FABRICATION OF PHOTOGALVANIC CELL COMPOSED WITH BISMARK BROWN Y-G DIAZO DYE FOR SOLAR POWER GENERATION AND STORAGE

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Abstract:

Climate change presents a fundamental challenge to global sustainable development. Immediate action is required to set up progressive policy regimes and initiate concrete actions that will ensure huge reductions in greenhouse gas emissions. In this regard a photogalvanic cell composed with Bismark Brown Y-G, Ascorbic Acid and Sodim laurylsulphate chemicals as photosensitizer, reductant and surfactant respectively for conversion of solar energy into electrical energy. The photopotential, photocurrent, power at power point, fill factor (η), conversion efficiency and cell performance ($t_{0.5}$) at light intensity 10.4 mWcm^{-2} have been observed of the order of 846.0 mV, 860 μA, 127.28 μW, 0.1749, 1.22% and 140 minutes respectively. The best conditions for cell have also been observed for optimal cell performance.The effect of various parameters like concentration of photosensitizers, reductant and micelles, variation of pH, light intensity and diffusion path length were observed. A current–voltage (*i–V*) characteristic of the cell was studied. A tentative mechanism has been proposed for the generation of the photocurrent.

Keywords: Bismark Brown Y-G, Ascorbic acid, Sodium Lauryl Sulphate (SLS), Photogalvanic effect (PGE), fill factor (η), power point, conversion efficiency (CF).

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1. Introduction

Life on the planet earth is the manifestation of energy. The origin of fire, heat and light is energy. It is required to grow food grains which enable humans and animals to survive and work. Energy causes the great universal movement of the earth on its axis and around the sun.[1] To our Global economy energy is key driver. Its demand across various fields like domestic, institutional, commercial, and industrial fields is increasing by the day. The present time industrial world relies on the production, supply, and transport of energy, apart from using it for various end-use applications. Consumers around the globe seek an affordable secure, clean, and above all, abundantly available energy. These are the stakeholders who implement energy-related solutions through a range of supporting energy-related policies, generally associated with energy security, energy equity, and most importantly, environmental impacts. It is, thus, important to establish an all-encompassing energy industry to meet multiple and varied needs of a majority of energy consumers. Shortage of energy is a minor inconvenience to us, but for people in poorer countries it is a matter of life and death. The world energy demand is increasing due to population growth and to rising living standards.[2] Solar energy is a universal, decentralized, non-polluting, freely available green energy source and necessary for every kind of living organism. A photogalvanic cell is an important device that provides a desirable pathway for converting solar energy into electrical energy.[3] In photogalvanic cell (PG) two electrodes are used and the light is absorbed by the electrolyte i e dye solution. An electron transfer occurs between the excited dye molecules and electron donor or acceptor molecules added to the electrolyte. A photovoltage generates between two electrodes after absorbing the photon of light by the electrolyte. So the PG cells are essentially concentration cells and are based on some electrochemical reactions, which give rise to high energy products on excitation by a light of photon. This energy product loose energy electrochemically lead to generate the electricity called as a photogalvanic effect (PGE). First of all the PGE was observed in equilibrium of Ferrous ferric iodine iodide but this effect was systematically investigated in Thionine-Iron system.[5-7] Depending on the polymer-dye ratio, a red shift is observed as compared to the spectrum of free thionine. Photogalvanic potential is found to depend strongly on the polymer-dye ratio.[8] Rohatgi-Mukherji et al have reported a photovoltage 615 mV in a redox system consisting with phenosafranine and EDTA in aqueous medium and this value increases with increasing temperature attaining 870 mV.[9] PG cells using toluidine blue diethylenetriamine penta acetic acid (TB - DTPA) and Methylene blue-EDTA have been developed by Ameta et al. [10-11] Current-voltage (i-v) characteristics and performance of the cells were determined. Gangotri et al[12-13] have increased the power output as well as storage capacity up to reasonable mark by using various photosensitizers with micelles in photogalvanic cell. PGE was invented in a PG cell containing SLS, Ascorbic acid and Azur A as a surfactant, reductant and photosensitizer, respectively.[14] Genwa and Singh[15-16] have reported reasonable values of electrical output with different photosensitizers (Brilliant Blue-FCF, and Lissamine green-B) in photogalvanic cells for solar energy conversion and storage. The photogalvanic behaviour of Xylidine ponceau dye was studied in Xylidine ponceau–Tween 60–Ascorbic acid system. Cell generates maximum power of 68.77 µW in ideal conditions. Conversion efficiency was calculated by photopotential and photocurrent values at power point.[17] PG cell for enhancing the solar power generation and storage have studied with EDTA, Safranine-O and SLS chemicals. This cell showed greatly enhanced performance in terms of charging time (40 min), power (364.7 µW) and efficiency (8.93%).[18] PGE also observed by Koli[19] in spinach extract as photo-sensitizer for sun light conversion and storage. The observed cell performance (charging time 18 min, Open-circuit potential 1050 mV, Short-circuit current 1750 µA, storage capacity as half change time 44 min and efficiency ≈ 9.22%) was very encouraging to photogalvanics. The PGE in Aniline blue dye - Ascorbic acid - Sodium Lauryl Sulfate system has been observed in alkaline medium with aim of finding relatively proper combination of chemicals. The solar conversion efficiency, fill factor, cell performance, power at power point, open circuit potential and equilibrium photocurrent at 10.4 mWcm^{-2} have been observed of the order of

