International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

# Role of Anionic Surfactant on Energy Conversion and Storage Capacity in Photogalvanic Cell

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Accepted 10 October 2013, Available online 20 October 2013, **Vol.3, No.4 (October 2013)**

***Abstract***

*Studies of anionic surfactant on energy conversion and storage capacity in a photogalvanic cell containing Rhodamine 6G-EDTA-NaLS system. Photogalvanic cell is a device in which solar energy converts into electrical energy via formation of energy rich species that exhibit the photosgalvanic effect. The photopotential and photocurrent of the cell is observed 905.0 mV and 450.0 μA respectively. The conversion efficiency and fill factor of the cell are determined 1.265 % and 0.2516 respectively. The storage capacity (performance) of the cell is observed 170.0 minutes in dark. The effects of different parameters on the electrical output of the cell are observed and current-voltage (i -V) characteristics of the cell are also studied. The mechanism is proposed for the generation of photocurrent in photogalvanic cell.*

***Keywords:*** *photogalvanic effect, photopotential, photocurrent, conversion efficiency, storage capacity.*

## 1. Introduction

A large and cheap source of energy is an essential requirement for the development of a growing nation. The solar energy is the most readily available non-conventional source of energy which is most abundant and freely available renewable source of energy. The new approach for renewable energy sources has led to an increasing interest in photogalvanic cells because of their reliable solar energy conversion and storage capacity. The photogalvanic cells are those cells in which solar energy converts into electrical energy via formation of energy rich species that exhibit the photogalvanic effect. This cell works on photogalvanic effect. The photogalvanic effect was first of all recognised by Rideal and Williams (E.K. Rideal *et al*, 1925) and it was systematically studied by Rabinowitch (E. Rabinowitch, 1940), and then by other workers (A.E. Porter *et al*, 1959, M. Wolf, 1960, K.K. Rohtgi-Mukherjee *et al*, 1983, S. Madhwani *et al*, 2007, N.S. Dixit *et al*, 1982 and P.V. Kamat, 1985). Some researchers (W. Peng *et al*, 2003 and W.J. Albery *et al*, 1977) have studied on how to enhance the performance and optimum efficiency of dye sensitized solar cell for solar energy conversion. Later on studies on photogalvanic cell consisting of various photosensitizers with reductant, mixed sensitizers with reductant and sensitizer with reductant and surfactant for solar energy conversion and storage reported time to time (S.C. Ameta *et al*, 1989, K.M. Gangotri *et al*, 1997, 2005, 2001, 2010 and 2011, Chhagan Lal, 2007, A.K. Jana *et al*, 1999, S. Madhwani *et al*, 2007, K.R. Genwa *et al*, 2006, 2009 and 2012, K.K. Bhati *et al*, 2011 and M.K. Bhimwal *et al*, 2011). Recently some photogalvanic cells are developed by Chandra and his co-workers (M. Chandra *et al*, 2011, 2010 and 2012) for generation of electrical energy from various photosensitiser and reductant. The present work is the effort to observe the role of anionic surfactant (NaLS) on energy conversion and storage capacity in photogalvanic cell containing Rhodamine-6G and EDTA as a photosensitizer and reductant respectively.

## 2. Methodology

Rhodamine 6G (MERCK), NaLS (LOBA), EDTA (MERCK) and NaOH (MERCK) are used in the present work. All the solutions are prepared in doubly distilled water and the stock solutions of all chemicals are prepared by direct weighing and are kept in a colored container to protect them from the light. The whole cell is set systematically for photogalvanic studies, which consists of thin foil of electrochemically treated platinum as the electrode and saturated calomel electrodes as a reference electrode. The distance between the illuminated and dark electrode is 45.0 mm. An ordinary tungsten lamp of 200.0 W is used as light source. Water filter is used to cut-off IR radiations. The photopotetial is obtained as the difference between the initial potential of the cell in dark and the equilibrium potential attained by the cell under constant illumination. The potential is first measured in the dark and the change in potential on illumination is measured as a function of time. The solution is bubbled with prepurified nitrogen gas for nearly twenty minutes to

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remove dissolved oxygen. Solutions of dye, reductant, surfactant and sodium hydroxide are taken in an H-type glass tube. A platinum electrode (1.0 x 1.0 cm2) is immersed into one arm of the H-tube and a saturated calomel electrode (SCE) is kept in the other. The whole cell is first placed in dark till a stable potential is obtained and then, the arm containing the SCE is kept in the dark and the platinum electrode is exposed to a 200.0 W tungsten lamp. A water-filter is used to cut off infrared radiations.

