



(RESEARCH ARTICLE)



Enhanced electrical results of mixed dyes system (M.G. and T.B.+ D-arabinose + CTAB) in photogalvanic cell for conversion and storage

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Abstract

Our goal is to develop PG cells that convert and store solar energy with improved electrical output. To achieve this, the electrical observations were examined in an H-shaped PG cell system using various solutions of CTAB surfactant, D-arabinose, and Malachite Green (M.G.) and Toluidine Blue (T.B.). Distilled water was used to prepare various solutions, including dye, reductants, and surfactants. At a light intensity of 10.4 mWcm^{-2} , measurements of photopotential, photocurrent, power, fill factor, conversion efficiency, and cell performance ($t_{1/2}$) have been performed. 294.0 mV, 34.00 μA , 9.996 μW , 0.0918 and 0.03591%, and 85 minutes are the corresponding electrical values. Significant electrical results of developed PG cells were noted in this study, i.e., cell performance, conversion efficiency, and storage capacity. This research work is a novel application of PG cells for solar energy conversion and storage, with a focus on improved cell performance.

Keywords: Photogalvanic cell; Electrical results; Mixed dyes; CTAB; Fill factor

1. Introduction

Scientists drew attention towards various energy source to save the environment and eco system. Energy is the basic element of the universe. it is found in different forms. Koli (2021) reported on Sudan-I dye and Fructose chemicals based photogalvanic cells for electrochemical solar energy conversion and storage at low and artificial sun intensity [1]. As we know according to the first law of thermodynamics energy can neither be created nor destroyed it can be converted from one form to another. We know this too that total energy of universe remains constant the change in the amount of energy from one component to another is the equal to the change in the amount of the energy. Lal and Gangotri (2022) reported on innovation for prospective energy source through solar cell [2]. On the basis of source energy are divided in two parts as renewable energy, and non-renewable energy. Today any developing country needs clean and renewable source of energy to show its dominance in the world. Rathore et al. (2022) studied on photogalvanic cell for electrical output in solar energy conversion and storage: single surfactant as lauryl glucoside, Tartrazine as a photosensitizer and D-fructose as reductant [3]. Today solar energy is an important source among all source present in the nature such as nuclear energy, hydroelectric energy, geothermal energy, wind energy, biomass energy. Solar energy is a pure and natural source of energy which can never be exhausted. Kaswan et al. (2022) worked-on conversion of solar radiation into electrical energy by using solar cell [4]. We receive approximately 10,000 volts of energy from the sun of which we are able to utilise only one percent. We can use solar energy obtained from the sun to produce electricity. Scientific community felt the need for a device to utilize the solar energy obtained from the sun. Research work about use of solar energy was related to silicon based solar cell. Lal and Gangotri (2022) studied on innovation in progressive study for prospective energy source through photo-galvanic-system: D-Xylose+MB+Brij-35+NaLS [5]. Silicon based solar cell was quite good in quality and production but the biggest drawback of silicon based solar cell was the energy production along with high cost. Genwa and Prasad (2023) reported on innovative study of photogalvanics in solar energy transformation and performance analysis: Alizarin cyanine green, EDTA, and sodium stearate system [6]. Due to this