2.31%, 0.2445, 130 min, 240.24 ☐W, 1485 mV and 750☐A respectively.[20]

The scientific society has used different photosensitizers, surfactants, reductants in PG cells for conversion of solar energy into electrical energy but no attention has been paid to the use of dye with diazo group Bismark Brown Y-G as photosensitizer with ascorbic acid and sodium lauryl sulphate chemicals. So the system containing Bismark Brown Y-G dye as energy material to increase the electrical output and performance of the photogalvanic cell was planned. Therefore, the present work was undertaken to obtain better performance and commercial viability of the PG cell.

2. Result and Discussion

Effect of variation of dye, ascorbic acid and SLS concentration:
The effect of variation of Bismark Brown Y-G, Ascorbic acid and SLS concentration are given in table 1. Variation of dye concentration studied by using solution of different molar concentration of dye. It was observed that the photopotential, photocurrent and power enhanced with enhancing in concentration of Bismark Brown Y-G. A maximum (at 846 mV, 860 µA and 727.56 µW) was obtained for a particular value of dyes concentration (1.9 x 10^{-5} M), above which a decrease in electrical output of the cell was observed. Low electrical output observed at the minimum concentration range of dye due to limited number of dye molecules to absorb the major part of the light in the path, while higher concentration of dye again resulted in a decrease in electrical output because intensity of light reaching the molecule near the electrode decrease due to absorption of the major portion of the light by the dye molecules present in the path. Therefore corresponding fall in the electric output. With the increase in concentration of the reductant [ascorbic acid], the photopotential, photocurrent and power were found to increase till it reaches a maximum value at 1.7 x 10^{-3} M. On further increase in concentration of ascorbic acid, 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 the molecules available for electron donation to the

cationic form of dye. On the other hand, the movement of dye molecules hindered by the higher concentration of the reductant to reach the electrode in the desired time limit and it will also result in to a decrease in electrical output. The electrical output of the cell was increased on increasing the concentration of surfactant (SLS). A maximum result was obtained at a certain value (2.5 x 10^{-3}M) of concentration of SLS. On further increasing the surfactant concentration it react as a barrier and major portion of the surfactant photo bleach the less number of dye molecules so that a down fall in electrical output was observed.

Effect of variation of pH:
Photogalvanic cell containing Bismark Brown Y-G −Ascorbic acid–SLS system was found to be quite sensitive to pH of the solution. It was observed that there is an increase in the photopotential, photocurrent and power of the system with the increase in pH value (In the alkaline range). At pH 11.85 a maxima was obtained. On further increase in pH, there was a decrease in photopotential, photocurrent and power. The optimum electrical output was obtained at particular pH value. It may be due to better availability of reductants donar form at that pH value. The results showing the effect of pH are summarized in the table 2.

