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A Comparative study on the Performance of Photogalvanic cells with mixed Surfactant for Solar Energy conversion and storage: D-Xylose- Methylene Blue systems

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Abstract

The comparative performance of photogalvanic cells were studied for conversion and storage of solar energy by using (NaLS+Tween-80) and (NaLS+ CTAB) as different mixed surfactant with D-Xylose as reductant and Methylene blue as photosensitizer in the different mixed surfactants systems. The observed conversion efficiencies for (NaLS+Tween-80) and (NaLS+ CTAB) with D-Xylose and Methylene blue are 0.5313% and 0.4326% respectively. The Maximum photopotential are 870 mV and 825 mV where as the maximum photocurrent is 240 mA and 220 mA respectively. The Short circuit current or photocurrent at equilibrilium is 210 mA and 190 mA respectively. The fill factors 0.3024 and 0.2870 are experimentally observed at the power point of the photogalvanic cells where the absolute value is 1.0. The photogalvanic cells so developed can work for 100 and 90 min. in dark if it is irradiated for 150 and 160 min. respectively. The exhaustive efforts have still scope to increase the efficiency and economical viability by selecting many more combinations of two different surfactants and choosing proper reductant and photosensitizer (dye) in the photogalvanic cells for solar energy conversion and storage.

Keywords: Mixed surfactant, Photopotential, Photocurrent, Methylene blue, D-Xylose, Short circuit current.

Introduction

The economical development and standard of living of humanity is directly related with each other and totally depend upon the energy consumption. The energy is the most vital part of the human society to come into progressive processes. The energy is only option for any country to get the existence in the field of development and its security. The sources of energy are being used by human beings whether they are in rural or urban area of the country. In the ancient time the fossil fuels were widely used like wood, coal, kerosene etc. and rate of consumption of these fossil fuels is so rapid to reaching towards their complete depletion. The sources of fossil fuels have their own limits along with their high cost and pollution creating nature. The photogalvanic effect was First of all observed by Rideal and Williams[1] and then it was systematically investigated by Rabinowitch[2-3] and later by various other workerstime to time[4–5]. Ameta et al. studied. photogalvanic cells for solar energy conversion and storage[6-7]. Dube et al. reported Use of an Azur-A-NTA system in a photogalvanic cell for solar energy conversion[8]. Gangotri et al. reported by Effect of dyes along with surfactant was studied[9-10]. Genwa and Gangotri have reported comparative studies in anionic cationic and nonionic surfactant and Azur B–NTA–CPC system in photogalvanic cell[11]. Gangotri and Gangotri studied micellar effect of photogalvanics for solar energy conversion and storage using Safranine O-EDTA-CTAB-80 system[12]. Gangotri and Bhimwal carried out a comparative study on the performance of photogalvanic cell with different photosensitizer for solar energy conversion and storage[13]. A detailed Literature survey reveals that different photosensitizer, mixed surfactants and reductants have been used in photogalvanic cell for development of photogalvanic system[14-22]. Mao et al. studied the Influence of the mixed micelles on the electron transfer reaction[23].Thareja et al. observed the Influence of Surfactants on the Rheology and Stability of Crystallizing Fatty Acid Pastes [24]. Molina-Bolivar et al. reported the energetics of clouding and size effects in non-ionic surfactant mixtures on influence of alkyl chain length and NaCl addition[25]. Lee and Lee have reported the mixed micellizations of TTAB with other surfactants (DTAB, CTAB, Tween-20, Tween-40 and Tween-80)[26]. Ageev et al. observed the correlation between wetting and deterging abilities in mixed surfactant solutions[27].

Recently different groups of scientists[23-27] have worked on the mixed surfactants for different purposes and applications but none of the researcher has made attention to use mixed surfactants for solar energy conversion and storage in photogalvanic cell. In the present research work, it has been planned to increase the conversion efficiency, electrical output, performance of cell, storage capacity and overall performance of the photogalvanic cell using mixed surfactants. After going through the literature, it has been found that the use of suitable photosensitizer, reductant and mixed surfactant in photogalvanic cells for better electrical outputs are must be needed. So, In this direction, A comparative study on the performance of photogalvanic cells in photogalvanic cell using D-xylose as

reductant, NaLS + Tween-80 and NaLS +CTAB as mixed surfactants with methylene blue as photosensitizer was planned.

