Improvement of the Photogalvanic Cell for Solar Energy Conversion and Storage: Rose Bengal–Oxalic Acid –Tween 80 System


Abstract

In our work, Rose Bengal was used as photosensitizer with Oxalic acid as reductant and Tween 80 as surfactant for the enhancement of the conversion efficiency and storage capacity of photogalvanic cell for its commercial viability. The observed value of the photogeneration of photopotential was 666 mV and photocurrent was 119.5 \( \mu \)A whereas maximum power of the cell was 79.58 \( \mu \)W. The observed power at power point was 22.308 \( \mu \)W and the conversion efficiency was 0.258 %. The fill factor 0.328 was experimentally determined at the power point of the cell. The photogalvanic cell so developed can work for 230 min in dark on irradiation for 72 min, i.e. the storage capacity of the photogalvanic cell is. The effects of different parameters on electrical output of the cell were observed and a tentative mechanism has also been proposed for the generation of photocurrent in photogalvanic cell. The photogalvanic cell was subjected to the solar energy in Egypt on summer. A higher photovoltage of 815 mv was obtained. The cell can keep the energy for a longer time. On the recycling using solar energy for seven days using the same cell solution the same photovoltage and photocurrent was obtained.

Keywords : Rose Bengal; Photogalvanic cell; Fill factor; Conversion efficiency; Power point

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1. Introduction

Today, global warming and the rapid decrease in energy resources caused by the large-scale consumption of fossil fuels have become serious. Accordingly, renewable energy resources are attracting a great deal of attention, and solar energy is one of the most promising future energy resources. The photochemical production of electricity has attracted the attention of many scientists as a viable media for solar energy conversion. The photogalvanic effect was first discovered in 1925 by Rideal and Williams [1] but was systematically investigated later by Rabinowitch [2].


A solar cell with sensitized rutile and anatase-based TiO₂ was evaluated by Park and Vande Lagemaat [18]. Tennakone et al. [19] used dye-sensitized photoelectrochemical and solid solar cells for charge separation, transport and recombination. The use of micelles in the photochemical conversion of solar energy has been investigated by Ameta et al. [20,21]. Schwarzburg and Waser [22] explored the origin of photovoltage and photocurrent in nanoporous, dye-sensitized, photoelectrochemical solar cells. The sensitization of nanoporous films of TiO₂ with santaline (red sandal wood pigment) and the construction of a dye-sensitized solid-state photovoltaic cell were attempted by Tennakone and Kumara [23]. Recently, Madhwani et al. [24] reported use of a luciferin-EDTA system in photogalvanic cells. The research in the field of photogalvanic cells is still in its infancy with respect to its viability and practical applicability and, therefore, requires thorough exploration to increase the conversion efficiency and storage capacity by selecting a suitable redox couple and photosensitizers.

In this paper we have been studied Rose Bengal-Tween 80- Oxalic acid system in a photogalvanic cell for solar energy conversion and storage. Also, we use the direct solar energy on May in Nasr city/ Cairo Egypt. This study also pays attention to the repeatability of the experiment for seven times with the same solution within seven days.

2. Experimental

A glass tube of H-shape was used containing known amount of the solutions of the photosensitizer, Rose Bengal with reductant oxalic acid, surfactant Tween and sodium hydroxide (Merck) in the present work. The total volume of the mixture was always kept 25.0 ml making up by doubly distilled water. All the solutions were kept in amber colored containers to protect them from sunlight. A platinum electrode of different sizes; 0.3, 0.5 and 1.0cm² were dipped in one limb having a window and a saturated calomel electrode (SCE) were immersed in another limb of the tube. The terminals of the electrode were connected to a digital pH meter (Hanna) and the whole cell was placed in the dark. The potential (mV) was measured in dark when the photogalvanic cell attained a stable potential. Then, the limb containing platinum electrode was exposed to a 200 W tungsten lamp (Philips) as light source. A water filter was placed between the illuminated chamber and the light source to cut-off infrared radiation. On illumination, the photochemical change of Rose Bengal was studied potentiometrically. The photopotential and photocurrent generated by the system was measured with the help of the digital pH meter and microammeter (Ruttonsha Simpson), respectively. The current voltage characteristics of photogalvanic cell have been studied by applying an external load with the help of a carbon pot (log 470 K) connected in the circuit through a key to have close circuit and open circuit device. The experimental set-up of photogalvanic cell is given in Fig.1.
Fig. 1. Experimental set-up of photogalvanic cell.