Effect of diffusion length:
The effect of variation of diffusion length (it is distance between the two electrodes) on the current parameters of the cell (i_{max}, i_{eq} and initial rate of generation of photocurrent) was studied using H-shaped cells of different dimensions. It was observed that in the first few minutes of illuminations there is sharp increase in the photocurrent. As consequences, the maximum photocurrent (i_{max}) increase in diffusion length because path for photochemical reaction was increased, but this is not observed experimentally. Whereas equilibrium photocurrent (i_{eq}) decreased linearly. Therefore, it may be concluded that the main electroactive species are the leuco or semi form of dye (photosensitizer) in the illuminated and dark chamber respectively. The reductant and its oxidation product act only as electron carriers in the path. The results are summarized in table 3.

The effect of electrode area on the current parameters of the cell was also studied. It was observed that with the increase in the electrode area the value of maximum photocurrent (i_{max}) is found to increase. The results are summarized in table 4.

Effect of light intensity:

The effect of light intensity was studied by using intensity meter (Solarimeter model-501). It was found that photocurrent showed a linear increasing behaviour with the increase in light intensity whereas photopotential increases in a logarithmic manner. This increase in number of photons with increase in light intensity. The effect of variation of light intensity on the photopotential and photocurrent is graphically represented in Fig. 1

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

The short circuit current (i_{sc}) 860 µA and open circuit voltage (V_{oc}) 846 mV of the photogalvanic cell were measured with the help of a microammeter (keeping the circuit closed) and with a digital pH meter (keeping the 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 multimeter, through which an external load was applied. The i-V characteristics of the photogalvanic cells containing Bismark Brown Y-G – Ascorbic acid–SLS system is graphically shown in Fig.2 and summarized in table 5. It was observed that i-V curve deviated from its regular rectangular shape. A point in the i-V curve, called power point (pp), was determined where the product of curve of current (i_{pp}) 430 µA and potential (v_{pp}) 296 mV was maximum. With the help of i-V curve, the fill-factor was calculated as 0.1749 using the formula:

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

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 $t_{1/2}$, i.e., the time required in fall of the output (power) to its half at power point in dark. It was observed that the cell containing Bismark Brown Y-G –Ascorbic acid–SLS system can be used in dark for 140.0 minutes. With the help of current and potential values at power point and the incident power of radiations, the conversion efficiency of the cell was determined as 1.22% using the formula. The results are graphically represented in time-power curve (Fig. 3).

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

Mechanism

When certain dyes are excited by the light in the presence of electron donating substance (reuctant), the dyes are rapidly changed into colorless form. The dye now acts as a powerful reducing agent and can donate electron to other substance and reconverted to its oxidized state. On the basis of earlier studies a tentative mechanism in the photogalvanic cell may be proposed as follows:

Illuminated chamber: On irradiation, dye molecules get excited.The excited dye molecules accept an electron from reductant and converted into semi or leuco form of dye, and the reductant into its excited form.

At Platinum Electrode

The semi or leuco form of dye loses an electron and converted into original dye molecule. 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. The scheme of mechanism is shown in Fig.4.

Materials and Methods

Bismark Brown Y-G (Loba Chemie PVT. LTD, Mumbai), Ascorbic acid (Qualigens fine Chemicals, Mumbai), SLS (Loba Chemie PVT. LTD, Mumbai) and NaOH (Loba Chemie PVT. LTD, Mumbai) were used in the present work. Solutions of ascorbic acid, Bismark Brown Y-G, SLS and NaOH (1N) were prepared in double distilled water (conductivity 3.5×10^{-5} Sm^{-1}) and kept in amber

coloured containers to protect them from sun light. A mixture of solutions of dyes, reductant, surfactant and NaOH was taken in an H–type glass tube which was blackened by black carbon paper to unaffected from sun radiation. A shiny platinum foil electrode (1.0 x 1.0 cm^2) was immersed in one limb of the H–tube and a saturated calomel electrode (SCE) was immersed in the other limb. Platinum electrode act as a working electrode and SCE as a counter electrode. The whole system was first placed in the dark till a stable potential was attained, then the limb containing the platinum electrode was exposed to a 200 W tungsten lamp (Philips). A water filter was used to cut off thermal radiation. Photochemical bleaching of the dye was studied potentiometrically. A digital multimeter (Haoyue DT830D Digital Multimeter) was used to measure the potential and current generated by the system respectively. The current voltage characteristics were studied by applying an external load with the help of Carbon pot (log 470 K) connected in the circuit the PG cell set-up is shown in Figure 5.