Material and Methods

Preparation of solutions: The solutions of mixed surfactants (NaLS+Tween-80, NaLS+ CTAB) photosensitizer (dye-methylene bue), reductant (D-xylose) and NaOH were prepared in doubly distilled water. The solution of NaOH was standardized before every experiment. The all type of solutions were kept in amber coloured volumetric flasks to protect them from electromagnetic radiation.

Experimental set–up of photogalvanic cell: An H shaped glass tube was fabricated and completely blackened except a window in one arm of the H tube. The known amount of solutions of mixed (two) surfactants, reductant D-xylose, photosensitizer- MB and NaOH were filled and desired amount of double distilled water was added to the solutions to make up 25.0 ml solutions in all the experiments. A saturated calomel electrode was dipped in one arm of the H-tube and a platinum electrode was dipped in another arm having a window (unblockened). The both terminals of electrodes were connected through the carbon pot, resistance key, digital pH meter and microammeter to measure the photopotential and photocurrent of the photogalvanic cell. A 200 W tungsten bulb was used as light sources and a water filter was used to cut of infra red radiations. The figure of experimental set-up is given in figure-1.

Results and Discussion

Effect of variation of mixed surfactant (NaLS+Tween-80) concentration on the system: For photogalvanic cell having methylene blue–D-xylose-NaLS+Tween-80 system, the photopotential and photocurrent varied with variation in concentration of mixed surfactants i.e. NaLS and Tween-80. In one case concentration of NaLS was kept constant and concentration of Tween-80 was varied. In other case the concentration of Tween-80 was kept constant and concentration of NaLS was varied. In both cases a maxima was found for a particular value of NaLS and Tween-80 concentration above which decrease in electrical output of photogalvanic cell was obtained. All observed results (NaLS+ Tween -80 mixed surfactant system) are summarized in table-1.