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reason it's use started decreasing now scientists started focusing on such cell through which we can achieve high production at low cost. Lal and Gangotri (2023) studied on innovative study in renewable energy source through mixed surfactant system for eco-friendly environment [7]. Further in this sequence second generation photovoltaic cell was discovered. which included thin film silicon cell and cadmium telluride cell. Over time the quality of the cells improved and third generation photovoltaic cells were discovered. Yadav et al. (2023) studied on electrical output in photogalvanic cell for conversion of energy and storage by using Bismarck brown with different reductant [8]. They observed very good results for efficiency. In which such an ultra-high efficiency concept photovoltaic cells and photovoltaic cells made of polymer cells with quantum dots incorporated. Ram et al. (2024) studied on innovative study of the photogalvanics for solar energy conversion and storage through brilliant yellow + NaLS + ascorbic acid system [9]. When sun is glowing, more energy is produced by solar cell. when cloud is present in the sky and they stop up the sunlight the efficiency of solar cell will decrease. Shadow from other objects (such surrounding buildings and trees) effect the system and less power is generated. Koli (2024) reported on comparative study of the photogalvanics of Sudan-I, Rhodamine-B, Fast green FCF, Brilliant cresyl blue, Naphthol green B, and chlorophyll 'a' photosensitizers at natural sunlight illumination intensity [10]. Solar system will be work best when system face is present in south direction and no shaded for large part of a day. Lal and Gangotri (2025) studied on comparative study on sunlight induced surfactants system in photogalvanics for solar energy conversion and storage and reported result in "Next Sustainability" journal [11]. The cell has acquired some disadvantages over time such as requiring large amounts of space to produce significant amounts of electricity. Lal (2025) studied on innovative study for enhanced performance of the photogalvanic cells for solar energy conversion and storage [12]. A complete dependence on the sun at all times. Such as during cloudy weather and at night reduces the efficiency of photovoltaic cell. high costs are required to completely install photovoltaic cells. Jonwal et al. (2025) reported on natural surfactant fenugreek seeds based photogalvanic cell for solar energy conversion and storage [13]. To overcome all these problems, scientists turned their attention towards photogalvanic cells. Photogalvanic cells are rechargeable with sunlight in which surfactants solution are potentially important for efficient energy conversion and storage. Gahlot et al. (2025) studied on enhanced electrical results of mixed dyes system (M.G. and T.B. + D-Arabinose + NaLS system) in photogalvanic cell for conversion and storage [14]. The research work on PG cell will be an important contribution to solar energy filed. By the help of these compounds, we can increase the efficiency of photogalvanic cells by using surfactant, reductant, mixed dyes system.

2. Experimental

2.1. Material and apparatus

Table 1 Materials required for photogalvanic study

S. No.	Chemicals	Specifications
1.	Malachite Green (MG)	E. Merck
2.	Toluidine Blue (TB)	E. Merck
3	Sodium hydroxide	E. Merck
4	CTAB	E. Merck
5	D (-) Arabinose system	S.D. Fine
6	Digital pH meter (Model-335)	Systronics
7.	A Microammeter (MO-65)	Systronics

2.2. Preparation of photogalvanic solutions

In the double distilled water MG and TB mixed dyes system, D (-) Arabinose with surfactants CTAB have been prepared. All solutions have prepared in double distilled water with the help of a precision balance by direct weighing methods. To protect from radiation, we put solutions in borosilicate glass laboratory flasks. The strength of MG, TB, D-Arabinose, CTAB and NaOH concentration were 1.6×10^{-5} M, 1.6×10^{-5} M, 1.92×10^{-3} M, 6.4×10^{-3} M and 1N, respectively.

2.3. Experimental setup of photogalvanic cell (Procedure)

We took H shape glass tube for experimental analysis which was completely blackened except for a small portion on the side of the glass top which was not blackened. This H shaped glass tube is filled 25 ml by solution of MG & TB mixed dyes system, reductant, NaOH with surfactants CTAB. For the preparation of solution, we have used double distilled

water. Now both electrodes (Calomel electrode and Platinum electrode) are connected in both arms differently. The entire arms are blackened except a small portion now and we dipped $1.0 \times 1.0 \text{ cm}^2$ Pt electrode.

The cathode parts of the cell are connected with pH meter to calculate photopotential and photocurrent of the cell. Now we put set of the cell in the dark and the set of cells is kept in dark until a uniform potential is achieved now with 200 W tungsten light ECE is illuminated towards to platinum electrode. The water filter was used to protect the photogalvanic solutions from light.

3. Results and Discussion

Overall observed experimental result of photogalvanic cell are represented in Table 2, which reports electrical output of CTAB- [MG & TB mixed dyes] system with reductant D-Arabinose.