3. Conclusions

The PG cell have inbuilt storage capacity and stored energy can be used in absence of light whereas photovoltaic cell needs extra hardware as battery for energy storage, PG cells are favourable than photovoltaic cells because low cost materials are used in these cells. The conversion efficiency, storage capacity, power at power point and fill factor are recorded as 1.22%, t1/2 140.0 min, 127.28μW and 0.1749 respectively in Bismark Brown Y-G –Ascorbic acid–SLS system.

Table -1. Effect of variation of Bismark Brown Y-G, Ascorbic acid and SLS concentrations
Light Intensity = 10.4 mW cm^{-2} , Temperature = 303 K , pH = 11.85

Concentrations	Photopotential (mV)	Photocurrent (μA)	Power (μW)
Bismark Brown Y-G × 10^{-5} M			
1.5	570.0	524.0	298.68
1.7	688.0	612.0	421.056
1.9	846.0	860.0	727.56
2.1	680.0	598.0	406.64
2.3	592.0	458.0	271.36
[Ascorbic acid] x 10^{-3} M			
1.3	586.0	464.0	271.90
1.5	682.0	584.0	398.29
1.7	846.0	860.0	727.56
1.9	678.0	560.0	379.68
2.1	592.0	451.0	266.99
[SLS] x 10^{-3} M			
2.1	552.0	452.0	249.50
2.3	657.0	642.0	421.79
2.5	846.0	860.0	727.56
2.7	753.0	650.0	489.45
2.9	628.0	530.0	332.84

Table –2 Effect of Variation of Ph
Bismark Brown Y-G = 1.9 x 10^{-5} M   Light Intensity = 10.4 mW cm^{-2}
[Ascorbic acid] = 1.7 x 10^{-3} M   Temperature = 303 K
[SLS] = 1.6 x 10^{-3} M

pH	Photopotential (mV)	Photocurrent (μA)	Power (μW)

11.75	652.0	535.0	348.82
11.80	741.0	632.0	468.31
11.85	846.0	860.0	727.56
11.90	760.0	656.0	498.56
11.95	652.0	505.0	329.26

Table- 3 Effect of Diffusion Length			
Diffusion Length DL (mm)	Maximum Photocurrent i_{max} (μA)	Equilibrium Photocurrent i_{eq} (μA)	Rate of initial generation of Current (μA min^{-1})
35	882.0	866.0	23.21
40	884.0	863.0	23.26
45	888.0	860.0	23.37
50	890.0	858.0	23.42
55	894.0	856.0	23.53

Table - 4 Effect of Electrode Area		
Electrode Area (cm^2)	Maximum photocurrent i_{max} (μA)	Equilibrium photocurrent i_{eq} (μA)
0.70	882.0	865.0
0.85	885.0	863.0
1.00	888.0	860.0
1.15	890.0	858.0
1.30	893.0	855.0

Table-5 Current-Voltage (i-V) characteristics of the cell					
S.No.	Potential (mV)	Photocurrent (μA)	S.No.	Potential (mV)	Photocurrent (μA)
1.	956	0	21.	450	270
2.	946	5	22.	430	280
3.	910	10	23.	428	285
4.	890	15	24.	394	315
5.	880	20	25.	384	323
6.	851	25	26.	370	330
7.	842	30	27.	355	340
8.	758	40	28.	325	375
9.	753	50	29.	319	388
10.	737	60	30.	296	430
11.	721	75	31.	278	440
12.	671	95	32.	258	465
13.	653	105	33.	251	480
14.	631	115	34.	238	505
15.	607	125	35.	210	580
16.	576	135	36.	190	610
17.	550	155	37.	180	620
18.	526	170	38.	93	720
19.	512	180	39.	00	750