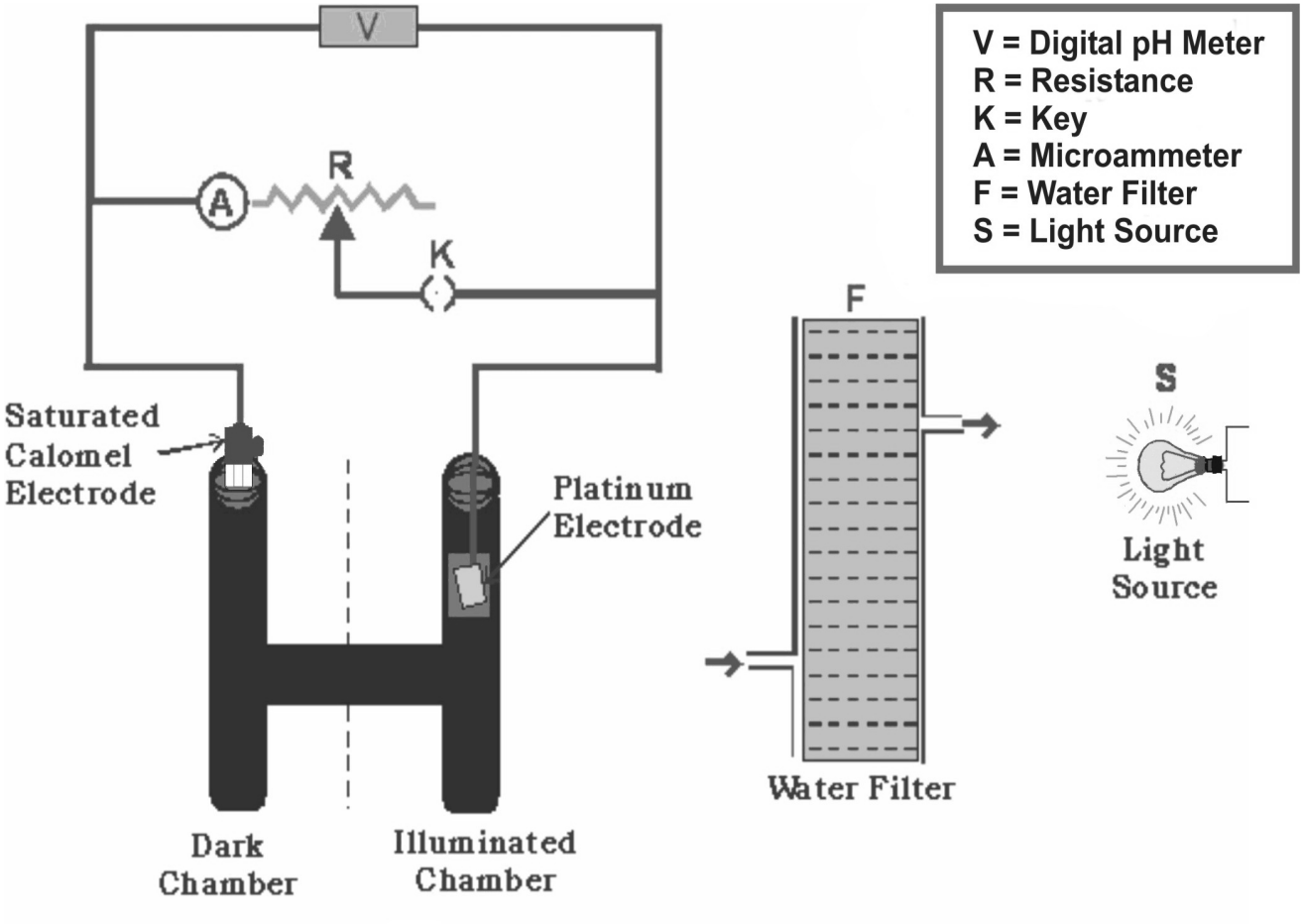

Figure-1
Experimental set-up for photogalvanic cell

Table-1
Effect of Variation of Methylene blue, D-Xylose, NaLS, Tween-80 and pH

Methylene blue -D-xylose-NaLS+Tween-80			
Parameters	**Photopotential (mV)**	**Photocurrent (μA)**	**Power (μW)**
[Methylene blue] $\times 10^{-5}$ M			
3.60	548.0	142.0	79.46
3.80	597.0	181.0	106.27
4.00	645.0	210.0	135.45
4.20	604.0	177.0	103.89
4.40	562.0	136.0	79.80
[D-Xylose] $\times 10^{-3}$ M			
1.96	543.0	138.0	78.81
1.98	598.0	185.0	108.32
2.00	645.0	210.0	135.45
2.02	602.0	177.0	110.66
2.04	554.0	143.0	79.46
[NaLS] $\times 10^{-3}$ M			
6.36	536.0	144.0	79.80
6.38	599.0	185.0	107.09
6.40	645.0	210.0	135.45
6.42	592.0	182.0	111.38
6.44	512.0	138.0	82.22
[Tween-80] $\times 10^{-4}$ M			
5.60	562.0	157.0	83.18
5.90	603.0	185.0	110.70
6.20	645.0	210.0	135.45
6.50	597.0	177.0	109.55
6.80	555.0	148.0	81.65
pH			
12.78	538.0	145.0	80.62
12.81	587.0	178.0	108.22
12.84	645.0	210.0	135.45
12.87	592.0	181.0	102.68
12.90	542.0	152.0	77.82

Light Intensity = 10.4 mWcm^{-2} Temp. = 303 K

Effect of variation of mixed surfactant (NaLS+ CTAB) concentration on the system: For photogalvanic cell having methylene blue–D-xylose-NaLS+CTAB system, the photopotential and photocurrent varied with variation in concentration of mixed surfactants i.e. NaLS and CTAB. In one case concentration of NaLS was kept constant and concentration of CTAB was varied. In other case the concentration of CTAB was kept constant and concentration of NaLS was varied. In both cases a maxima was found for a particular value of NaLS and CTAB concentration above which decrease in electrical output of photogalvanic cell was obtained. All observed results (NaLS+CTAB mixed surfactant system) are summarized in table-2.

Effect of variation of photosensitizer (Methylene blue) concentration on the system: Dependence of photo potential and photocurrent on the concentration of photosensitizer (methylene blue) was studied. It was observed that lower concentration of photosensitizer resulted into a fall in photopotential and photocurrent because fewer photosensitizer (dye–methylene blue) molecules are available for the excitation and consecutive donation of the electrons to the platinum electrode. A greater concentration of dye 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. All observed results (NaLS+ CTAB mixed surfactant system and NaLS+ Tween -80 mixed surfactant system) are summarized in table-1 and 2.