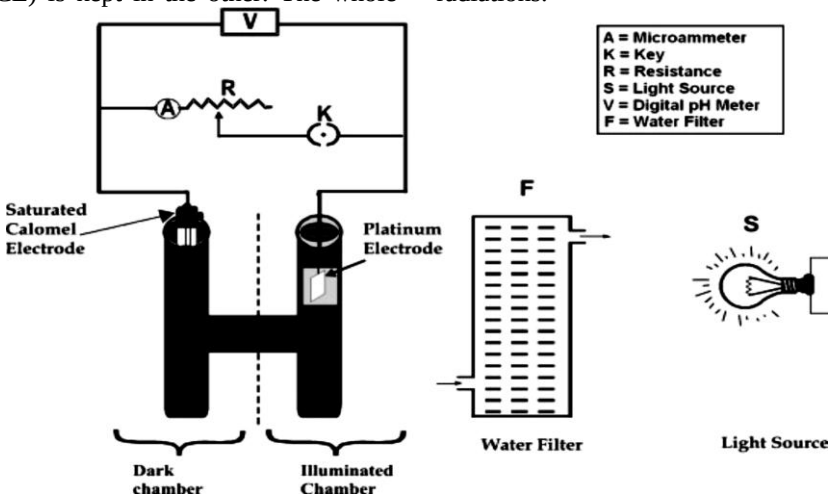


**Figure 1** Experimental set-up of photogalvanic cell

The photochemical bleaching of Rhodamine 6G is studied potentiometrically. A digital pH meter (Systronics Model-335) and a microammeter (Ruttonsha Simpson) are used to measure the potential and current generated by the cell, 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 Figure 1. The effect of variation of different parameters has also been observed. The rate of change in potential after removing the source of illumination is 0.85mV $min^{-1}$ in Rhodamine 6G-EDTA-NaLS cell.

## 3. Results and Discussion

*3.1 Variation of photopotential and photocurrent with time in Rhodamine 6G-EDTA-NaLS cell*

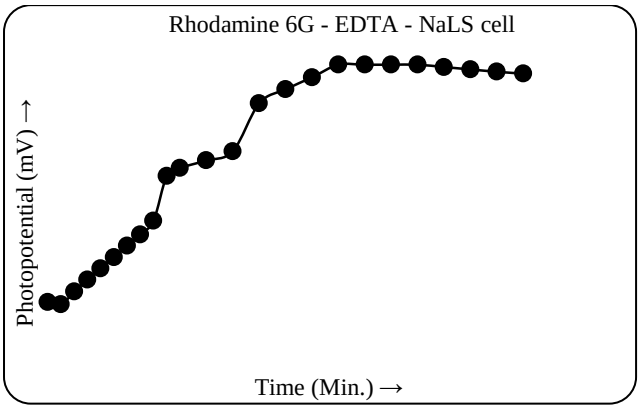


**Figure 2** Variation of Photopotential with Time

The photopotential of Rhodamine 6G- EDTA-NaLS cell is measured at different pH values and maximum photopotential is found at pH 11.60. All the subsequent measurements are made at this pH value. The variation of photopotential with time for this system is shown in Figure 2. As can be seen from the figure that the photopotential increase upon illumination to a value of 1162.0 mV in about 140.0 minutes and remains constant on further illumination. When the light is switched-off, the system does not regains its original potential; thereby, showing that the system is not perfectly reversible. The photo induced short circuit currents of Rhodamine 6G-EDTA-NaLS system in photogalvanic cell is shown in Figure 3. On illumination, maximum photocurrent 510.0 μA in 140.0 minutes in Rhodamine 6G-EDTA-NaLS system.