20.	500	210	**Fill factor (η) = 0.1749**

Bismark Brown Y-G -Ascorbic acid-SLS System
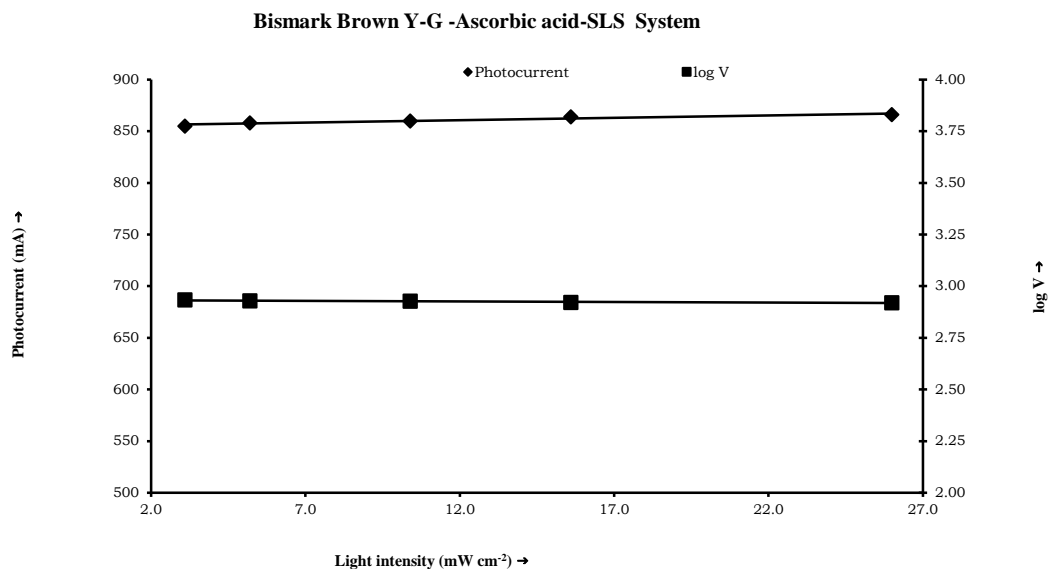
Fig. 1 VARIATION OF PHOTOCURRENT AND log V WITH LIGHT INTENSITY

Bismark Brown Y-G -Ascorbic acid-SLS system
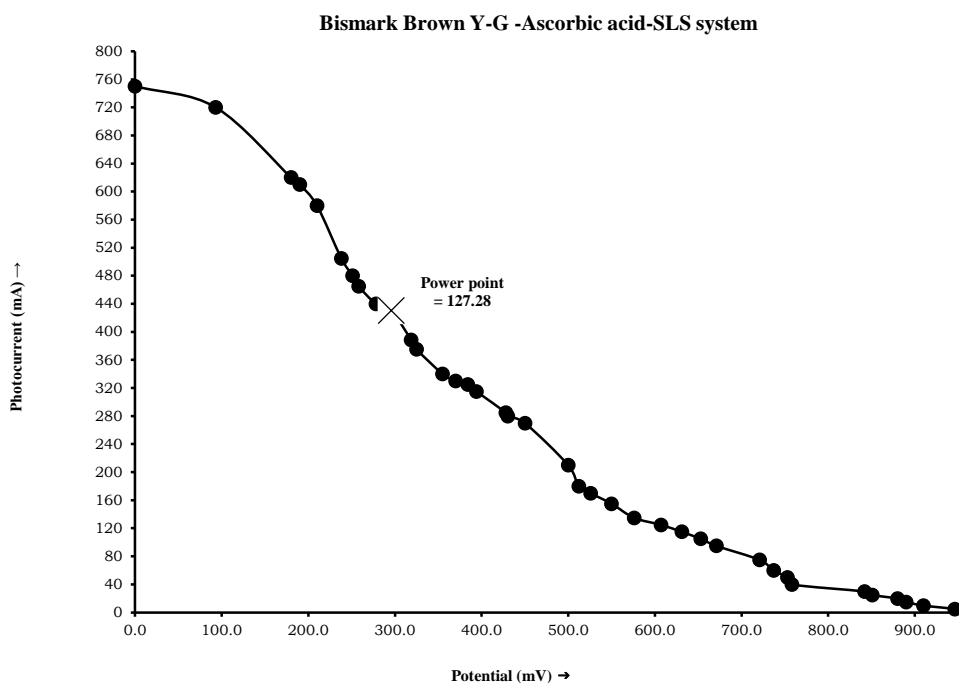
Fig. 2 CURRENT VOLTAGE (i-V) CURVE OF THE CELL

