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Enhanced Electrical Results of Mixed Dyes System (M.G. and T.B. + D-arabinose + NaLS system) in Photogalvanic Cell for Conversion And Storage

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Abstract

Objective: To develop PG cells with enhanced electrical output for solar energy conversion and storage. **Methods:** The electrical observations were studied in an H-shaped PG cell system with different solutions of Malachite Green (M.G.) and Toluidine Blue (T.B.), D-arabinose and Sodium Lauryl Sulphate (SLS). Different solution like dyes, reductant, and surfactant were prepared in distilled water. **Findings:** Photopotential, photocurrent, power, fill factor, conversion efficiency, and cell performance ($t_{1/2}$) have observed at a light intensity of 10.4 mWcm^{-2}. These electrical results are 178.0 mV, 26 μA, 46.28 μW, 0.1203, 0.0264%, and 105 minutes, respectively. **Novelty:** In this study, significant electrical output, i.e. cell performance, conversion efficiency, and storage capacity of developed PG cells were observed. With particular attention to enhanced cell performance, this study is novel work of PG cell for solar energy conversion and storage.

Keywords: Electrical results; Mixed dyes; Sodium Lauryl Sulphate; Conversion and storage

1 Introduction

The use of electrical results depends on its conversion and based on PG cells for electrochemical solar energy conversion and storage at specific sun intensity[(1)]. Lal and Gangotri worked on innovation for prospective energy source through solar cell[(2)]. Rathore et. al studied on electrical output in solar energy conversion and storage by surfactant lauryl glucoside and reported very good results[(3)],[(4)]. Photogalvanic (PG) effect related sun light that get energized species and these high energy products jumps into energy levels and radiate energy[(5)]. PG cell based better research as innovation in progressive study for prospective energy source through photo-galvanic-system: D-Xylose+MB+Brij-35+NaLS and study was reported in International Journal Energy Research[(6)]. Genwa and Prasad reported on performance analyzing by using of alizarin cyanine green, EDTA, and sodium stearate system[(7)]. The Research in innovative study in renewable energy source through mixed surfactant system for eco-friendly environment better way and published in Environmental Science and Pollution Research journal[8]. Further development took place and photogalvanic cell was discovered by different scientists[9]. The factor of fill for Bismarck Brown (BB) - Ascorbic Acid (AA), BB - EDTA, and BB - Glucose systems were 0.54 %, 0.48 % and 0.40 %, Efficiencies of conversion for BB - AA BB - EDTA, and BB - Glu systems were 0.899 %, 0.614 % and 0.405 % and Capacities of storage for BB - AA, BB - EDTA, and BB - Glu systems were 40 min., 34 min. and 31 min., respectively[10]. Ram et at studied on PG by BY + NaLS + AA system and published in Indian Journal of Science and Technology[11]. Further this research work supported by increase the efficiency of photogalvanic cell by using some dyes surfactants and reductants, photosensitive[12]. The better storage and transformation were reported time to time, i.e., comparative study on sunlight induced surfactants system in photogalvanics for solar energy conversion and storage has been studied[13].

Recently, very good results are reported, i.e., Innovative study for enhanced performance of the photogalvanic cells for solar energy conversion and storage[14], Natural surfactant fenugreek-based PG cell for solar energy conversion and storage[15] and fabrication of photogalvanic cell composed with natural and synthetic dyes for the generation and storage of solar power[16].

2 Methodology

The current generation was studied in an H-shaped PG cell system with Sodium Lauryl Sulphate (SLS) and different solutions of M.G. and T.B. + D-arabinose. Different solution like Dyes (malachite green, toluidine blue) were prepared by keeping the concentration of 2×10^{-6} M Reductant (D-Arabinose) at 1.92×10^{-3}M, surfactant (NaLS) at 3.2×10^{-3}M and NaOH concentration at 1N.

Table 1. Material & apparatus used for research work

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

Preparation of PG cell solution: Solutions of dyes (malachite green & toluidine blue), Reductant (D-Arabinose) surfactants (NaLS) and NaOH were prepared in double distilled water. The solutions of PG cell were prepared by weighing it in double distilled water with the help of a precision balance. To avoid electromagnetic radiation, these solutions are Kept in dark with sealed borosilicate glass laboratory flasks. Different solutions were prepared by keeping the concentration of 2×10^{-6}M Reductant (D-Arabinose) at 1.92×10^{-3}M, surfactant (NaLS) at 3.2×10^{-3}M and NaOH concentration at 1N. These solutions were then kept in a dark container away from sunlight.