3. Results and discussion

3.1. Effect of variation of photosensitizer (Rose Bengal) concentration on the system

The effect of variation of Rose Bengal concentration on photopotential, photocurrent and power is represented in Figure 2. With the increase in concentration of the photosensitizer (Rose Bengal) in present system, the photopotential and photocurrent were found to increase until it reaches a maximum value of $10.16 \times 10^{-5}$ M. On further increase in concentration of photosensitizer, a decrease in electrical output of the cell was found. At lower concentration range of photosensitizer, there are a limited number of photosensitizer molecules to absorb the major portion of the light in the cell and a fewer number of electrons reach to the platinum electrode, therefore, there is low electrical output, whereas higher concentration of the photosensitizer does not permit the desired light intensity to reach the electrodes and hence, there is corresponding fall in the power of the cell.
3.2. Effect of variation of reductant (oxalic acid) concentration on the system

The effect of variation of reductant concentration on the photopotential and photocurrent of system is shown in Figure 3. It was observed that with the increase in concentration of the reductant (oxalic acid), the photopotential was found to increase till it reaches a maximum value of 1.9×10⁻³ M. On further increase in concentration of reductant, a decrease in the electrical output of the cell was observed.

The fall in power output was also resulted with decrease in concentration of reductant due to less number of molecules available for electron donation to the dye. On the other hand, the movement of dye molecules may be hindered by the higher concentration of reductant to reach the electrode in the desired time limit and it will also result into a decrease in electrical output.

3.3. Effect of variation of surfactant (Tween) concentration on the system

Surfactant play a vital role to solubilize the system by forming high molecular weight aggregates or micelles in dilute solution. Surfactant also enhanced the electrical output of the photogalvanic cell by making process of photo ejection of electron easier if the dye and surfactant are opposite in charge, the photo ejection of electron will be more pronounced and hence the efficiency of photo galvanic cell will increases. Surfactant form a charge-transfer complex with the dye upon exposure to light and retard the degradation of dye.
The effect of surfactant Tween concentration was investigated in the present system. It was observed that electrical output of the cell was found to increase on increasing the concentration of surfactant reaching a maximum value of $6 \times 10^{-2}$ M. On further increase in the concentration, a fall in photopotential, photocurrent and power of the photogalvanic cell was observed. The results are shown in Fig. 4.

![Fig. 4. variation of surfactant concentration on the system](image)

### 3.4. Effect of pH on the system

The photogalvanic system is quite sensitive for pH variation. The electrical output of the photogalvanic cell was changed by the variation of pH on the system. It can be observed from Table 1 that there is an increase in electrical output of the cell with the increase in pH values. At pH 13.52 a maxima was obtained. On further increase in pH, there was a decrease in photopotential and photocurrent. Thus, photogalvanic cells containing the Rose Bengal–Oxalic acid–Tween system were found to be quite sensitive to the pH of the solutions.