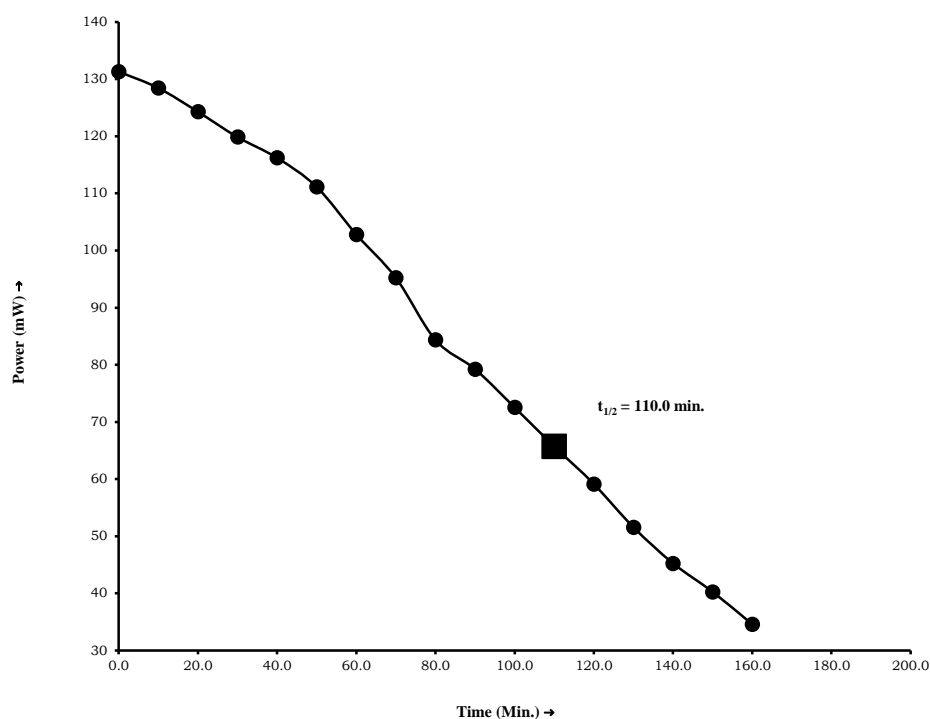**Bismark brown Y-G - Ascorbic acid - SLS System**

$t_{1/2}$ = 110.0 min.

Fig. 3 TIME-POWER CURVE OF THE CELL
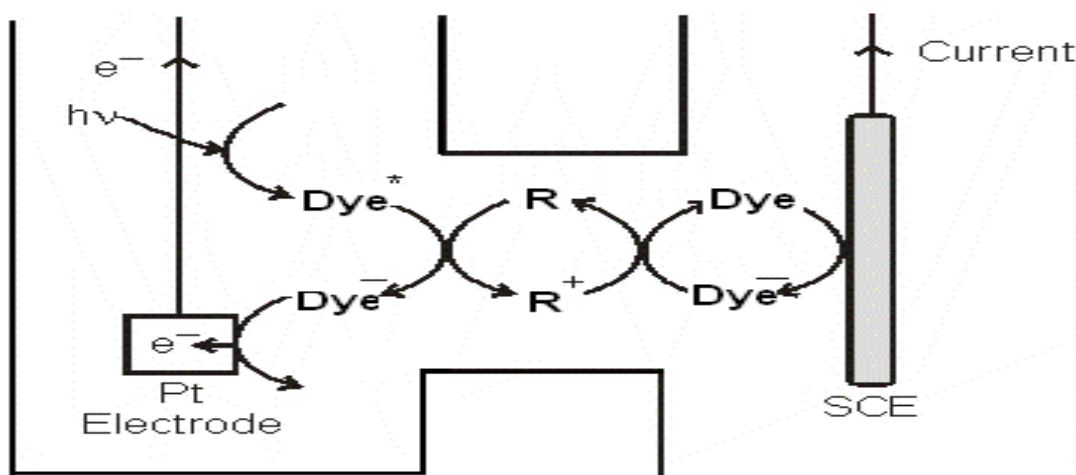
Fig. 4 Scheme of mechanism

