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Study of Photogalvanic Effect by using Marigold Flower as Natural Photosensitizer, Xylose as Reductant and Tween 80 as Surfactant for Solar Radiation Conversion and Storage

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Abstract

Objective: A study work plan has been put up for methodical work in the field of solar energy Photogalvanic (PG) cells. It was suggested and required to do experiments with PG cells in sunlight conditions. Improving the conversion of solar energy into electricity and storing it in PG cells is the goal of our study. **Method:** An H-shaped glass tube with two arms was manufactured using the specially developed PG (Figure 1) cell. Many characteristics of a PG cell with an MG+D-Xylose+Tween-80 system was investigated. **Findings:** The open circuit voltage, voltage at dark, photopotential (PP), and photocurrent (PC) recorded in this investigation are 1080.00 mV, 165.00 mV, 915.00 mV, and 674.00 μA, respectively. The Fill Factor (FF) and Conversion Efficiency (CE) that were observed 1.891% and 0.2732, respectively. **Novelty:** Through the adjustment of PG cells' numerous parameters, the effects of solar energy were investigated. Based on the aforementioned results, PG systems have demonstrated through experimentation that they are an effective system and should be further investigated, particularly with regard to improving solar energy output and storage.

Keywords: D-Xylose; Tween - 80; Marigold; Photocurrent; Natural dye

1 Introduction

The rapid depletion of fossil energy resources and resultantly need of alternative sources of energy are major concerns. As a result, renewable energy sources are becoming more popular, with solar energy being one of the most promising in the future.

Photogalvanic research is an emerging area of study. A photogalvanic cell that is specifically designed to function better was developed. Brings down the price of the photogalvanic cell to make it commercially viable. Study of electrical output in photogalvanic cell for solar energy conversion and storage [1] and high-performance dye-sensitized solar cells [2] were systematically investigated in the photo chemical properties. Nature-based dye-sensitized solar cells [3,4] and solar energy conversion through brilliant yellow+NaLS+AA system [5] have been systematically studied. Hybrid photoelectrodes for photoelectrochemical energy conversion [6], Photocatalysis for thermochromic materials [7], EDTA+TB+NaLS based work for electrical output [8], Innovation for prospective energy source [9], and Mixed surfactant for photogalvanic effect [10] were studied. Tartrazine with DSS single surfactant [11], Alizarin cyanine green with sodium stearate [12], The contribution of chemical components of PG electrolyte towards potential, power and current of PG cells [13], C DEA with ACG [14], Methylene blue system with mixed surfactant [15] were studied for better results.

Later on, Nano-rod ZnO for photocatalytic application [16], FCF dye [17], alizarin red dye [18], brilliant cresyl blue dye [19] have been done for finding the relatively better and efficient dye for enhancement performance of a PG cell. The photoelectrochemical and spectrophotometric study of dye-surfactant [20] have been reported the PG cell about sun intensity for PG cell.

Recently, different researchers also studied on photogalvanic cell for electrical output in solar energy conversion and storage by using of surfactant, photosensitizer, and reductant. Innovation in progressive study for solar energy source using PG system: D-Xylose+MB+Tween - 80+NaLS was the focus of work [21]. The recent work also been adding on innovative research on renewable energy sources using a combined surfactant system for green environments [22]. In order to feed everyone on the planet, the scientific community worldwide is obligated to find sustainable energy sources. In this way, the manuscript has a significant amount of storage, conversion efficiency, and electrical output.

2 Methodology

2.1 Laboratory work: Marigold flower extract

We have collected the marigold flowers and by using a simple extraction process, the marigold flower extract was obtained in the laboratory. The samples were contacted with a solvent that was dissolved the solutes. Our aim was to extract by separation of the soluble marigold flower, leaving behind the insoluble part, known as the residue and the product obtained (extract) is relatively in a liquid phase (after removing solvent) in dried powder form. The distribution of a solute between two phases is an equilibrium condition described by partition theory. This is based on mobile phase of the initial solvent into the extracting solvent by using a liquid extraction solvent (water).