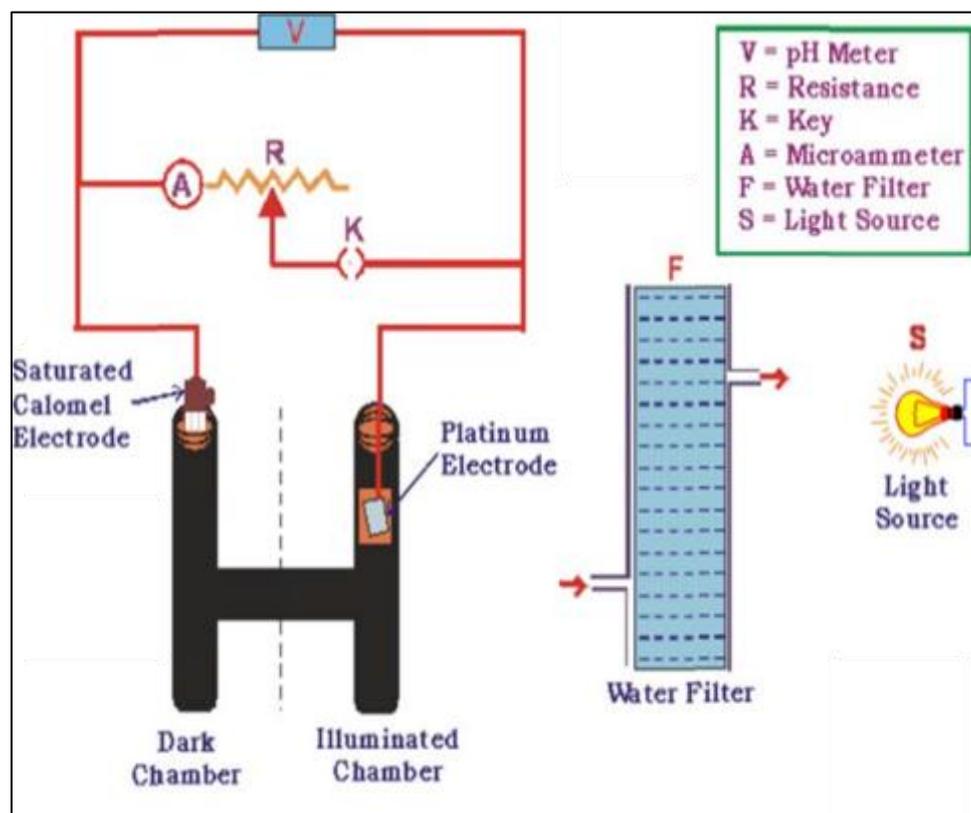


Figure 1 Experimental setup of photogalvanic cell

Table 2 Electrical parameters and observations of (M.G & T.B) dye system

S.NO.	Electrical parameters	Observations of (M.G & T.B) dyes system D (-) Arabinose with CTAB
1	Open Circuit Voltage (V_{oc}) mV	484.0
2	Short Circuit current i_{sc} (μA)	34.0
3	Photopotential (mV)	294.0
4	Current at power point i_{pp} (μA)	15.0
5	Fill factor (η)	0.0918
6	Conversion efficiency (%)	0.03591
7	$t_{1/2}$ (min.)	85.0

3.1. Effect of variation of dyes (MG and TB) concentration

By experimental analysis we observed that the concentration of photosensitizer (M.G & T.B) effect the electrical parameter (photopotential & photocurrent) of PG cell. when the concentration of photosensitizer is low. The electrical output of the cell also low, then increasing the concentration of photogalvanic cell the electrical output of cell will also increase. We observed maximum output of the cell at concentration of MG 1.6×10^{-5} M & TB 1.6×10^{-5} M. If we increase the concentration further the electrical parameters start decreasing. because the source of light absorbed by the dye's molecule located away from the platinum electrode. While the dye molecule located near platinum electrode do not absorb the desired light, due to which the output of the cell decreases. All experimental results are shown in Table -3 and 4.