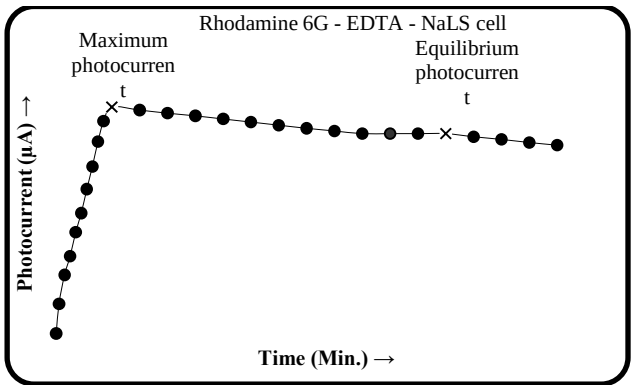


**Figure 3** Variation of Photocurrent with Time

*3.2. Effect of variation of pH on the cell*

The effect of variation in pH on photoelectric parameters of cell is studied. It is found that the cell containing

Rhodamine 6G-EDTA-NaLS to be quite sensitive to the pH of the solution. It is observed that there is an increase in the photoelectric parameters of this cell with the pH value (In the alkaline range). At pH 12.40 a maxima is obtained. On further increase in pH, there is a decrease in photoelectric parameters. It is observed that the pH for the optimum condition has a relation with pKa of the reductant and the desired pH is higher than in pKa value (pH>pKa). The reason of the change in electrical output is that the availability of the reductant in its anionic form, which is a better donor form. The above same is presented in Table 1.

**Table 1** Effect of variation of pH on the cell

| Parameters | Photopotential (mV) | Photocurrent (μA) | Power (μW) |
|---|---|---|---|
| pH | | | |
| 12.32 | 762 | 348 | 265.18 |
| 12.36 | 846 | 405 | 342.63 |
| 12.4 | 905 | 450 | 407.25 |
| 12.44 | 828 | 395 | 327.06 |
| 12.48 | 735 | 328 | 241.08 |

*3.2. Effect of diffusion length and electrode area on the cell*

The effect of variation in diffusion length (distance between the two electrodes) on the photoelectric parameters of the cell ($i_{max}$, $i_{eq}$ and initial rate of generation of photocurrent) is studied using H-shaped cells of different dimensions. The effect of electrode area on the photoelectric parameters of the cell is also reported here. It is observed that both $i_{max}$ and rate of change in initial generation of photocurrent (μA $min^{-1}$) increase with respect to the diffusion length whenever the equilibrium photocurrent ($i_{eq}$) shows a small decrease with respect to the diffusion length. The reason of the change in electrical output is that the main electroactive species are the leuco or semi-leuco form of dye (photosensitizer) and the dye in illuminated and dark chamber respectively. The reductant and its oxidation product act only as electron carriers in the path. The rate of change in photoelectric parameters with respect to the diffusion length is graphically

**Table 2** Effect of diffusion length

| Diffusion Length DL (mm) | Maximum photocurrent $i_{max}$ (μA) | Equilibrium photocurrent $i_{eq}$ (μA) | Rate of initial generation of photocurrent (μA $min^{-1}$) |
|---|---|---|---|
| 35 | 496 | 464 | 13.78 |
| 40 | 502 | 458 | 13.94 |
| 45 | 510 | 450 | 14.17 |
| 50 | 518 | 444 | 14.39 |
| 55 | 526 | 438 | 14.61 |

presented in Table 2. Similarly, Table 3 shows rate of change in photoelectric parameter with respect to electrode area. It is found that the maximum photocurrent show increasing fashion with electrode area whereas the equilibrium photocurrent ($i_{eq}$) show decreasing fashion.

**Table 3** Effect of electrode area

| Rhodamine 6G-EDTA-NaLS | Electrode area ($cm^2$) | | | | |
|---|---|---|---|---|---|
| | 0.7 | 0.85 | 1 | 1.15 | 1.3 |
| Maximum photocurrent $I_{max}$ (μA) | 492 | 500 | 510 | 522 | 532 |
| Equilibrium photocurrent $i_{eq}$ (μA) | 474 | 462 | 450 | 436 | 422 |

*3.4 Conversion efficiency of the cell*

Conversion efficiency is the important characteristics of any photogalvanic cell. The i-V characteristics of Rhodamine 6G-EDTA-NaLS system in photogalvanic cell have been investigated to estimate the power conversion efficiency of the cell. The maximum possible power output from the cell can be obtained from the rectangle of maximum area, which can be drawn under i-V curve. The power points (a point on the curve, where the product of potential and current was maximum) in i-V curves are determined and their fill factor and conversion efficiency are also calculated by using the formula.