2.2 Laboratory work: PG cell set up

An H-shaped glass tube with two arms was manufactured using the specially developed PG (Figure 1) cell. With the exception of a window, both arms were fully blackened and attached to a saturated calomel electrode and PT electrode, respectively. To make 25.00 ml, an H-shaped container was filled with the solutions of 5 ml of M/1000 Tween - 80, 5 ml of M/1000 D-xylose reductant, 5 ml of natural dye as MG extract, 1M sodium hydroxide, and distilled water. In order to measure the electrical output of the cell circuit during the experiment, the resistance key, carbon pot, digital pH meter, and micro-ampere were attached to both ends of the electrodes. A 200 W filament electric bulb was utilized as the light source. In order to set up the experiment, IR radiations were blocked using the water filter. Double-distilled water was used to prepare these solutions in order to ensure accurate electrical results. By using a titration procedure with an oxalic acid solution, sodium hydroxide solutions were standardized. To keep these solutions safe from light, they were kept in amber-colored containers.

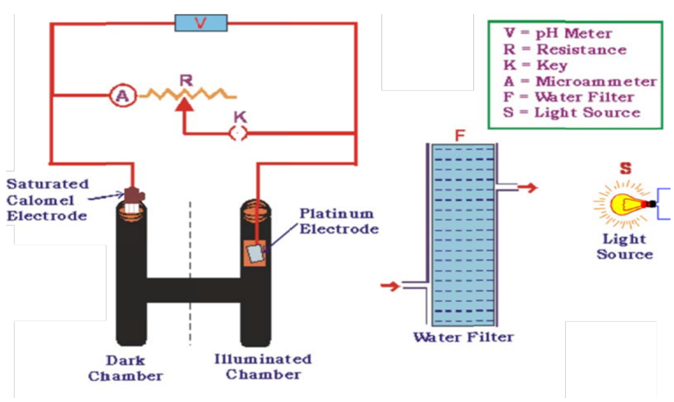

Fig 1. Methodology set up for PG cell

3 Results and Discussion

3.1 Variation of natural dye as marigold (photosensitizer) concentration

For this particular photogalvanic system, a dye concentration of 5 ml is ideal (Table 1). In the course of the experiment, it was discovered that in the D-Xylose+MG+Tween-80 system, the electrical results increased and reached their optimal nature at 5 ml of MG dye before decreasing (from 6 ml to 10 ml) when the resulting volume of MG dye was increased from 2 ml to 5 ml. minimal amounts of MG dye (between 2 and 5 ml) associated the light source from being fully absorbed, resulting in minimal electrical output. On the other hand, at a larger concentration range of MG (5 ml), there are so many molecules that the molecule close to the electrode is not illuminated by the intended light source. Better outcomes were attained when the ideal molecules were present at a middle MG (5 ml) range, where the ideal light source did reach the molecule close to the electrode. In relation to the open circuit voltage, voltage at dark, PP, and PC, the observed optimum values are 1080.00 mV, 165.00 mV, 915.00 mV, and 674 μA, in that order. The CE and FF that were observed were 1.892% and 0.2732, respectively. Table 1 and Figure 2 present the observed results for the variation of photosensitizer concentration in the D-Xylose+MG+Tween-80 system.

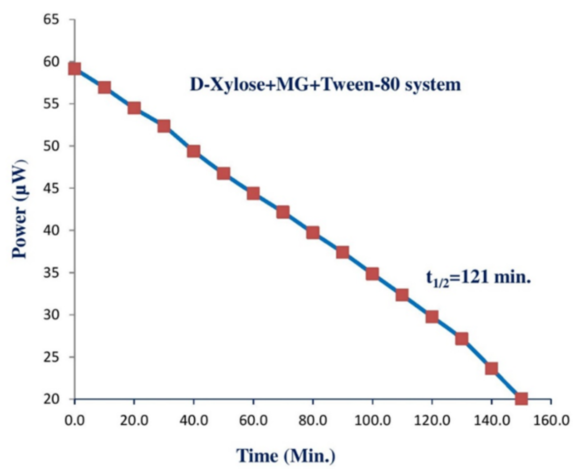

Fig 2. Performance of the PG cell

Table 1. Effect of Variation of MG, D-Xylose, Tween - 80 and pH

Volume/ concentration	PP (mV)	PC (μA)	Power (μW)
MG (in ml) Light Intensity = 10.4 mWcm^{-2}, Temperature = 303 K, Pt electrode area = 1.0 cm $\times$ 0.85 cm			
3.00	720.00	483.00	347.76
5.00	915.00	674.00	616.71
6.00	687.00	465.00	319.45
[D-Xylose] $\times$ **10^{-4} M**			
1.50	718.00	420.00	301.56
2.00	915.00	674.00	616.71
2.50	711.00	461.00	327.77
[Tween - 80 $\times$ **10^{-4} M]**			
8.90	743.00	412.00	306.11
9.00	915.00	674.00	616.71
9.10	665.00	387.00	257.35
pH			
12.20	675.00	423.00	285.52
12.30	915.00	674.00	616.71