Effect of variation of reductant (D-xylose) concentration on the system: The electrical output of the photogalvanic cell was affected by the variation of reductant (D-xylose) concentration on the system. The Lower concentration of reducing agent resulted into a fall in electrical output because fewer reducing agent molecules were available for electron donation to

photosensitizer (dye–methylene blue) molecule. The Large 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. All observed results with respects to D-xylose are summarized in table-1and 2.

Effect of variation of pH on the system: The electrical output of the photogalvanic cell was affected by the variation of pH on the system. It can be observed from the table-1 that there is an increase in electrical output of the cell with the increase in pH values. At pH range 12.84-13.20, a maxima was obtained. On further increase in pH, there was a decrease in photopotential and photocurrent. Thus, photogalvanic cells containing the methylene blue D-xylose systems were found to be quite sensitive to the pH of the solutions. It was 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 may be the availability of the reductant in its anionic form, which is a better donor form. All observed results with respects to pH are summarized in table-1 and 2.

Effect of diffusion length: Effect of variation of diffusion length (distance between the two electrodes) on the current parameter of the cell (i_{max}) has been studied using H-shaped cells of different dimensions. It is observed that in the first few minutes of illuminations there is sharp increase in the photocurrent. As a consequence, the maximum photocurrent (i_{max}) of photocurrent increase with increase in diffusion length, but this is not observed experimentally. Therefore, it may be concluded 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. All observed results with respects to diffusion length are summarized in table-3 and 4.

Effect of electrode area: The effect of electrode area on the current parameters of the cell has also been studied. It was observed that with the increase in the electrode area the value of maximum potential (i_{max}) is found to increase. All observed results with respects to effect of electrode area are summarized in table-5 and 6.

Current–voltage (i-V) characteristics of the photogalvanic cell. The photogalvanic cell containing methylene blue- D-xylose-NaLS+Tween-80 system, 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 methylene blue-D-xylose system are reported in figure-2 and 3. It was observed that current–voltage (i-V) curve deviated from their regular rectangular shapes. A point in i-V curve, called power point (pp) was determined where the product of current and potential was maximum and the fill-factor was calculated using the following formula:

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

Where V_{pp} and i_{pp} represent the value of potential and current at power point, respectively and V_{oc}, i_{sc} represent open circuit voltage and short circuit current, respectively. The value of fill factor (η) = 0.3024 and 0.2870 were obtained and the power point of cell (pp) = 55.25μW and 44.99μW were determined on the methylene blue -D -xylose-NaLS+Tween-80 and methylene blue –D- xylose-NaLS+ CTAB system, respectively.

Cell performance and conversion efficiency: The performance of the photogalvanic cell was observed by applying an external load (necessary to have current at power point) after termination the illumination as soon as the potential reaches a constant value. The performance was determined in terms of $t_{1/2}$, (figure-4 and 5) i.e., the time required in fall of the output (power) to its half at power point in dark. It was observed that the cells can be used in dark for 100 minutes and 90 minutes. The conversion efficiency of the cells was determined as 0.5313 % and 0.4326% using the following formula:

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{A\ 10.4 mW cm^{-2}} \times 100\% \quad (2)$$

Where $V_{pp,}$ i_{pp} and A are photopotential at power point, Photocurrent at power point and electrode area respectively.

Mechasnism: On the basis of above investigations the mechanism of the photocurrent generation in the photogalvanic cell may be proposed as follows:

Illuminate Chamber

$$MB \xrightarrow{h\nu} MB^{*} \quad (3)$$

$$MB^{*} + R \longrightarrow MB^{-}\text{ (semi or leuco)} + R^{+} \quad (4)$$

At platinum electrode

$$MB^{-} \longrightarrow MB + e^{-} \quad (5)$$

Dark Chember

At counter electrode:

$$MB + e^{-} \longrightarrow MB\text{ (semi or leuco)} \quad (6)$$

$$MB^{-} + R^{+} \longrightarrow MB + R \quad (7)$$

Here MB MB^{-}, R and R^{+} are the dye (methylene blue), its leuco form, reductant (D-xylose) and its oxidized form, respectively.