Table 3 Effect of variation of [MG] concentration

CTAB - [MG, TB] system	[Malachite green] $\times 10^{-5}$ M				
	1.2	1.4	1.6	1.8	2.0
Photopotential (mV)	184	237	294.0	252	202
Photocurrent (μ A)	21	29	34.0	32	23
Power (μ W)	3.864	6.873	9.996	8.064	4.646

[CTAB] = 6.4×10^{-3} M Intensity of Light = 10.4 mWcm^{-2} [Toluidine blue] = Constant, [D-Arabinose] = 1.92×10^{-3} , pH of system = 12.8, Temp. = 303 K

Table 4 Effect of variation of [TB] concentration

CTAB - [MG, TB] system	[TB] $\times 10^{-5}$ M				
	1.2	1.4	1.6	1.8	2.0
Photopotential (mV)	169	221	294.0	233	195
Photocurrent (μ A)	20	27	34.0	30	24
Power (μ W)	3.380	5.967	9.996	6.990	4.680

[CTAB] = 6.4×10^{-3} M, Intensity of Light = 10.4 mWcm^{-2} , [MG] = Constant, [D-Arabinose] = 1.92×10^{-3} Temp. = 303 K pH of system = 12.8

3.2. Effect of variation of reductant D (-) Arabinose concentration

By the experimental analysis we measured that if we change the concentration of reductant D (-) Arabinose then the results of photogalvanic cell also change. When we increase the concentration of reductant the electrical parameter of cell also increases because the electrical parameter depends on movements of dyes molecules. Further we increase the concentration of reductant the movements of dyes molecules are hindered due to which the dyes molecules cannot reach to electrode with in their prescribed time limit that's why the electrical output of the PG cell will decrease. The maximum output of the cell measured on at 2.4×10^{-3} M concentration of the reductant. We observed photocurrent 34.0μ A and photopotential 294.0 mV. All observed results of current study are reported for mixed dye system.

3.3. Effect of variation of surfactant (CTAB) concentration

When the experimental study was conducted on MG & TB mixed dyes system with the variation of surfactant (CTAB) concentration. we analysed that if the concentration of surfactant increases the electrical parameter (photopotential & photocurrent) of photogalvanic cell also increase. The maximum output of the photogalvanic cell was obtained at 6.4×10^{-3} M concentration of surfactant (CTAB). If we increase the concentration of surfactant further the electrical parameter of photogalvanic cell will decrease, which is graphically represented in Fig 2. When we add surfactant to the solution it helps in dissolving the dyes. Due to which the dyes dissolve well in the solution and electron comes out easily from the dye and photogalvanic cell works well. We can say this as well that surfactant combines with dyes and forms a protective layer due to which the dyes do not get damaged in light. this experiment also done in the absence of surfactant we found that the cell output was very low. The effect of surfactant concentration on photopotential and photocurrent are represented in Table-5.

Table 5 Effect of variation of [CTAB] concentration

CTAB - [MG& TB] system	[CTAB] × 10 ⁻³ M				
	5.8	6.2	6.4	6.8	7.2
Photopotential (mV)	174.0	211.0	294.0	247.0	196.0
Photocurrent (µA)	24.0	29.0	34.0	27.0	21.0
Power (µW)	4.176	6.119	9.996	6.669	4.116

[MG] = 1.6 × 10⁻⁵ M [Toluidine Blue] = 1.6 × 10⁻⁵ M Intensity of Light = 10.4 mWcm⁻² [D-Arabinose] = 1.92 × 10⁻³ pH of system = 12.8 Temp. = 303 K