Continued on next page

Table 1 continued

12.40	679.00	324.00	219.99

3.2 Variation of D-xylose (Reductant) concentration

For this photogalvanic system, the ideal reductant concentration is 2.00 x 10^{-4} M D-xylose (Table 1). It was discovered during the experiment that as the concentration of D-xylose reductant is increased (from 1.50 $\times$ 10^{-4} M to 2.00 $\times$ 10^{-4} M), the electrical output also increases, reaches its maximum value at that specific concentration (2.00 $\times$ 10^{-4} M), and then starts to drop in the D-Xylose+MG+Tween-80 system. There are fewer D-xylose reductant molecules available to donate electrons to MB in order to produce the cationic form at lower concentrations of 1.50 $\times 10^{-4}$ M. However, when D-xylose reductant is present in higher concentrations (2.50 $\times 10^{-4}$ M), more reductant molecules are accessible to donate electrons to dye, forming the cationic form that impedes the photosensitizer. Good results were obtained when the D-xylose reductant concentration was in the intermediate range (2.00 $\times 10^{-4}$ M). This is because the ideal number of D-xylose reductant molecules is present at this concentration, creating an environment that is suitable for the semi-or leuco form of dye molecules. In relation to the open circuit voltage, voltage at dark, PP, and PC, the observed optimum values are 1080.00 mV, 165.00 mV, 915.00 mV, and 674 μA, in that order. CE and FF were 1.892% and 0.2732, respectively, that were noted (Table 1 and Figure 2).

3.3 Variation of Tween - 80 concentration

For better outcomes, the ideal concentration of micelles is 9.00 x10^{-3} M (Table 1). When the concentration of Tween-80 increased (around its CMC value), the electric power of the PG cell with the D-Xylose+MG+Tween-80 system increased and reached an optimal position. It then declined when the concentration of Tween-80 increased even higher. Less capacity to solubilize the molecules for the electron transfer process in hydrophilic hydrophobic contact at lower concentrations (Tween-80 = 8.90$\times 10^{-4}$ M). Alternatively, more surfactant molecules are accessible for the electron transfer process in hydrophilic hydrophobic interactions at greater concentrations of surfactant (Tween-80 = 9.10 $\times 10^{-4}$ M), which may result in less electron transfer. The photogalvanic system's electrical output is significantly affected at the intermediate range of surfactant concentration (Tween-80 = 9.00$\times 10^{-4}$ M). The reason for this is that surfactants can aid in the separation of photoproducts by interacting with the micelle interface in a hydrophilic–hydrophobic manner. Because a certain surfactant increases the solubility and stabilization of dye molecules in water, the electrical output generally increases when it is present. In PG cells, a surfactant combination may produce a better precipitation than a single surfactant precipitate done separately. For mixes, the propensity of individual components to disperse among an unaggregated state and a combined state can differ. As a result, a micelle's mixed surfactant composition may be very different from the equilibrium single surfactant monomers. The only factors that could affect the processes that are important are the composition of the aggregate or the monomer. For instance, the concentration and composition of a surfactant affects its ability to adsorb on dyes like MG, and the makeup of micellar particles affects how well a dye dissolves in micelles. In relation to the open circuit voltage, voltage at dark, PP, and PC, the observed optimum values are 1080.00 mV, 165.00 mV, 915.00 mV, and 674 μA, in that order. The CE and FF that were observed were 1.892% and 0.2732, respectively. Table 1 and Figure 2 present the observed results for the varying levels of surfactant in the D-Xylose+MG+Tween-80 system.

3.4 Variation of diffusion length

The initial rate of PC production of PG cells with MG+D-Xylose+Tween - 80 system and the cell's current parameter (i_{max}, i_{eq}) were detected with changes in diffusing lengths (distance across two electrodes). It was discovered that while the equilibrium PC (i_{eq}) exhibits very slight decreasing tendencies, the peak photocurrent (i_{max}) and rate (μA min^{-1}) continue to increase with an increase in diffusion length. Thus, in a virtual sense, the change in diffusing length cannot affect it. The photocurrent is acquired as the minimal value and the beginning production of photocurrent were obtained on a short diffusing length (3.6 cm), where the absorbing capacity of the light source is limited by the smallest amount of dye molecules. However, superior results were obtained at a maximum diffusion length because there is a higher number of dye molecules absorbing the light source. In the MG+D-Xylose+Tween-80 system, the obtained results were presented for variation in diffusion length (Table 2).