<table>
<thead>
<tr>
<th>pH</th>
<th>Photopotential (mV)</th>
<th>Photocurrent (μA)</th>
<th>Power (μW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.89</td>
<td>375.5</td>
<td>59.5</td>
<td>22.34</td>
</tr>
<tr>
<td>13.74</td>
<td>401.5</td>
<td>71.5</td>
<td>28.71</td>
</tr>
<tr>
<td>13.62</td>
<td>504.0</td>
<td>84.5</td>
<td>42.58</td>
</tr>
<tr>
<td>13.52</td>
<td>666.0</td>
<td>119.5</td>
<td>79.58</td>
</tr>
<tr>
<td>13.40</td>
<td>618.0</td>
<td>53.9</td>
<td>33.31</td>
</tr>
<tr>
<td>13.26</td>
<td>613.0</td>
<td>48.7</td>
<td>29.85</td>
</tr>
<tr>
<td>13.11</td>
<td>611.0</td>
<td>41.5</td>
<td>25.36</td>
</tr>
<tr>
<td>12.98</td>
<td>531.0</td>
<td>32.5</td>
<td>17.26</td>
</tr>
</tbody>
</table>

[Rose Bengal] $= 10.16 \times 10^{-5}$ M; [oxalic acid] $= 1.9 \times 10^{-3}$ M; [Tween] $= 6 \times 10^{-2}$ M; light intensity $= 25.0$ mWcm$^{-2}$; temperature $= 298$ K.
3.5. Effect of diffusion length on the system

The effect of the variation of diffusion length (distance between the two electrodes i.e. saturated calomel electrode and Pt electrodes) on the electrical output of the photogalvanic cell was studied using H-cells of different dimensions.

It was observed that in the first few minutes of illumination there was a sharp increase in the photocurrent and then there was a gradual decrease to a stable value of photocurrent. This behavior of photocurrent indicates an initial rapid reaction followed by a slow rate determining step. On the basis of the effect of diffusion path length on the current parameters, as investigated by Kaneko and Yamada [25] it may be concluded that the leuco or semi-reduced form of dye, and the dye itself are the main electroactive species at the illuminated and the dark electrodes, respectively. However, the reducing agents and its oxidized products behave as the electron carriers in the cell diffusing through the path. It was observed that the current increases on increasing the diffusion length. The results are graphically represented in Fig. 5.

![Fig. 5. Variation of electrical output with diffusion length on the system](image)

3.6. Effect of electrode area on the system

The effect of variation of electrode area of Pt electrode on the electrical output of the photogalvanic cell was studied using different measurements of electrode areas. The results are graphically represented in Fig.6. it was observed that with an increase in the electrode area, the power of the cell was found to increase.

![Fig. 6. Variation of electrical output with electrode area on the system](image)
3.7. Current–voltage (i–V) characteristics of the photogalvanic cell

The short circuit current (i_sc) and open circuit voltage (V_oc) of the photogalvanic cells were measured with the help of a microammeter (keeping the circuit closed) and with a digital pH meter (keeping the other circuit open), respectively. The current and potential values in between these two extreme values were recorded with the help of a carbon pot (log 470 K) connected in the circuit of microammeter, through which an external load was applied. The Current–Voltage (i–V) characteristics of the photogalvanic cell containing Rose Bengal–Oxalic acid–Tween system is graphically represented in Fig. 4.

A point in i–V curve, called power point (pp) is determined where the product of current and potential was maximum and the fill factor is calculated using the following formula:

\[ \text{Fill factor (Ff)} = \frac{V_{pp} \times I_{pp}}{V_{oc} \times I_{sc}} \]

Where as V_{pp} and I_{pp} represent the value of photopotential and photocurrent at power point, respectively, and V_{oc} and i_sc represent open circuit voltage and short circuit current, respectively. The value of fill factor (Ff = 0.328) was obtained and the power point of cell (pp) = 22.308 μW was determined on the system.

![Fig.7. Current–potential (i–V) of the cell](image)

3.8. Storage capacity of the photogalvanic cell

The storage capacity of the photogalvanic cell was observed by applying an external load (necessary to have current at power point) after termination of the illumination as soon as the potential reaches a constant value. The storage capacity was determined in terms of t_{1/2}, i.e., the time required in fall of the electrical output (power) to its half at power point itself. It was observed that the photogalvanic cell can be used in dark for 230.0 min on irradiation for 72.0 min. The results are graphically represented in Fig.8.