Experimental set up of PG cell: An H shaped glass tube which completely blackened except a small portion on the side of the glass tube was opened, which was considered as PG cell setup, Figure 1 [6],[8],[9],[13]. Now experimental solution (25 ml) was filled into cell which appropriate number of surfactants, dyes, reductants, NaOH and double distilled water was taken. Now a calomel electrode was dipped in one arm of this H shaped glass tube and a 1.0×1.0 cm^2 platinum electrode was dipped in another arm. The platinum electrode was dipped in the arm where we had not blackened a small portion. To find out the photopotential and photocurrent of PG cell the cathode part of the cell is connected to the pH meter. Now the set of cells is kept in the dark and the set of cells is kept in dark until a uniform potential is achieved. Now the arm with the platinum electrode is diagonally illuminated with 200 W tungsten light. Place water filter between the cell and light source as this water filter blocks infra-red radiations.

3 Result and discussion

The electrical observation of NaLS– [Malachite Green & Toluidine Blue mixed dyes] system with reductant D-Arabinos were reported. The industrial and scientific properties of surface are directly affected by surfactant of PG cell system. Gradually the complete knowledge of the scientists started moving towards solar energy and during this time photogalvanic cell was prepared by them. It was demonstrated that a variety of parameters, such as variations in pH, light intensity, and diffusion length, as well as the concentration of photosensitizers, reductant, and surfactant. Overall practical analysis is represented in Table 2.

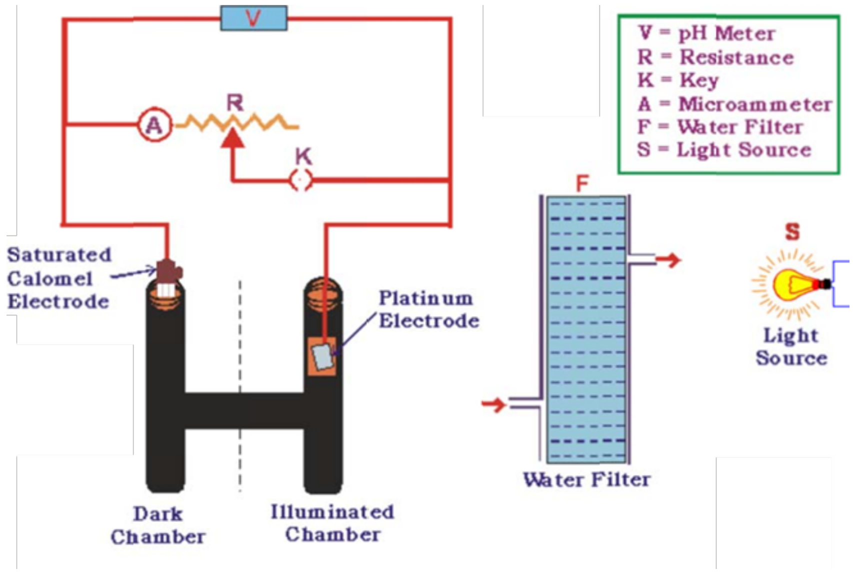

Fig 1. Setpup of PG cell

Table 2. Observed results of NaLS + Mixed dyes [MG & TB] + D-Arabinose

S. No.	Electrical Parameters	Observed Values
1.	Open Circuit Voltage (V_{OC}) mV	408.0
2.	Short Circuit current i_{sc} (μA)	26.0
3.	Photopotential ΔV (mV)	178.0
4.	Current at power point i_{pp} (μA)	10.0
5	Fill factor (η)	0.1203
6	Conversion efficiency (%)	0.02644
7	$t_{1/2}$ (Min.)	105

Study the effect of dyes concentration: The effect of changing the concentration of dyes on the power output of the cell was studied and it was found that the cell works with high efficiency at this concentration of Malachite green 2 x 10^{-6} M Toluidine blue 2 x 10^{-6} M on changing this concentration. on increasing or decreasing the concentration the efficiency of the cell decreases (Table 3, 4). The dyes solution present in the PG cell absorbs the rays of light and the cell reaction starts hence the concentration of dyes effects the efficiency of cell. When the concentration of dyes was low, few dyes molecules were present to absorb light, allowing few electrons to reach the platinum electrode and resulting in lower electrical output from the cell. The concentration of dyes is increased further the electrical output of the cell decrease because the part of main light is absorbed by the dye's molecules situated away from the Pt electrode and the dyes molecules situated near the platinum electrode cannot get desired light and the output of cell becomes low.