Table-2

Effect of Variation of Methylene blue, D- Xylose, NaLS, CTAB and pH

Methylene blue -D-Xylose-NaLS+CTAB			
Parameters	**Photopotential (mV)**	**Photocurrent (μA)**	**Power (μW)**
[Methylene blue] ×10^{-5} M			
3.60	564.0	138.0	77.80
3.80	602.0	162.0	97.50
4.00	655.0	190.0	124.45
4.20	612.0	165.0	101.0
4.40	556.0	142.0	79.0
[D-Xylose] × 10^{-3} M			
1.96	572.0	138.0	78.94
1.98	618.0	162.0	100.12
2.00	655.0	190.0	124.45
2.02	612.0	165.0	100.95
2.04	558.0	142.0	79.24
[NaLS] × 10^{-3} M			
6.36	578.0	138.0	79.76
6.38	613.0	162.0	99.31
6.40	655.0	190.0	124.45
6.42	615.0	165.0	101.48
6.44	568.0	142.0	80.66
[CTAB] × 10^{-4} M			
6.80	578.0	138.0	78.76
7.00	613.0	162.0	98.31
7.20	655.0	190.0	124.45
7.40	615.0	165.0	101.48
7.60	568.0	142.0	80.66
pH			
13.04	557.0	138.0	76.87
13.12	608.0	162.0	98.50
13.20	655.0	190.0	124.45
13.28	613.0	165.0	101.12
13.36	552.0	148.0	78.38

Light Intensity = 10.4 mWcm^{-2} **Temp. = 303 K**

Table– 3
Effect of diffusion length

Methylene blue -D-Xylose-NaLS+Tween-80			
Diffusion length (mm)	**Maximum photocurrent i_{max} (μA)**	**Equilibrium photocurrent i_{eq} (μA)**	**Rate of initial generation of photocurrent (μA min^{-1})**
35.0	232.0	218.0	7.25
40.0	236.0	214.0	7.38
45.0	240.0	210.0	7.50
50.0	244.0	206.0	7.63
55.0	249.0	202.0	7.78

[Methylene blue] = 4.0 × 10^{-5} M, Light Intensity = 10.4 mW cm^{-2}, [D-Xylose] = 2.0 × 10^{-3}M, Temperature = 303 K, [NaLS] = 6.40 × 10^{-3} M, pH = 13.20, [Tween-80] = 6.2 × 10^{-4} M

