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Role of Cationic Micelles and Reductant for Solar Energy Conversion and Storage in Photogalvanic Cell

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Abstract

Studies of cationic micelles and reductant in photogalvanic cell for solar energy conversion and storage. Photogalvanic cell is a device 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. Photogalvanic effect was studied in a photogalvanic cell containing Azur B-EDTA-CTAB cell. The observed cell performance in terms of maximum potential, maximum photocurrent, short-circuit current, power at power point, conversion efficiency and storage capacity in terms of half change time are -1035.0 mV, 475.0 μA, 395.0 μA, 104.50 μW, 1.004 % and 140.0 minutes, respectively . The mechanism is proposed for the generation of photocurrent in photogalvanic cell.

Keywords: - Photogalvanic effect, photopotential, photocurrent, conversion efficiency, storage capacity.

Introduction

Achieving a secure, efficient and clean energy supply is one of the major issues of facing the world community. Since, there is an urgent need to focus the higher attention on development of new energy sources. 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. A device in which solar energy converts into electrical energy via formation of energy rich species that exhibit the photogalvanic effect is known as photogalvanic cell. This cell works on photogalvanic effect. The photogalvanic effect was first of all recognised by Rideal and Williams [1] and it was systematically studied by Rabinowitch [2-3], and then by other workers [4-9]. Some researchers [10-11] 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 reductants, mixed sensitizers with reductant and sensitizers with reductants and surfactanst for solar energy conversion and storage reported time to time [12-23]. Recently some photogalvanic cells were developed by Meena and his co-workers [24-26] for generation of electrical energy from various photosensitiser and reductant. Present work is the effort to observe the Role of cationic micelles (CTAB) and reductant (EDTA) with dye (Azur B) in photogalvanic cell for solar energy conversion and storage.

Experimental Methods

Azur B (MERCK), CTAB (MERCK), EDTA (MERCK) and NaOH (MERCK) are used in the present research 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 colored container to protect them from the light. The entire cell is set systematically for photogalvanic studies, which consists of thin foil of electrochemically treated platinum as 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 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 remove dissolved oxygen. Solutions of dye, reductant, micelles 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 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. The photochemical

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bleaching of Azur B 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 0.90mV min^{-1} in Azur B-EDTA-CTAB cell.

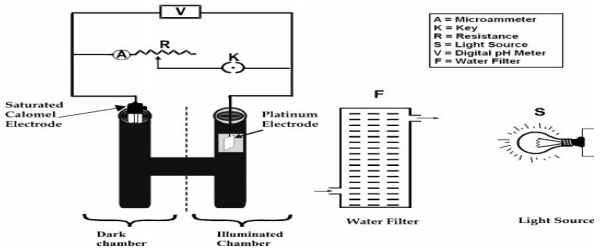

Figure-1 Experimental set-up of photogalvanic cell

Results and Discussion

Effect of variation in photosensitizer, reductant and micelles concentration on the cell

The effect of variation in photosensitizer, reductant and micelles concentration on photoelectric parameters is studied. It is observed that the photopotential and photocurrent are increasing with respect to the concentration of the photosensitizer, reductant and micelles. A maximum is obtained for a particular value of photosensitizer (Azur B) concentration, reductant (EDTA) concentration and micelles (CTAB) concentration. On further increase in concentration of photosensitizer (Azur B), reductant (EDTA) and micelles (CTAB), a decrease in the electrical output of the cell is obtained.

The reason of the change in electrical output is that lower concentration of photosensitizer resulted into a fall in electrical output because fewer photosensitizer (Azur B) molecules are available for the excitation and consecutive donation of the electrons to the platinum electrode whereas the higher concentration of photosensitizer again resulted into a decrease into electrical output as the intensity of light reaching the dye molecules near the electrode decrease due to absorption of the major portion of the light by dye molecules present in the path.

The reason of the change in electrical output is that the lower concentration of reducing agent resulted into a fall in electrical output because fewer reducing agent molecules are available for electron donation to photosensitizer (Azur B) molecule whereas the higher concentration of reducing agent again resulted into a decrease in electrical output, because the large number of reducing agent molecules hinders the dye molecules from reaching the electrode in the desired time limit.

The reason of the change in electrical output is that the micelles solubilize the dye molecules up to highest extent at or around their micelles concentration. The above variations are reported in Table 1.

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 Azur B-EDTA-CTAB 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 13.20 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 reported in Table 1.