Table 3. Effect of Variations of MG Concentration

NaLS– [Malachite Green & Toluidine Blue mixed dyes] System	[Malachite Green] x 10^{-6} M				
	1.6	1.8	2.0	2.2	2.4
Photopotential (mV)	129	163	178.0	149	137
Photocurrent (μA)	19	23	26.0	21	20
Power (μW)	2.451	3.749	4.628	3.129	2.740

NaLS = 3.2 x 10^{-3}M Intensity of Light = 10.4 mWcm^{-2} D-Arabinose =1.92 x10^{-3}
Temp. = 303 K pH of system = 12.70 toluidine blue =constant

Effect of variation of reductant D(-) Arabinose] concentration: We found through experimental studies that the power generation capacity of the cell increase with increase in concentration of reductant and after particular range, its changes,

Table 4. Effect of Variations of TB Concentration

NaLS– [Malachite green & Toluidine blue mixed dyes] System	[Toluidine Blue] x 10^{-6} M				
	1.6	1.8	2.0	2.2	2.4
Photopotential (mV)	127	161	178.0	145	129
Photocurrent (μA)	19	21	26.0	23	22
Power (μW)	2.413	3.381	4.628	3.335	2.838

NaLS = 3.2 x 10^{-3}M Intensity of Light = 10.4 mWcm^{-2} D-Arabinose =1.92 x10^{-3} Temp. = 303 K pH of system = 12.70 malachite green = constant

accordingly. We obtained maximum photocurrent 26.0 μA and photopotential 178.0 μA at 1.92 x 10^{-3}M concentration of reductant. further increase in the concentration of reductant leads to decrease in the value of electrical generating capacity of the cell. When the concentration of reductant was low, the number of electrons donating molecules in the dyes was also low. But when the concentration of reductant is increased then the movement of dyes molecules is hindered due to which the dyes molecules cannot reach the electrode within their prescribed time limit and hence the power generation decreases.

Effect of variation of surfactant (NaLS) concentration: Experimental study was carried out on the cell with mixed dyes system (Malachite green and Toluidine blue) and surfactants (sodium lauryl sulphate). By practical study we found that with increase in concentration of surfactant (NaLS) the output of cell also increased. the highest electrical production capacity of the cell was obtained at 3.2 x 10^{-3}M concentration of the surfactants (NaLS). On further increasing this concentration of surfactants we observed a decrease in the value of photocurrent and photopotential of the cells. We also performed this experiment in the absence of surfactant and found that the cell output was very low. The highest output of the cell at 3.2 x 10^{-3}M concentration of surfactants demonstrates the presence of charge transfer interaction between the dyes and surfactants. The photo ejection of electron from dyes surfactants depends on the charge on micelle. There is no cost in any way, and it is not harmful to the environment either we get solar energy in large quantities from the sun, but we use it in very small quantities. The effect of surfactants concentration on cell output is presented in Table 5 and Figure 2.

Table 5. Effect of Variations of [NaLs] Concentration

NaLS– [Malachite Green, Toluidine Blue mixed dyes] System	[NaLs] x 10^{-3}M				
	2.8	3.0	**3.2**	3.5	3.7
Photopotential (mV)	147.0	160.0	**178.0**	149.0	131.0
Photocurrent (μA)	18.0	21.0	**26.0**	23.0	14.0
Power (μW)	2.646	3.36	**4.628**	3.427	1.834

Malachite Green = 2.0 x10^{-6} M Toluidine Blue = 2.0 x10^{-6} M D-Arabinose =1.92 x10^{-3} pH of system = 12.70

Effect of variation of pH on the system: The effect of pH value on the photocurrent and photopotential of the cell was studied using a solution containing different concentration of NaOH in malachite green and toluidine blue mixed dyes system. We found that the highest photocurrents and photo potential of the cell was obtained at 12.7 pH value. the cell potential decreased with increase in pH value (Table 6). The high electricity production of the cell at this pH value 12.7 indicates that the reductant behaves as a good donor at this pH.