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

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

Observed data of fill factor and current-voltage (i-V) characteristics for this system are reported in Table 4 and Figure 4, respectively. The conversion efficiency of the Rhodamine 6G-EDTA-NaLS photogalvanic cell has been calculated to be 1.265% and the conversion efficiency and sunlight conversion data for this system is reported in Table 5.

**Table 4** i-V Characteristics of the cell

| Cell | $V_{oc}$ (mV) | $i_{sc}$ (μA) | $V_{pp}$ (mV) | $i_{pp}$ (μA) | η |
|---|---|---|---|---|---|
| Rh 6G-EDTA-NaLS | 1162 | 450 | 658 | 200 | 0.2516 |

**Table 5** Conversion efficiency and sunlight conversion data

| Cell | Fill Factor (η) | Conversion Efficiency (%) | Sunlight conversion data | |
|---|---|---|---|---|
| | | | Potential (mV) | Currents (μA) |
| Rh 6G-EDTA-NaLS | 0.2516 | 1.2653 | 1162 | 510 |

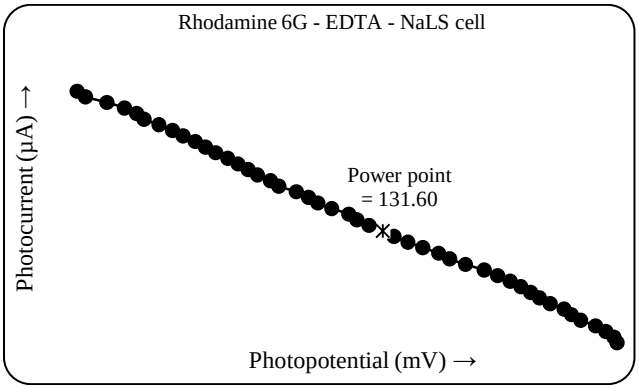


**Figure 4** Current-Voltage (i-V) curve of the cell

*3.5 Performance of the cell*

The performance of the photogalvanic cell is observed by applying an external load (necessary to have current at power point) after terminating the illumination as soon as the potential reaches a constant value. The performance is determined in terms of $t_{1/2}$, i.e., the time required in the fall of the output (power) to its half at power point in dark. It is observed that the cell can be used in dark for 170.0 minutes, whereas photovoltaic cell cannot be used in the dark even for a second. The performance and $t_{1/2}$ of this cell are reported in Figure 5 and Table 6, respectively.

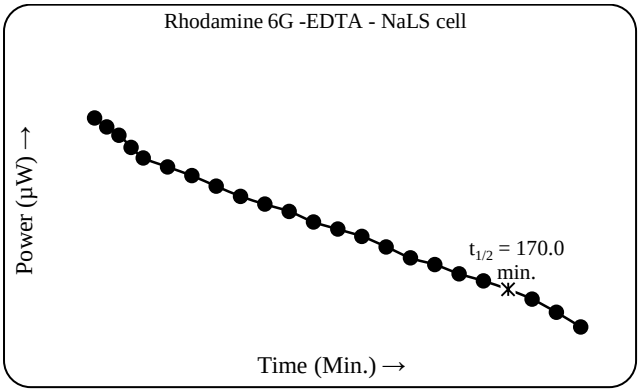


**Figure 5** Performance of the cell

**Table 6** Performance of the photogalvnic cell in dark

| Cell | Power (μW) | $t_{1/2}$ (min.) |
|---|---|---|
| Rhodamine 6G-EDTA-NaLS | 131.6 | 170 |

On the basis of these observations, a mechanism is suggested for the generation of photocurrent in the photogalvanic cell as:

*4.1 Illuminated chamber*

On irradiation, dye molecules get excited.

$$\text{Dye} \xrightarrow{h\nu} \text{Dye}^* \qquad (4.1)$$

The excited dye molecules accept an electron from reductant and get converted into semi or leuco form of dye, and the reductant into its excited form

$$\text{Dye}^* + \text{R} \longrightarrow \text{Dye}^- \text{ (Semi)} + \text{R}^+ \qquad (4.2)$$

