obtained values are 1065.00 mV, 150.00 mA, and 52.01 μW, respectively. All observed results for are reported in Tables 1, 2 and 3 and Figures 2,

3 and 4.

3.4 Variation of pH on the PG system

In this present study, concentration of hydrogen ions was observed and on increase the alkaline nature (increase the pH), the current parameters are also increased gradually and attains a maximum value of particular range (pH=12.64 at max.) and subsequently got decreased in EDTA+TB+NaLS system. On a lower range (pH < 12.64) of pH and higher range (pH > 12.64) the optimum results are not obtained. Whereas, appreciable results are obtained at intermediate range (pH = 12.64)). This is due to the nature of TB (dye molecules), which is better for photochemical process. The PP_{max}, PC_{max} and P_{max} are recorded for variation of NaLS on the PG system and obtained values are 1065.00 mV, 150.00 mA, and 52.01 μW, respectively. Tables 1, 2 and 3 shows the variation of pH on EDTA+TB+NaLS system.

3.5 Variation of diffusion length on the PG system

During experimental work, diffusion length from 35 mm to 55 mm was used for the cell. The current parameters of the PG cell were studied in EDTA+TB+NaLS system. If diffusion length is increased, the rate of initial generation of photocurrent is increased. Better results are obtained at 45.00 mm with photocurrent (150.00 μA), equilibrium photocurrent (70.00 μA), and initial generation of photocurrent (16.6 μA/min), respectively. Lower and higher diffusion length (35 mm and 55mm) are not suitable for dye molecules to absorb the light source, and resultantly, photocurrent is obtained as a respective manner: maximum photocurrent (158.00 μA) equilibrium photocurrent (64.00 μA), and initial generation of photocurrent (18.2.78 μA/min.) were obtained. Table 2 shows the variation of diffusion length on EDTA+TB+NaLS system.

3.6 Variation of electrode area of the cell

Electrode area was used from 0.70 cm^2 to 1.30 cm^2 for the current parameters of the PG cell. The maximum photocurrent (i_{max} in mA) and equilibrium photocurrent (i_{eq} in mA) were studied. On 0.70 cm^2 of electrode area, maximum photocurrent (260.00 μA) and equilibrium photocurrent (243.00 μA) were obtained and 1.30 cm^2 of electrode area, maximum photocurrent (280.00 μA) and equilibrium photocurrent (227.00 μA) were obtained. At 1.00 cm^2 of electrode area electrode area, maximum photocurrent (270.00 μA) and equilibrium photocurrent (235.00 μA) were obtained which are comparatively better electrical outputs in EDTA+TB+NaLS system. The observed results are shown in Table 3 for variation of electrode area on EDTA+TB+NaLS system.

3.7 (i-V) characteristics of the PG cell

The fill-factor (FF) and power point (PP) were calculated (equ. 1):

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

$$\text{Power Point } (pp) = V\,pp \times i_{pp} \tag{2}$$

Where

V_{pp} is value of potential, i_{pp} is current at power point, V_{oc} is open circuit voltage, i_{sc} is short circuit current

The value of FF of the cell circuit was calculated as 0.3670 and the pp was obtained as 27.36 μW for the PG cell. Figure 3 shows the power point of a cell in EDTA+TB+NaLS System.

3.8 Cell performance and conversion efficiency of the PG system

The determined performance is (Figure 4) in terms of $t_{1/2}$ and the observed value was 120.00 minutes in dark. PG cell conversion efficiency (CE) was determined as 0.2630 % (equ 3)

$$\text{Conversion efficiency } = \frac{V_{pp} \times i_{pp}}{A10.4mW\ cm^{-2}} \times 100\% \tag{3}$$

Where $V_{pp,}$ is photopotential at power point of cell, i_{pp} is photocurrent at power point of cell, A is electrode area of cell

3.8 Mechanisms

Experimentally, the following chemical transformation takes place, indicating the flow of electrons in the cell circuit.