Table 6. Study on Variations of pH of the system

NaLS– [Malachite Green, Toluidine Blue mixed dyes] System	pH				
	12.3	12.5	12.7	12.9	13.0
Photopotential (mV)	151.0	156.0	178.0	161.0	149
Photocurrent (μA)	19.0	20.0	26.0	22.0	17.0
Power (μW)	2.869	3.120	4.628	3.542	2.533

NaLS = 3.2 x 10^{-3}M Malachite green = 2.0 x10^{-6} M Toluidine blue = 2.0 x10^{-6} M D-Arabinose =1.92 x10^{-3}

Current-voltage characteristics of the cell: When the cell was in place, light was shone on it and its voltage (v_{oc}) and current (I_{sc}) were measured. The voltage was measured with digital pH meter (the circuit open) and current was measured with microammeter (when the circuit close). Then by applying different loads between v_{oc} and isc, the value of currents and voltage

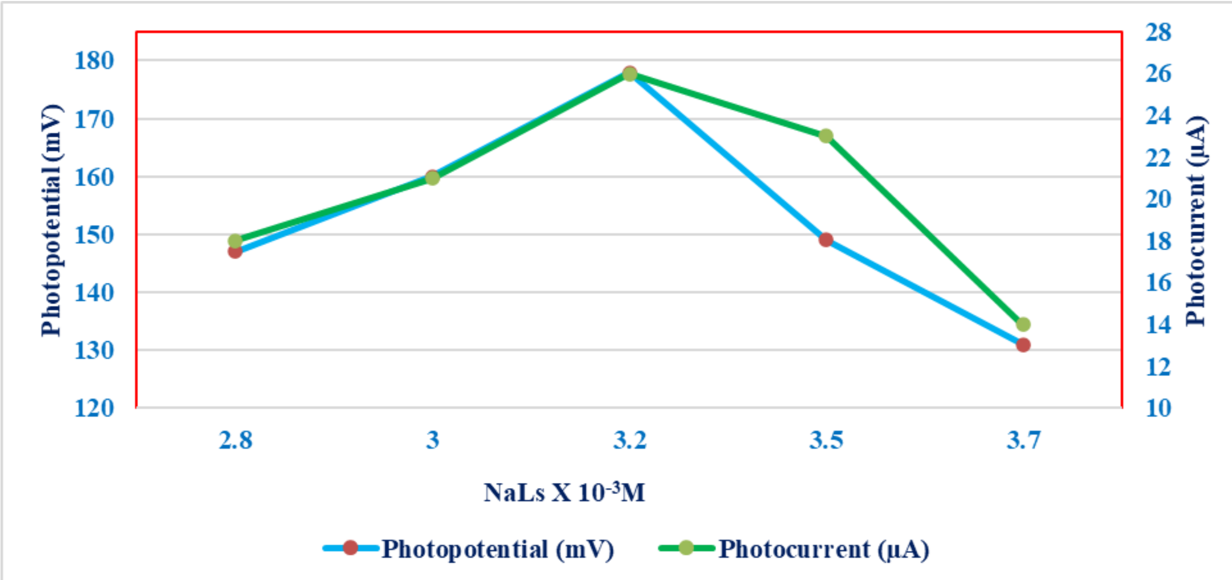

Fig 2. Observed photopotential and photocurrent

are taken which gives the idea about i-v properties of the cell. The i-v calculations for malachite green and toluidine blue mixed dyes system are shown in the graph. There is a point on these i-v curve where the product of potential and current is maximum, that point is called power point (Figure 3). On the basis of result malachite green & toluidine blue mixed dyes system fill factor value is 0.1203. The current-voltage characteristic of the cell was investigated.

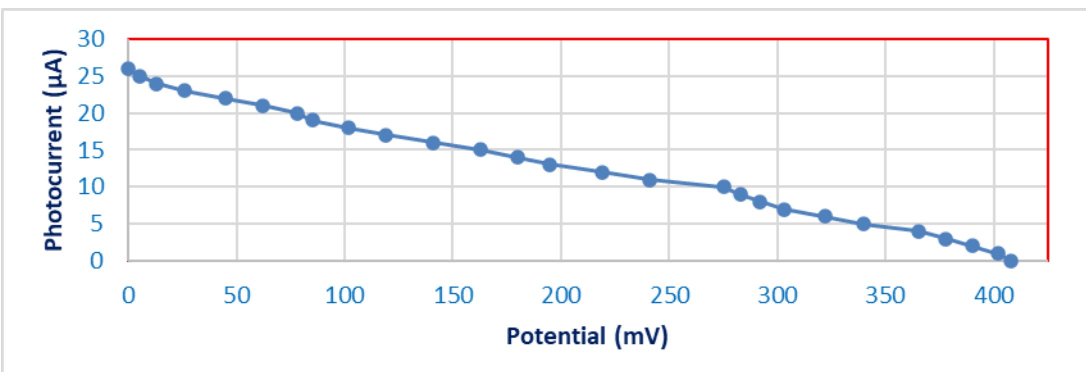

Fig 3. Current-voltage characteristics of the cell

Performance, conversion efficiency and fill factor of the cell: The storage capacity and performance of the cell is represented by $T_{1/2}$. Malachite green and toluidine blue mixed dyes system with surfactants (NaLS) $T_{1/2}$ 105 minute was obtained. For this system we can obtain $T_{1/2}$ by keeping the cells at power point stage in the dark and recording the amount of time needed for the power output to drop to half its value. By using platinum foil electrode (1.0 x1.0 cm^2). The calculated fill factor and conversion efficiency 0.1203 and 0.0264 % with malachite green and toluidine blue mixed dyes system. Additionally, ideal conditions for cell performance have been identified.