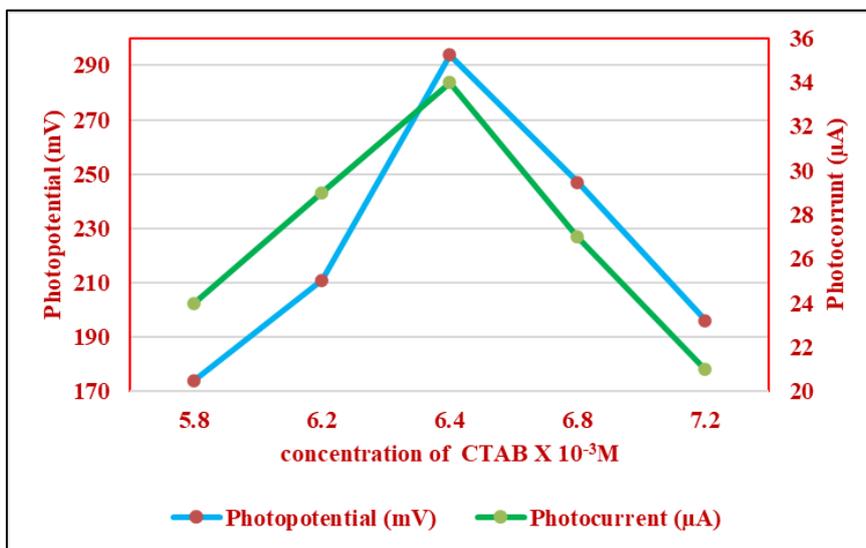


Figure 2 Observations of photopotential and photocurrent with CTAB concentration

3.4. Effect of variation of pH on the system

We practically analysed variation of pH on photogalvanic cell with mixed dyes system (MG & TB) with different concentration of NaOH. We observed that if we increase the pH value photopotential & photocurrent of the cell will increase and we get maximum output of the PG cell at 12.8 pH value. further increasing pH value photopotential & photocurrent of the PG cell will decrease. This indicate that reductant behave as a good donor at pH 12.8. All experimental results are shown in Table 6.

Table 6 Study on variations of pH on the system

CTAB - [MG & TB] system	pH of the system				
	12.0	12.4	12.8	13.0	13.2
Photopotential (mV)	197.0	234.0	294.0	267.0	223.0
Photocurrent (µA)	23.0	31.0	34.0	29.0	26.0
Power (µW)	4.531	7.254	9.996	7.743	5.798

[CTAB] = 6.4 × 10⁻³ M Intensity of Light = 10.4 mWcm⁻² [MG] = 1.6 × 10⁻⁵ M [Toluidine blue] = 1.6 × 10⁻⁵ M [D-Arabinose] = 1.92 × 10⁻³ Temp. = 303 K

3.5. Current-voltage characteristics of the cell

The electrical output of photogalvanic cell was measured by using a micrometre and digital pH meter respectively. MG & TB mixed dyes system i-v calculation are shown in graph. There is a point in i-v curve where photopotential and photocurrent are maximum is called as power point. Fill factor value for MG & TB mixed dyes system with surfactant (CTAB) is 0.0918. The current voltage results of photogalvanic cell are reported in Fig 3.

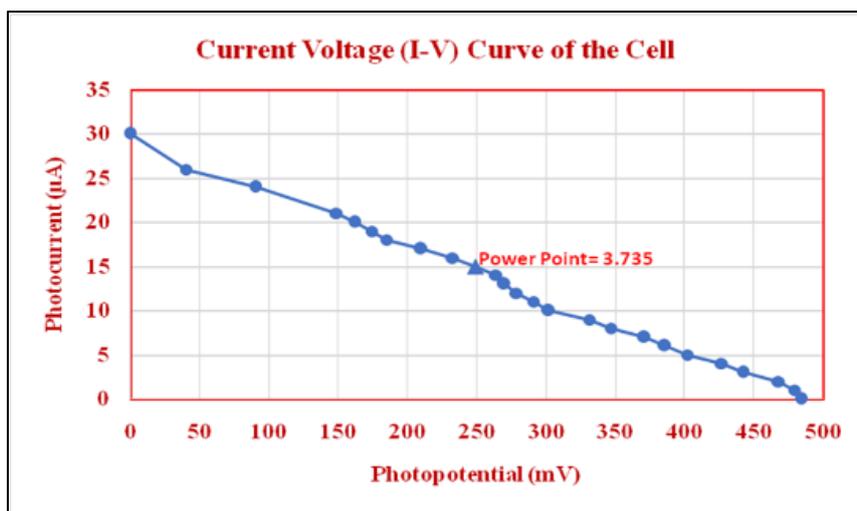


Figure 3 Current-voltage characteristics of the cell

3.6. Performance of the cell, conversion efficiency and fill factor of the cells

During experiment, $t_{1/2}$ was obtained 85 minutes for MG & TB mixed dyes system with surfactant (CTAB). We obtained $t_{1/2}$ by keeping the cell at power point stage in dark and recording the amount of time needed for the power output to drop to half its value. By the help of equation 1 & equation 2. The obtained fill factor and conversion efficiency were 0.0918 and 0.03591 % for MG & TB mixed dyes system with platinum foil electrode ($1.0 \times 1.0 \text{ cm}^2$).

$$\text{Conversion Efficiency} = \frac{V_{pp} \times i_{pp}}{10.4 \text{ mW/cm}^2} \times 100\% \quad \dots(1)$$

$$\text{Fill factor (ff)} = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}} \quad \dots(2)$$

Where: - V_{pp} = Potential, i_{pp} = Current at power point, V_{oc} = Open circuit voltage, i_{sc} =Short circuit current.