![Fig.8. Storage capacity of the cell](image)
3.9. Conversion efficiency of the photogalvanic cell

The conversion efficiency of system containing Rose Bengal as photosensitizer is calculated using the electrical output at power point and the power of incident radiations.

The conversion efficiency of the photogalvanic cell is determined as 0.258 % using the following formula:

\[
\text{Conversion Efficiency} \% = \frac{V_{pp} \times V_{ipp}}{10.4 \text{ mWcm}^{-2} \times \text{Electrode area}} \times 100
\]

3.10. The performance of photogalvanic cell

The overall performance of the photogalvanic cell was observed and reached to remarkable level in the performance of photogalvanic cells with respect to electrical output, initial generation of photocurrent, conversion efficiency and storage capacity of the photogalvanic cell. The results so obtained in Rose Bengal–Oxalic acid–Tween system are summarized in Table 2.

Table 2: The performance of the photogalvanic cell

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Observed Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Circuit Voltage (Voc)</td>
<td>666 mv</td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td>119.5 μA</td>
</tr>
<tr>
<td>Time of Illumination</td>
<td>2 min</td>
</tr>
<tr>
<td>Storage Capacity (t1/2)</td>
<td>230 min</td>
</tr>
<tr>
<td>Conversion efficiency (η)</td>
<td>0.258%</td>
</tr>
<tr>
<td>Fill factor (Ff)</td>
<td>0.328</td>
</tr>
<tr>
<td>Current at power point (ipp)</td>
<td>83.7 μA</td>
</tr>
<tr>
<td>Potential at power point (Vpp)</td>
<td>312 mv</td>
</tr>
<tr>
<td>Power at power point (Pp)</td>
<td>22.3 μW</td>
</tr>
<tr>
<td>Maximum power</td>
<td>79.58 μW</td>
</tr>
</tbody>
</table>

[Rose Bengal] = 10.16 × 10^{-5} M; [Oxalic acid] = 1.9 × 10^{-3} M; [Tween] = 6 × 10^{-2} M; light intensity = 25.0 mWcm^{-2}; temperature = 298 K.

3.11. Mechanism

On the basis of these observations, a mechanism has been suggested for the generation of photocurrent in the photogalvanic cell as given below.

The solution does not bleach during illumination, indicating the possibility of generation of the reduced, semi- or leuco-D. A feasible mechanism for photoinduced electron transfer from the surfactant to the D dye is suggested.

\[
\begin{align*}
\text{D}^+ + \text{S}^+ & \rightarrow \text{D}^- + \text{S}^+ \\
\text{D}^- + \text{e}^- (\text{anode reaction}) & \\
\text{S}^+ + \text{e}^- (\text{cathode reaction}) & \\
\end{align*}
\]
The overall forward (light) and back (dark) reactions in the cell under continuous illumination may be represented as:

\[
\begin{align*}
D^- + S & \overset{\text{light}}{\longrightarrow} D^2^- + S^+ \\
& \overset{\text{dark}}{\longrightarrow}
\end{align*}
\]

5. Conclusion

Scientists have been studying the harvesting of solar energy through techniques like photoelectrochemical, photovoltaic and photogalvanic cells. Photovoltaic cells are widely used for solar energy conversion but owing to their lack of storage capacity, the photogalvanic cells have emerged as preferred research field as they have the added advantage of inherent storage capacity. The use of Rose Bengal as photosensitizer and Oxalic acid as reductant, has not only enhanced the electrical output but also increased the conversion efficiency and storage capacity of photogalvanic cells. However, using the sunlight in May in Egypt gives rise to increase the produced power of the cell. The reproducibility of the experiment seven times using the same solution gives the same power. The photogalvanic cells still have enough scope to put efforts to enhance the performance and reduce the cost.

References