Table 2. Effect of diffusion length on the system

[D-Xylose] = 2.0 $\times$ 10^{-4} M, Tween-80 = 9.0 $\times$ 10^{-4} M, pH = 13.00, Temperature = 303 K, Light Intensity = 10.4 mW cm^{-2}, Pt electrode area = 1.0 cm $\times$ 0.85 cm

DL (mm)	Maximum PC i_{max} (μ A)	Equilibrium PC i_{eq} (μ A)	Rate of initial generation of photocurrent (μA min^{-1})

Continued on next page

Table 2 continued

36.00	770.00	741.00	18.33
40.00	915.00	674.00	19.21
44.00	990.00	423.00	17.21

3.5 Variation of electrode area

The maximum PC (i_{max}) and equilibrium PC (i_{eq}) of the photovoltaic cell (PG) with D-Xylose+MG+Tween-80 system was found to be regularly increasing. However, the state of equilibrium PC was practically unaffected by an increase in electrode area, affecting it in the opposite direction. The MG+D-Xylose+Tween-80 system's observed electrode area variation results were provided (Table 3).

Table 3. Effect of electrode area on the system

[MG] = 5ml, [D-Xylose] = 2.0 × 10^{-4} M, pH = 13.00, [Tween - 80] = 9.00 × 10^{-4} M, Temperature = 303 K, Light Intensity = 10.4 mW cm^{-2}, Pt electrode area = 1.0 cm × 0.85 cm

MG-D-Xylose- Tween - 80 System	Electrode Area (cm^2)				
	0.75	0.80	0.85	0.90	0.95
Maximum PC i_{max} (μA)	461	568	713	676	389
Equilibrium PC i_{eq} (μA)	343	532	644	539	416

3.6 (i-V) characteristics (current–voltage) of cell

The electrical circuit was used to test the short circuit current (ISC) in the PG cell with the MG+D-Xylose+Tween - 80 system. It was noted that the measurements of photocurrent and photopotential V_{pp} reached their maximum values. The maximum potential that the circuit abides by is referred to as potential at power point (i_{pp}), and the maximum short circuit current is referred to as current at power point. These four values—i_{sc}, V_{oc}, V_{pp}, and i_{pp}—were utilized in the method to find the system's power point and to calculate the fill factor (FF) of the cell. The results showed that the FF of the cell was, 0.2732. The fill-factor was computed using Equation (1).

$$\text{Fill Factor}(\eta) = \frac{V_{PP} \times i_{pp}}{V_{OC} \times i_{sc}} \tag{1}$$

$$Power\ point\ (pp) = V_{pp} \times i_{pp} \tag{2}$$

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

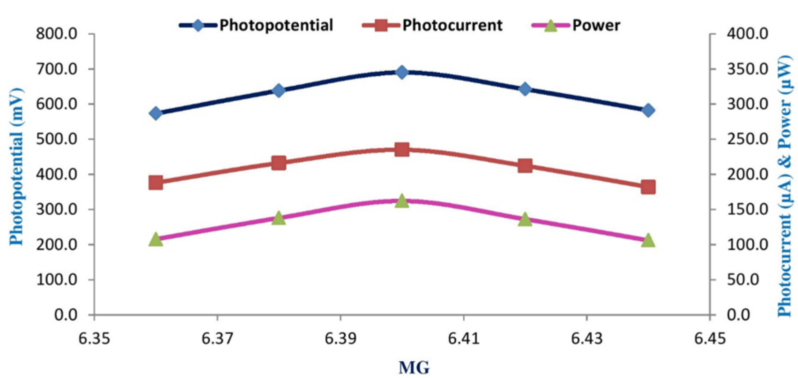

Fig 3. Variation of photopotential, photocurrent and power

3.7 Cell performance and conversion efficiency

The storage capacity of the MG+D-Xylose+Tween - 80 system has proven to be good. Cell storage capacity has been investigated under specific external stress conditions. By introducing an electric load from the light source, the D-Xylose+MG+Tween-80 system stopped the light source at the photocurrent value that was recorded at the PG cell's power point. When the PG cell reached half of its power in the off-light state, that time was noted. The cell's performance was expressed in terms of $t_{1/2}$. The performance of PG cells is measured in terms of $t_{1/2}$, and 121.00 minutes in the dark was the observed value. Equation (2) was used to calculate the PG cell CE, which came out to be 1.892 %. In the MG+D-Xylose+Tween-80 system, the PG cell's performance and conversion efficiency (CF) were reported (Table 4 and Figure 2).