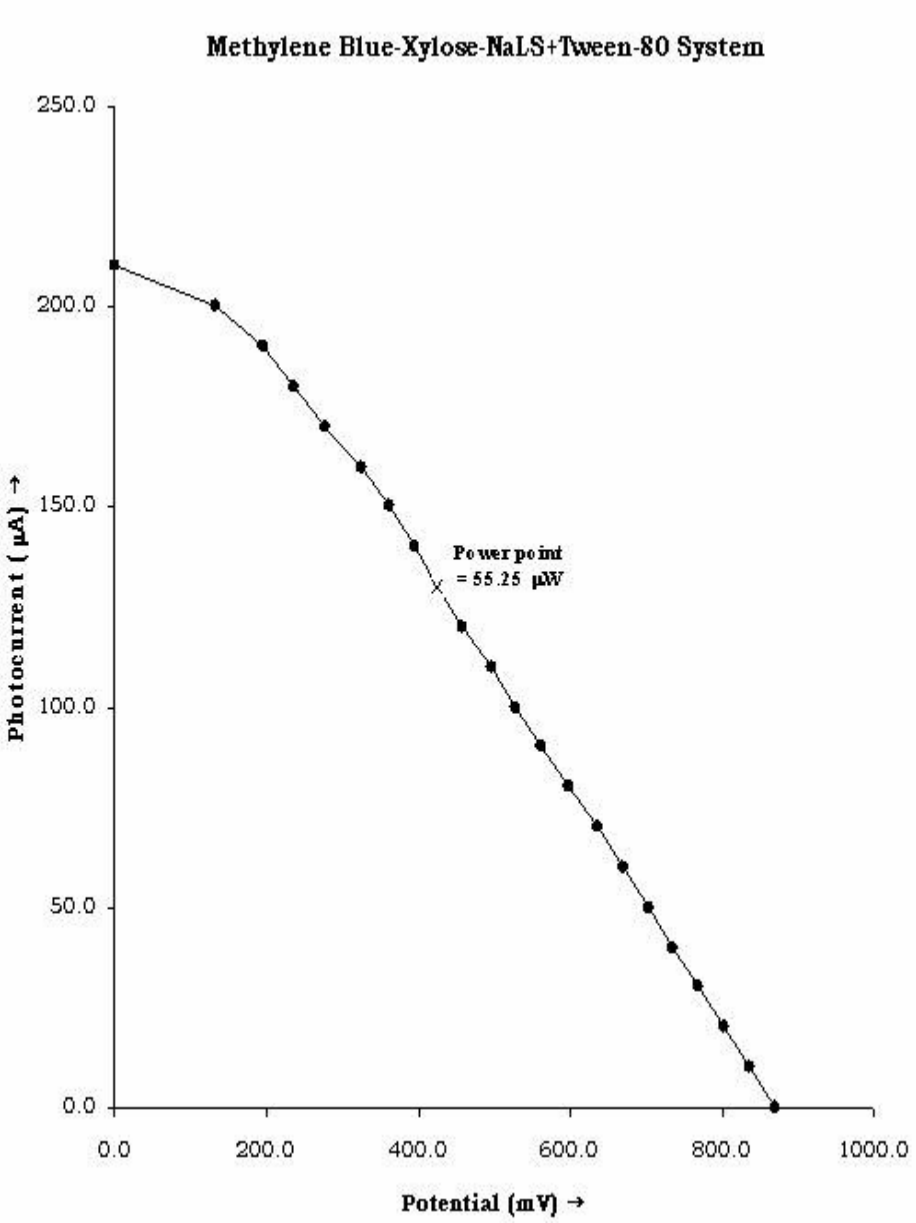

Figure-2
Current voltage (i-v) curve of the photogalvanic cell

Table–4
Effect of diffusion length

Methylene blue -D-Xylose-NaLS+ CTAB			
Diffusion length (mm)	**Maximum photocurrent i_{max} (μA)**	**Equilibrium photocurrent i_{eq} (μA)**	**Rate of initial generation of photocurrent (μA min^{-1})**
35.0	208.0	198.0	5.78
40.0	214.0	194.0	5.94
45.0	220.0	190.0	6.11
50.0	228.0	188.0	6.33
55.0	235.0	182.0	6.53

[Methylene blue] = 4.0×10^{-5} M, Light Intensity = 10.4 mW cm^{-2}, [D-Xylose] = 2.0×10^{-3}M, Temperature = 303 K, [NaLS] = 6.40×10^{-3} M, pH = 13.20, [CTAB] = 7.2×10^{-4} M