Table-1: - Effect of concentration (Azur B, EDTA and CTAB) and pH on the cell

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Parameters	Photopotential (mV)	Photocurrent (μA)	Power (μW)
(Azur B) × 10^{-5} M			
1.82	698.0	305.0	212.89
1.85	742.0	338.0	250.80
1.88	795.0	395.0	314.03
1.92	755.0	344.0	259.72
1.95	684.0	312.0	213.41
(EDTA) × 10^{-3} M			
1.06	713.0	313.0	223.77
1.11	752.0	346.0	260.19
1.16	795.0	395.0	314.03
1.20	747.0	352.0	262.94
1.25	688.0	309.0	212.59
(CTAB) × 10^{-3} M			
0.63	713.0	313.0	223.77
0.65	752.0	346.0	260.19
0.68	795.0	395.0	314.03
0.70	747.0	352.0	262.94
0.72	688.0	309.0	212.59
pH			
13.04	719.0	314.0	225.77
13.12	752.0	352.0	266.82
13.20	795.0	395.0	314.03
13.28	758.0	347.0	263.03
13.36	702.0	302.0	212.00

[Azur B] = 1.88 x 10^{-5} M; Light Intensity = 10.4 mW cm^{-2}; [EDTA] = 1.16 x 10^{-3} M;Temp. = 303 K; [TX-100] = 0.68 x 10^{-3} M; pH = 13.20

Effect of temperature and light intensity on the cell

The effect of temperature on the photoelectric parameters of the cell is studied. The effect of light intensity on the photoelectric parameters of the cell also investigated here. It is observed that the photocurrent of the photogalvanic cell is found to be increased with the temperature whereas the photopotential is decreased. Thereafter, the effect of temperature on total possible power output in the Azur B-EDTA-CTAB cell is also studied and it is observed that there a linear change between the both. The reason of the change in electrical output is that internal resistant of the cell decreases at higher temperature resulting into a rise in photocurrent and correspondingly, there will be a fall in photopotential. The same is presented in Figure 2. Similarly, Figure 3 shows rate of change in photoelectric parameter with respect to light intensity. The light intensity is measured in terms of $mWcm^{-2}$ with the help of solarimeter (CEL Model SM 203). It is found that the photocurrent show linear increasing fashion with light intensity whereas the photopotential show an increment in a logarithmic fashion.

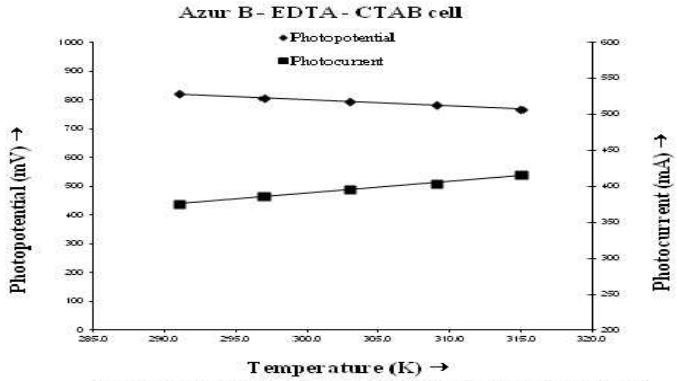

Figure-2 Variation of photopotential and photocurrent with temperature

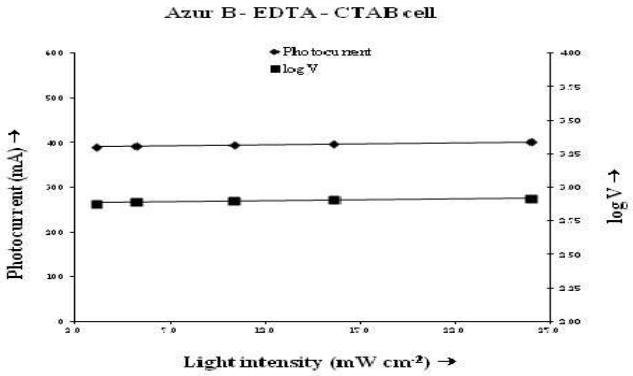

Figure-3 Variation of photopotential and log V with light intensity

Current-Voltage (i-V) characteristics of the cell

The short circuit current (i_{sc}) and open circuit voltage (V_{oc}) of the photogalvanic cells are measured with the help of a multimeter (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 are recorded with the help of a carbon pot (log 470 K) connected in the circuit of Multimeter, through which an external load is applied. The current – voltage (i-V) characteristics of the photogalvanic cells containing Azur B-EDTA-CTAB cell is graphically presented in Figure 4.