3.9.1 Illuminate Chamber

In the photophysical and photochemical process (equation-4), TB molecules (photosensitizer) absorb quantum radiation and get excited as follows. In the secondary process (equation-5) excited methylene blue accepts electrons from reductants and transfers its energy to other molecules for chain reaction.

$$TRB \xrightarrow{h\nu} TB^{*} \tag{4}$$

$$TB^{*} + R \longrightarrow TB + R^{+} \tag{5}$$

3.9.2 Photochemical reaction at Pt electrode

During the secondary process, the semi or leuco form of TB (equation-6) loses an electron to electrode and converts into the original methylene blue molecule.

$$TB^{-} \longrightarrow TB + e^{-} \tag{6}$$

3.9.3 Photochemical reaction at dark Chamber

At counter electrode: during photochemical process, TB molecules (photosensitizer) gain an electron from counter electrode and convert into a semi or leuco form of TB molecule as fellows (equation-7) and finally, TB (leuco/semi form) and the reductant (oxidized form), combine to give original TB dye and EDTA reductant(R) molecules (equation-8) and the whole photochemical cyclic process continues.

$$TB + e^{-} \longrightarrow TB^{-} \tag{7}$$

$$TB^{-} + R^{+} \longrightarrow TB + R \tag{8}$$

Where: TB is Toluidine blue (dye), TB* is excited form of toluidine blue
TB^{-} is semi or leuco form of toluidine blue, R is Reductant, R^{+} is oxidized form

Table 4. Effect of EDTA+TB+NaLS for PGS

S. No.	Parameters	Single surfactant NaLS
1.	Open Circuit Voltage (V_{OC})	**1065.0 mV**
2.	Photopotential (DV)	**743.0 mV**
3.	Maximum Photocurrent (i_{max})	**150.0 mA**
4.	Short Circuit Current (i_{sc})	**70.0 mA**
5.	Equilibrium Photocurrent (i_{eq})	**70.0 mA**
6.	Current at Power Point (i_{pp})	**45.0 mA**
7.	Potential at Power Point (V_{pp})	**608.0 mV**
8.	Power at Power Point (PP)	**27.36 mW**
9.	Fill factor (h)	**0.3670**
10.	Conversion Efficiency (%)	**0.2630 %**
11.	$t_{1/2}$	**24.0 min**
12	Charging Time (min.)	**60.0 min**

4 Conclusion

4.1 Novelty and Prospectus and Recommendation

The main focus of investigation was reduction in cost of PG cells along with enhancement of electrical results. The aim has been achieved by observing the good amount of storage capacity of EDTA+TB+NaLS system. The efficient systems, if reached to desired extent of reduced cost and overall efficiency, may replace the existing PG cells in the market and would be capable of feeding the electrical demand of humanity.

4.2 Importance of work

On the basis of the observed results of the PG cell (Table 4), we have observed that the EDTA+TB+NaLS surfactants have not only enhanced the electrical output of the cell but also enhanced the energy conversion of the cell for PGS. The PG cells may be the best fuel cell in the field of solar radiation transformation and potential, with respect to current parameters. The open circuit voltage is 1065.00 mV for EDTA+TB+NaLS PG cell and already reported open circuit voltage as 895.00 mV (Lal and Gangotri, 2022). EDTA+TB+NaLS PG cell fill factor was 0.3670 and previously reported fill factor were 0.211, 0.200, 0.240 and 0.207 (Koli et al., 2021) . Whereas, the maximum photocurrent observed was at 150.00 uA in EDTA+TB+NaLS PGS, and already reported results were 190 uA (Rathore et al. 2022). Thus the impact of solar energy was studied by varying the various parameters in PG cell. Conclusively, the currently observed PG cell performance is relatively higher than the reported PG systems[5,8,9] . The effects will be made to develop the PG cell having higher electrical output than the already reported results (see reference no.,[5,8,10]). The efficient systems, if reached to desired extent, may replace the existing solar cells in the market and would be capable of feeding the electrical demand for sustainable development.

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