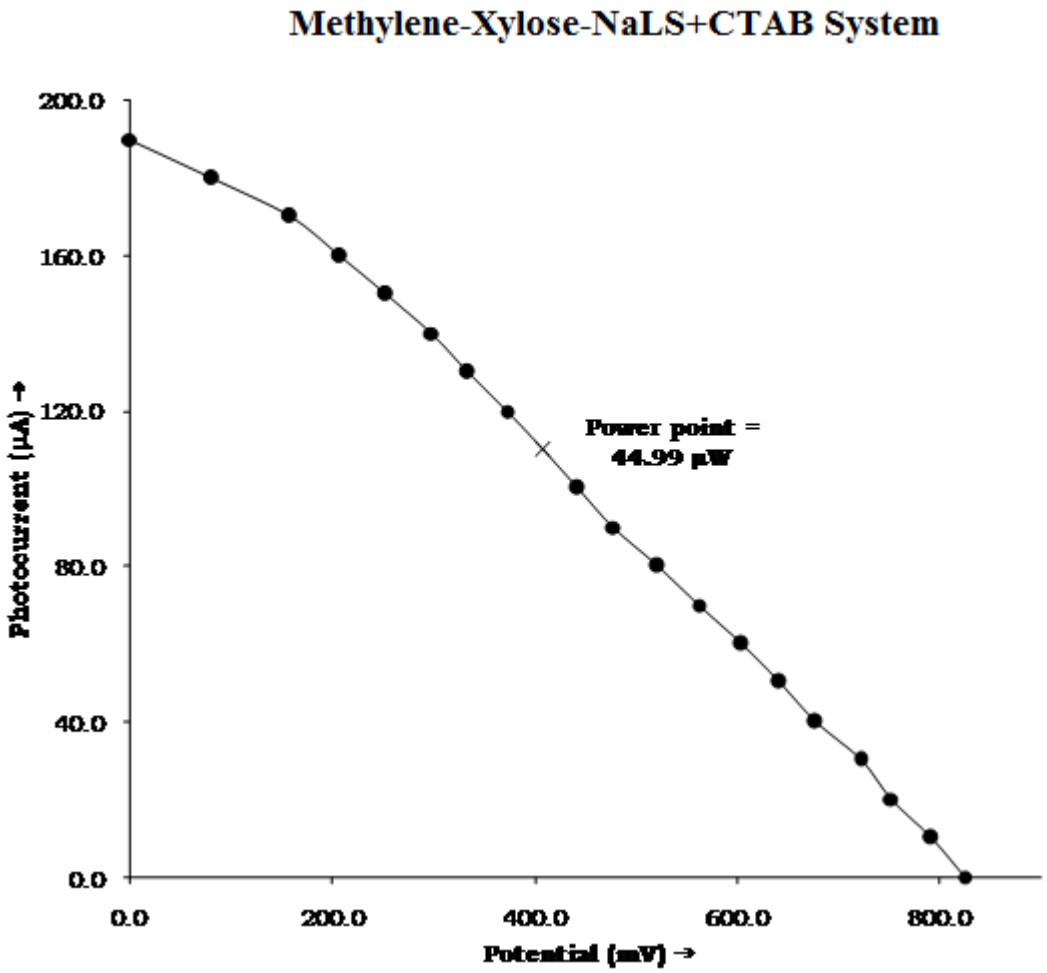

Figure-3
Current voltage (i-v) curve of the photogalvanic cell

Table- 5
Effect of electrode area

Methylene blue -D-Xylose-NaLS+Tween-80					
Electrode Area (cm^2)	0.70	0.85	1.00	1.15	1.30
Maximum photocurrent i_{max} (μA)	232.0	236.0	240.0	244.0	248.0
Equilibrium photocurrent i_{eq} (μA)	222.0	218.0	210.0	203.0	196.0

[Methylene blue] = 4.0×10^{-5} M, Light Intensity = 10.4 mW cm^{-2}, [D-Xylose] = 2.0×10^{-3}M, Temperature = 303 K, [NaLS] = 6.40×10^{-3} M, pH = 13.20, [Tween-80] = 6.2×10^{-4} M

Table- 6
Effect of electrode area

Methylene blue –D -Xylose-NaLS +CTAB					
Electrode Area (cm^2)	0.70	0.85	1.00	1.15	1.30
Maximum photocurrent i_{max} (μA)	209.0	215.0	220.0	226.0	232.0
Equilibrium photocurrent i_{eq} (μA)	197.0	194.0	190.0	187.0	183.0

[Methylene blue] = 4.0×10^{-5} M, Light Intensity = 10.4 mW cm^{-2}, [D-Xylose] = 2.0×10^{-3}M, Temperature = 303 K, [NaLS] = 6.40×10^{-3} M, pH = 13.20, [CTAB] = 7.2×10^{-4} M

Conclusion

The Methylene blue-D-Xylose-NaLS+Tween-80 system in photogalvanic cell is the most efficient with respect to conversion efficiency and storage capacity of solar energy with comparison to Methylene blue -D-xylose-NaLS+ CTAB system in the our research work. Hence, the better mixed surfactants affect the overall efficiency and we are in position to state that photogalvanic cells may be developed with mixed surfactants systems. It still requires the selection of proper combinations of surfactants and proper concentrations of the used solutions. It is suggested that we should go for as much low as possible, the low concentration of the solution and low cost substances along with their higher stability in the systems for economic viability. Conclusively the exhaustive efforts have still scope to increase the efficiency and economical viability by selecting many more comparative combinations of two different surfactants and choosing proper reductant and photosensitizer in the photogalvanic cells for solar energy conversion and storage with respect to mixed surfactant (NaLS+Tween-80, NaLS+ CTAB) systems.

Nomenclature: V_{oc} =open circuit voltage, V_{pp} =photopotential at power point, i_{eq} = photocurrent at equilibrium, i_{max} =maximum photocurrent, i_{pp} =photocurrent at power point, i_{sc} =short circuit current, $t_{1/2}$ =Performance of cell, ml =milliliter, pp =power point, mV =millivolt, M =molarity, η =fill factor, mA =microampere, mW =microwatt.

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