SCE = Saturated calomel electrode   D = Dye (Photosensitizer)
R = Reductant   D = Semi & Leuco form

V = pH meter
R = Resistance
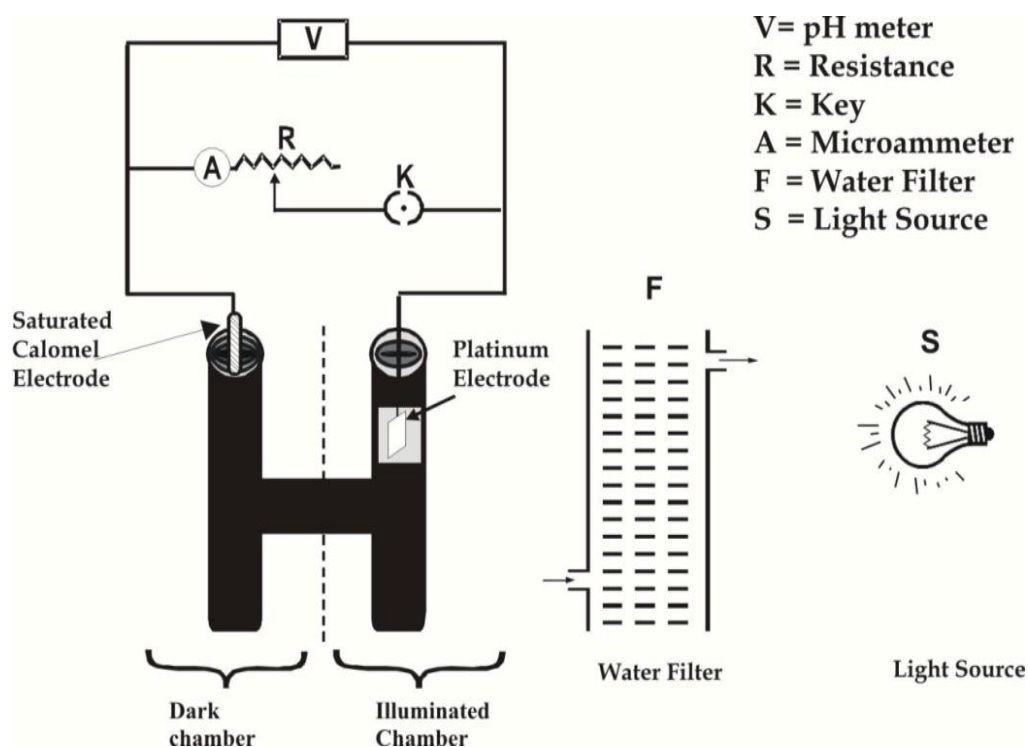K = Key
A = Microammeter
F = Water Filter
S = Light Source