$$\text{Conversion Efficiency } = \frac{V_{pp} \times i_{pp}}{10.4\, mW/cm^{-2}} \times 100\% \tag{1}$$

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

Where:

V_{pp} = potential

i_{pp} = current at power point

V_{oc} = open circuit voltage

i_{sc} = short circuit current

On the basis of data, we can say that malachite green and toluidine blue mixed dyes system cell is good in terms of solar energy conversion and performance.

Effect of variation of diffusion length: Using H shaped cells with different dimensions the effect of photocurrent rate on the cell and current parameters (i_{max} and i_{eq}) was also studied. We observed that the value of i_{max} increases while the value of i_{eq} decreases as the area of the cell increase. this increase and decrease are due to the increase in photochemical reaction path. We can say that this change occurred due to the flow of electrode active species produced in the cell reaction. The particles that carry the main electron are the leuco and semi leuco forms of dyes. The work of these two forms is just that they carry the electron from one place to another. The observed electrical results are reported in Table 7.

Table 7. Effect of Variations of diffusion length of the cell

Diffusion Length DL (mm)	Max. photocurrent imax (μA)	Equ. photocurrent ieq (μA)	Rate of initial generation of current (μA min-1)
35	47	35	1.61
40	51	31	1.73
45	**56**	**26**	**1.87**
50	65	23	1.98
55	74	19	2.12

NaLS = 3.2 x 10^{-3}M Malachite Green = 2.0 x10^{-6} M Toluidine Blue = 2.0 x10^{-6} M D-Arabinose =1.92 x10^{-3} pH of system = 12.70

Mechanism: On the basis of practical analysis, a mechanism is proposed for the generation of photocurrent in the photo galvanic cell. A photochemical mechanism for the photocurrent has been proposed, which is as follows

Illuminated chamber:

(M.G & T.B) $\xrightarrow{hv}$ (M.G& T.B)* $\longrightarrow$ (M.G & T.B)'

(Ground State) (First excited state) (Triplet state)

(M.G & T.B)'+ R $\longrightarrow$ (M.G & T.B) $^-$ + R^+

(semi or leuco of dyes)

At Platinum electrode:

(M.G & T.B) $^-$ $\longrightarrow$ (M.G & T.B) + e^-

Dark chamber :

At SCE :- (M.G & T.B) + e^- $\longrightarrow$ (M.G & T.B) $^-$

(semi or leuco of dyes)

(M.G & T.B) $^-$ + R^+ $\longrightarrow$ (M.G & T.B) + R

Here (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.

Comparison with published research work: We have stated that our study has brought innovations compared to earlier reports. The obtained results are betters and represent the novelty of manuscript. The PG cell performance and efficacy were found 24.00 minutes and 0.2630%, respectively[(9)]. The obtained results are better in comparison with the literature with respect to storage capacity and obtained results as 105 minutes. Bismarck Brown (BB) - Ascorbic Acid (AA), BB - EDTA, and BB - Glucose systems were Capacities of storage for BB - AA, BB - EDTA, and BB - Glu systems were 40 min., 34 min. and 31 min., respectively[(10)]. For the BY+NaLS+AA, the observed photopotential, maximum photocurrent and fill factor were 924.00 mV and 630.00 μA, 0.3422, respectively[(11)]. Photopotential, photocurrent, power, fill factor, conversion efficiency, and cell performance ($t_{1/2}$) have all been evaluated at a light intensity of 10.4 mWcm-2. These values are around 178.0 mV, 26 μA, 46.28 μW, 0.1203, 0.0264%, and 105 minutes, respectively.

4 Conclusion

This study presents a PG cell with enhanced storage and conversion capacity by using D-Arabinose, malachite green and toluidine blue mixed dyes system with NaLS. The manufactured PG cell had a storage capacity of 105 minute and a conversion efficiency of 0.0264%. Hence the developed PG cell with mixed photosensitizer (Malachite Green+ Toluidine Blue) dyes system using D-Arabinose as surfactants appeared productive from the viewpoint of storage capacity.

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