On the basis of electrical data, we can state that MG and TB mixed dyes system is good in terms of solar energy conversion and performance.

3.7. Effect of variation of diffusion length

Table 7 Effect of variation of diffusion length

Diffusion Length DL (mm)	Maximum photocurrent i_{max} (μA)	Equilibrium photocurrent i_{eq} (μA)	Initial Rate of generation of current ($\mu\text{A min}^{-1}$)
35	71.0	48.0	1.03
40	78.0	39.0	1.17
45	84.0	34.0	1.29
50	89.0	29.0	1.39
55	93.0	25.0	1.53

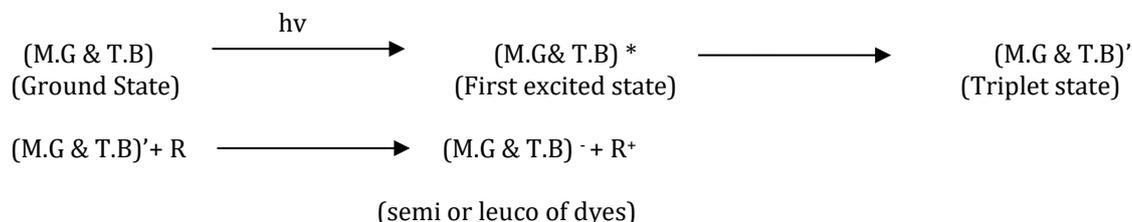
[CTAB] = $6.4 \times 10^{-3} \text{ M}$ Intensity of Light = 10.4 mWcm^{-2} [MG] = $1.6 \times 10^{-5} \text{ M}$, [Toluidine Blue] = $1.6 \times 10^{-5} \text{ M}$, [D-Arabinose] = 1.92×10^{-3} pH of system = 12.8 Temp. = 303 K

By using H shape cell with different dimension (35 mm to 55 mm) to determine electrical output for MG & TB mixed dyes system with surfactant (CTAB). We observed that with increasing the area of cell the value of i_{max} increase and the value of i_{eq} decrease. These changes occurred due to the flow of electrode active species produced in the cell reaction. The work of these two forms (leuco and semi leuco) is just that they carry the electron from one place to another. The maximum result of the cell occurred with diffusion length of 45 mm. All experimental results are shown in Table 7.

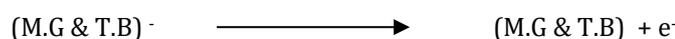
3.7.1. Mechanism

On the basis of practical analysis, a mechanism is proposed for the generation of photocurrent in the photogalvanic cell, which is as follows

3.7.2. Illuminated chamber:



At Platinum electrode: -



Dark chamber: -



Where (M.G & T.B), (M.G & T.B)⁻ show dyes and her reduced form of dyes. R and R⁺ denoted as reductant and oxidized form of reductant.

Nomenclature

SE = Solar energy, RE = Renewable energy, PG = Photogalvanic, MG = Malachite Green, TB = Toluidine Blue, $T_{1/2}$ =Cell storage capacity, CT = Charging time, i_{max} = Maximal photocurrent, PGS = Photogalvanic system, DL = Diffusion length FF= fill factor, CE= Conversion efficiency, CP = Cell performance

4. Conclusion

By using D (-) Arabinose, MG and TB mixed dyes system with CTAB, we can increase storage capacity, conversion efficiency, fill factor & charging time of photogalvanic cell. Developed photogalvanic cell had a storage capacity of 85 minutes and a conversion efficiency of 0.03591%. Fill factor and charging time of the cell are 0.0918, 160 minutes, respectively. The maximum result of the cell occurred with diffusion length of 45 mm. By the all-experimental result, we can say that this photogalvanic cell with mixed photosensitizer using D-Arabinose with CTAB appear to be beneficial in terms of electrical results.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors have no any conflict of interest.

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