Fig.5 Photogalvanic Cell Set-up

4. References

1. Kothari, D.P., Singal, K.C. and. Ranjan, R.(2011). Renewable energy sources and emerging technologies.Second edition PHI Learning private limited, New Delhi.
2. Hodgson, P.E. (2008). The Energy Crisis, Corpus Christi College Oxford, 140.
3. Bard, A.J., Memming, R. and Miller, B. (1991).Terminology in semiconductor electrochemistry and photo electrochemical energy conversion, Pure and Appl. Chem.,63, 569 .
4. Kamat, P.V., Karkhanawala, M. D. and Moorthy, P. N. (1979). Study of Ferrous-Thionine System Part II- Power Output in Homogeneous & Heterogeneous Type Photogalvanic Cells, Indian J. Chem., 18A, 210.
5. Rabinowitch, E. (1940). The Photogalvanic Effect I : The Photochemical Properties of the Thionine-Iron System, J. Chem. Phys., 8, 551.
6. Rabinowitch, E. (1940). The Photogalvanic Effect II: The Photogalvanic Properties of Thionine-Iron System, J.Chem. Phys., 8, 560.
7. Rideal, E. K. and Williams, E. G. (1925). The Action of Light on the Ferrous Iodine Iodide Equilibrium, J. Chem. Soc. Trans., 127, 258.
8. Tamilarasan, R. and Natrajan P.(1981). Photogalvanic Cell: Iron (II) - Poly (N–acrylamidomethyl thionine) System, Indian J. Chem., 20A, 213.
9. Rohatgi-Mukherji, K.K., Roy, M. and Bhowmik,B. B. (1983). Photovoltage Generation of the Phenosafranine Dye EDTA Sandwich Cell, Solar Energy, 31, 417.
10. Ameta, S. C., Ameta, R. C., Balaand, M. and Dubey, T. D. (1991). Use of toluidine blue – diethylenetriamine penta acetic acid (TB - DTPA) system in photogalvanic cell for solar energy conversion, J. Chim. Phys.,88, 191.
11. Ameta, S. C., Khamesra, S., Chittora A. K.and Gangotri, K. M. (1989). Use of sodium lauryl sulphate in a photogalvanic cell for solar energy conversion and storage: Methylene blue-EDTA system, International journal of energy research,13, 643.
12. Gangotri, K. M., Genwa, K. R., Kalla, P., Regar, O. P., Lal, C. and Meena, R. (1994). Photogalvanic Cells as a Device for Solar

Energy Conversion and Storage, Asian J. Chem. Reviews., 5, 69 .

13. Gangotri, K. M. , Regar, O. P., Lal, C., Kalla, P. and Meena, R.C. (1997). Use of micelles in photogalvanic cell for   solar   energy conversion and storage: Toludine blue-glucose-Acetyl   pyridinium   chloride   system, The   Arabian J. Sci. Engg., 22, 115.

14. Genwa, K. R. and Chouhan, A. (2006).Role of heterocyclic dye (Azur A) as a photosensitizer in photogalvanic cell   for   solar energy conversion and storage: NaLS-ascorbic acid system, Solar Energy,80 1213.

15. Genwa, K.R. and Singh, K. (2012). Development of photogalvanic cell and its application in solar energy conversion and storage Int. J. Chem., 1, 542.

16. Genwa, K. R. and Singh, K. (2013). Optimum efficiency of Photogalvanic cell for solar energy conversion:Lissamine green B-ascorbic acid-SLS System, Smart Grid and Renewable Energy, 4, 306.

17. Genwa and, K. R. and Sagar, C. P. (2014). Xylidine ponceau dye based photogalvanic cell: Energy conversion for sustainable development. Eur. Chem. Bull. 3, 76.

18. Gangotri, P. and Koli, P. (2017). Study of the enhancement on photogalvanics: Solar energy conversion and   storage in EDTA-safranine –O-NaLS system. Sustainable Energy Fuels, 1, 882.

19. Koli, P. (2018). Photogalvanic effect of natural photosensitizer (crude Spinach extract) in artificial light for simultaneous solar power generation and storage. Environ. Prog. Sustainable Energy, 37, 1800.

20. Rathore, J, Pareek, R. K. and Singh, K. (2022). Significance of Aniline blue in liquid phase dyesensitized Photo Galvanic cell for Solar powergeneration and Storage by using Ascorbic acid andSodium Lauryl Sulphate chemicals, Res. J. Chem. Environ. 26 (3) 45-53.