*At platinum electrode*

The semi or leuco form of dye loses an electron and get converted into original dye molecule

$$\text{Dye}^- \longrightarrow \text{Dye} + e^- \qquad (4.3)$$

*4.2 Dark chamber*

*At calomel electrode*

Dye molecules accept an electron from electrode and get converted into semi or leuco form

$$\text{Dye} + e^- \longrightarrow \text{Dye}^- \text{ (Semi)} \qquad (4.4)$$

Finally leuco/semi form of dye and oxidized form of reductant combine to give original dye and reductant molecule. This cycle of mechanism is repeated again and again leading production of current continuously.

$$\text{Dye}^- + \text{R}^+ \longrightarrow \text{Dye} + \text{R} \qquad (4.5)$$

Where Dye, Dye*, $Dye^-$, R and $R^+$ are the dye, excited form of dye, semi or leuco form of dye, reductant and oxidized form of the reductant, respectively. The process of mechanism in photogalvanic cell is graphically represented in Figure 6.

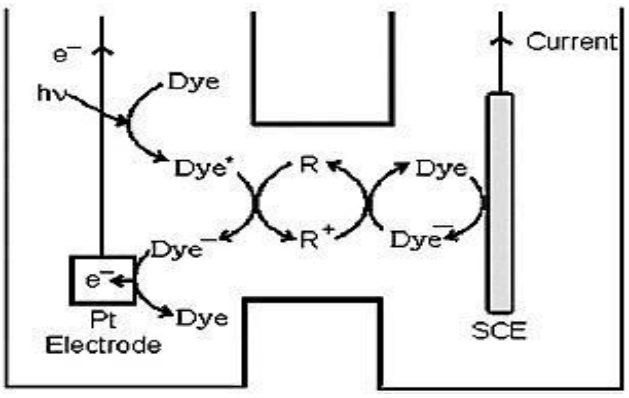


**Figure 6** Processes of mechanism in photogalvanic cell

**5. Conclusion**

On the basis of the results, it is concluded that sodium lauryl sulphate with EDTA and Rhodamine 6G can be used successfully as an anionic surfactant in a photogalvanic cell. The conversion efficiency and storage capacity of the cell is 1.265% and 170.0 minutes respectively. It has been observed that the anionic surfactants have not only enhanced the energy conversion but also the storage capacity (performance) of the cell.

## Nomenclature

$i_{eq}$ = photocurrent at equilibrium $i_{max}$ = maximum photocurrent
$i_{pp}$ = photocurrent at power point $i_{sc}$ = short circuit current
ml = milliliter mV = millivolt
M = molarity pp = power poin
$t_{1/2}$ = storage capacity of cell DV = observed photopotentia
$V_{oc}$ = open circuit voltage $V_{pp}$ = photopotential at power point
$\eta$ = fill factor mA = microampere
mW = microwatt Rh = Rhodamine

| S. No. | Parameter | Observed value in Rhodamine 6G-EDTA-NaLS cell |
|---|---|---|
| 1 | Dark potential | 257.0 mV |
| 2 | Open circuit voltage ($V_{OC}$) | 1162.0 mV |
| 3 | Photopotential (DV) | 905.0 mV |
| 4 | Equilibrium photocurrent ($i_{eq}$/ $i_{sc}$) | 450.0 μA |
| 5 | Maximum photocurrent ($i_{max}$) | 510.0 μA |
| 6 | Initial generation of photocurrent | 25.5 μA $min^{-1}$ |
| 7 | Time of illumination | 140.0 min |
| 8 | Storage capacity ($t_{1/2}$) | 170.0 min |
| 9 | % of storage capacity of cell | 121.42% |
| 10 | Conversion efficiency | 1.27% |
| 11 | Fill factor ($\eta$) | 0.2516 |

[Rhodamine 6G] = 2.59 x $10^{-5}$ M; Light Intensity = 10.4 mW $cm^{-2}$; [EDTA] = 1.44 x $10^{-3}$ M; Tempt. = 303 K; [NaLS] = 1.14 x $10^{-3}$ M; pH = 12.40

## Acknowledgement

The authors are grateful to The Head, Department of Chemistry, MLS University, Udaipur, Rajasthan - 313001 (INDIA) for providing the necessary laboratory facilities to conduct this research work.
One of the authors (A.S. Meena) is thankful to Ministry of New and Renewable Energy (MNRE), Government of India, New Delhi-110003 (INDIA) for the financial assistance to this research work.

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