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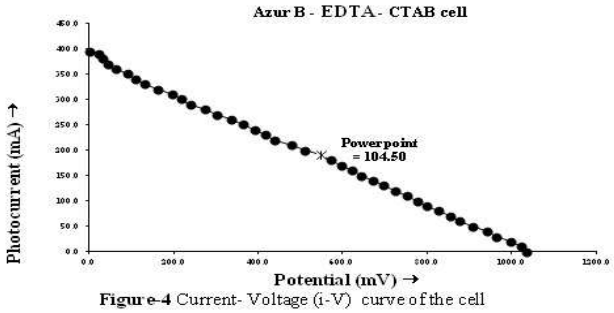

Figure-4 Current- Voltage (i-V) curve of the cell

Storage capacity (performance) and conversion efficiency of the cell

The storage capacity (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 storage capacity (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 140.0 minutes, whereas photovoltaic cell cannot be used in the dark even for a second. A photogalvanic cell has the advantage of being used in the dark but at lower conversion efficiency. The results are graphically presented in Figure 5. The conversion of the efficiency of the cell is determined as 1.004% with the help of photocurrent and photopotential values at the power point and the incident power of radiations by using the formula.

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

$$\text{Conversion Efficiency} = \frac{V_{pp} \times i_{pp}}{10.4\ \text{mW cm}^{-2}} \times 100\% \qquad \ldots\ldots\ (2)$$

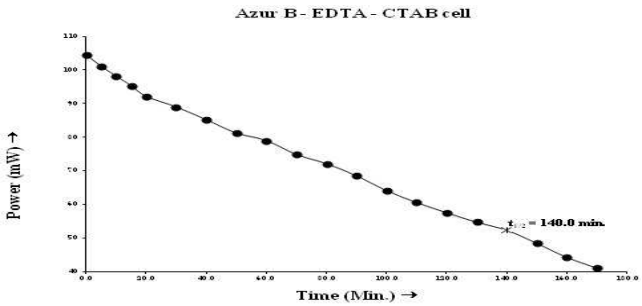

Figure-5 Performance of the cell

Mechanism

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

Illuminated chamber

On irradiation, dye molecules get excited.

$$\text{Dye} \xrightarrow{h\nu} \text{Dye}^* \qquad \ldots..\ (3)$$

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.

$$\text{Dye}^* + \text{R} \longrightarrow \text{Dye}^- \text{ (Semi)} + \text{R}^+ \qquad \ldots(4)$$

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At platinum electrode:

The semi or leuco form of dye loses an electron and gets converted into the original dye molecule.

$Dye^- \longrightarrow Dye + e^-$ … (5)

Dark chamber

At calomel electrode:

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

$Dye + e^- \longrightarrow Dye^-$ (Semi) … (6)

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.

$Dye^- + R^+ \longrightarrow Dye + R$ … (7)

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.

5. Conclusion

On the basis of the results, it is concluded that CTAB and EDTA with Azur B can be used successfully as cationic micelles and reductant respectively in a photogalvanic cell. The conversion efficiency and storage capacity of the cell is 1.004% and 140.0 minutes respectively. It has been observed that the cationic micelles (CTAB) and reductant (EDTA) have not only enhanced the electrical parameters but also the conversion efficiency and storage capacity (performance) of photogalvanic cell. Photovoltaic cells have better conversion efficiency than photogalvanic cells while photogalvanic cells have better storage capacity than photovoltaic cells. Thus, photogalvanic cells showed good prospects of becoming commercially viable.

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 point
$t_{1/2}$	=	storage capacity of cell	DV	=	observed photopotential
V_{oc}	=	open circuit voltage	V_{pp}	=	photopotential at power point
η	=	fill factor	mA	=	microampere
mW	=	microwatt			

S.N.	Parameter	Observed Value
1	Dark potential	240.0mV
2	Open circuit voltage (V_{OC})	1035.0mV
3	Photopotential (DV)	795.0mV
4	Equilibrium photocurrent (i_{eq})	395.0 mA
5	Maximum photocurrent (i_{max})	475.0 mA
6	Initial generation of photocurrent	19.0 mA min^{-1}
7	Time of illumination	150.0 min
8	Storage capacity ($t_{1/2}$)	140.0 min
9	% of storage capacity of cell	93.33%
10	Conversion efficiency	1.004%
11	Fill factor (η)	0.2556

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