$$Conversion\ efficiency = \frac{V_{pp}\ \times\ i_{pp}}{A\ 10.4mWcm^{-2}} \times 100\% \tag{3}$$

Where: $V_{pp,}$ is PP at power point of cell, i_{pp} is PC at power point of cell, A is electrode area of cell.

Table 4. Effect of surfactants [Tween - 80] with natural dye system for PG cell

S.No.	Parameters	Results
1.	Open Circuit Voltage (V_{OC})	1080.00 mV
2,	V dark	165.00 mV
3.	Photopotential (DV)	915.00 mV
4.	Short Circuit Current (i_{sc})	674.0 μA
5.	Current at Power Point (i_{pp})	365.0 μA
6.	Potential at Power Point (V_{pp})	547.0 mV
7.	Power at Power Point (PP)	199.00 μW
9.	Fill factor (h)	0.2732
10.	Conversion Efficiency (%)	1.892%
11.	$t_{1/2}$	121.0 min.
12	Charging Time (min.)	92.0 min.

3.8 Reaction mechanism

The ensuing chemical change occurs experimentally and shows that current is flowing electrons. The suggested photochemical mechanism for converting solar radiation energy is provided for now's output.

- **Illuminate Chamber:** Excitement of MG molecules (photosensitizer) caused MG to receive an electron and migrate to xylose.

$$MG \xrightarrow{hv} MG^{*}\ (excited\ form) \tag{4}$$

$$MG^{*} + R \rightarrow MG^{-}(\text{semi or leuco}) + R^{+} \tag{5}$$

- **Photochemical reaction at platinum electrode**: The MG (dye) semi-or leuco form transforms back into the original dye molecule after losing an electron to the electrode.

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

- **Photochemical reaction at dark Chamber:**
  - **At counter electrode**: The photochemical cyclic process continues when MG (photosensitizer) molecules gain an electron from the electrode and change into leuco or semi-forms of the dye molecule. Ultimately, MG (leuco/semi form) and the reductant (oxidized form) combine to yield MG (original) dye and Xylose reductant (R) molecules.

$$MG + e^- \longrightarrow MG^- \ (semi\ form\ or\ leuco\ form) \tag{7}$$

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

Where**:** MG is Marigold (dye)**,** MG^* is excited form of Marigold**,** MG^- is semi or leuco form of Marigold, R is Reductant (D-xylose), R^+ is oxidized form of the reductant**.**

4 Conclusion

By choosing the appropriate redox pair in accordance with a sustainable environment, the PG cells significantly contributed to the decrease in costs necessary to achieve commercial viability. Many characteristics of a PG cell with an MG+D-Xylose+Tween-80 system was investigated. The open circuit voltage, voltage at dark, PP, and PC recorded in this investigation are 1080.00 mV, 165.00 mV, 915.00 mV, and 674 μA, respectively. The CE and FF that were observed were 1.892% and 0.2732, respectively. Through the adjustment of PG cells' numerous parameters, the effects of solar energy were investigated. Based on the aforementioned results, surfactants (Tween-80) have demonstrated through experimentation that they are an effective system and should be further investigated, particularly with regard to improving solar energy output and storage. In terms of solar radiation conversion and potential, photogalvanic cells might be the most efficient fuel cell available, given the limitations of present technology. If the efficient systems achieve the targeted level of cost and overall efficiency reduction, they could replace the current solar cells on the market and meet all of humanity's electricity needs.

5 Nomenclature

PG is photogalvanic, $t_{1/2}$=cell storage capacity, pp=power point, V_{pp}=photopotential at power point, V_{oc}=open circuit voltage, μA=microampere, h=fill factor, uW=microwatt, i_{eq}=photocurrent at equilibrium, i_{sc}=short circuit current, i_{pp}=photocurrent at power point, mV=millivolt, ml=milliliter, M = molarity, i_{max} is the maximal photocurrent, DL is Diffusion length, and MG is Marigold.

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