CURCUMIN, ARABINOSE AND BRIJ-35 CHEMICAL BASED PHOTOGALVANIC CELL FOR CONVERSION AND STORAGE OF SOLAR ENERGY INTO ELECTRICAL ENERGY

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Abstract:
Natural dye sensitized solar cells are one of the efficient third type of solar power generation cells that are generating green energy at low cost. Since no expensive equipment are required in their fabrication. In this paper review of the structure and operation principles of the Punica granatum dye sensitized solar cell is outlined. The main objective of this work is to harness and store the solar energy through natural dye-based Curcumin – Arabinose – Brij-35 photogalvanic cell. The photogalvanic cell in alkaline medium has shown hopeful and very effective improvement in solar energy conversion and storage. This combination of chemicals has shown harnessing of maximum power with a storage capacity as half change time ($t_{1/2}$) 110 minutes from the 10.4 $mWcm^{-2}$ artificial and low intense light. In this study the solar conversion efficiency, fill factor, power at power point, open circuit potential and equilibrium current has been observed in the order of 1.17%, 0.1448, 122.40 μW, 1024 mV and 825μA respectively.

Keywords: Natural Dye Sensitized solar cell, Curcumin, Arabinose, Brij-35, Photogalvanic effect, fill factor (FF), conversion efficiency (CE).

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1. Introduction

In times of fossil fuel shortage, increasing crude oil prices, as well as rejection of conventional energy sources (e.g. coal or nuclear power plants), sustainable energy forms become more and more the focus of attentions. Hydropower, wind power, geothermal power, or biomass processing are but a few of these sustainable resources. Another important source for renewable energy is solar power. Photovoltaics and solar thermal collectors are most widely used. Dye sensitized solar cells which are discussed in this application note are liquid phase cells. Manufacturing of Dye sensitized solar cells is simple, mostly low cost, and incorporate environmentally friendly materials. They have a good efficiency even under low flux of sunlight. However, a major drawback is the temperature sensitivity of the liquid electrolyte. Hence a lot of research is going on to improve the electrolyte's performance and cell stability. The world energy demand is increasing due to population growth and to rising living standards.[1]A non conventional energy source is a sustainable energy source that derives from the naturally. Alternatives to fossil fuels that are pure and limitless include renewable energy. Energy that is produced by natural processes and constantly replenished is known as renewable energy. Solar energy is universal, decentralized, non-polluting, freely available energy source and essential for every kind of living organism. Photogalvanic cell an important device that provides desirable route for conversion of solar energy into electrical energy. It is a third type of photoelectrochemical cell which is used for solar energy conversion.[2] In PG cell two inert electrodes are used and the light is absorbed by the electrolytic dye solution. An electron transfer occurs between the excited photo sensitizer dye molecules and electron donor or acceptor molecules added to the electrolyte. A photovoltage between the two electrodes is developed if the light is absorbed by the electrolytic solution. Accordingly, the PG cell is essentially a concentration cell and is based on some photochemical reaction, which gives rise to high energy products on excitation by a photon. This energy product loose energy electrochemically lead to generate the electricity called as a photogalvanic effect (PGE). First of all this effect was observed in equilibrium of ferrous ferric iodine iodide but this effect was systematically investigated in Thionine-Fe system.[3-6] Thionine has been condensed with poly (N-methylolacrylamide) to give a polymer-dye complex. Depending on the polymer-dye ratio, a longer wavelength shift (red shift) is observed as compared to the spectrum of free thionine. Potential of photogalvanic is found to depend strongly on the polymer-dye ratio. [7] The photo potential and current in PG cell containing toluidine blue and reductant, Fe (II), EDTA, triethanolamine and triethylamine have been determined. The power output with EDTA or amines as reductant were higher than Fe (II). The efficiency of the EDTA-Toluidine blue PG cell has been estimated to be about 0.0022 percent. The photoelectrochemical behaviour of toluidine blue in the presence of reductant has been examined by cyclic voltametry.[8] PG cells may play an important role in direct conversion of solar energy to electrical energy by some photochemical reactions. A number of PG systems have been fabricated with the aim of obtaining higher power output. A few among the studied PG systems with their maximum photopotential are: thionine-Fe ion aqueous system 250 mV, proflavine-EDTA aqueous system 476 mV and tolusafranine-EDTA aqueous system 844 mV. Authors have reported a photopotential 615 mV in a redox system consisting of 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 and Methylene blue-EDTA have been developed. The effects of different parameters like pH, concentration, temperature, electrode area, diffusion length etc on the electrical output of the cell were studied. Current-voltage (i-V) characteristics and performance of the cell were determined.[10-11] Gangotri K.M. et al have increased the electrical output as well as storage capacity up to reasonable mark by using various photosensitizer with micelles in photogalvanic cell.[12-13] PGE was studied in a PG cell containing ALS, ascorbic acid and Azur-A as a surfactant, reductant and photosensitizer, respectively. The effects of different parameters on the electrical output of the cell were observed. The observed conversion efficiency and storage capacity for this system were 0.5461 % and 110 minutes, respectively.[14] Genwa and Singh[15-17] have reported reasonable values of electrical output with different dyes i.e. Brilliant Blue, Lissamine green-B and Bromocresol green as photosensitizers in PG cells for solar power generation and storage. The PGE 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 photo potential and current values at power point.[18] Modified PG cell for increasing the power and storage capacity have studied in EDTA- Safranine O-ALS system. This cell showed greatly enhanced performance in terms of charging time forty minutes, equilibrium photocurrent 1700 µA, power 364.7 µW and conversion efficiency (8.93 percent).[19] The PGE observed by Gangotri and Mohan[20-21] in Trypan blue- Arabinose and Nile blue- Arabinose PG cell systems cells. PGE also observed in spinach extract as photo-sensitizer for solar energy conversion and storage. The observed cell performance (charging time 18 minutes, V_{oc} 1050 mV, I_{sc} 1750 µA, storage capacity as half change time 44 minutes and conversion efficiency ≈ 9.22 percent) was very encouraging to photogalvanics.[22] An investigation on the photogalvanic effect was carried out by Rathore and Singh[23] using a Janus green B-DSS-EDTA system. As a reductant, EDTA is employed in this process, while the azo dye Janus green B is used as photo sensitizers. Research group of Yadav et al.[24-27] have reported reasonable values of electrical output with different dyes as photosensitizer in photogalvanic cell in presence of surfactants and studied some new photogalvanic cells in view of electrical parameters and solar energy conversion and storage. 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 this system containing natural dye Curcumin, Arabinose and Brij-35 chemicals as energy material to enhance the power output and performance of the PG cell. Therefore, the present work was undertaken to obtain better performance and commercial viability of the PG cell.

2. Result and discussion

(a) Effect of variation of Curcumin, Arabinose and Brij-35 concentration:

The impact of variation Curcumin, Arabinose and Brij-35 concentration are given in table 1. The changes in dye concentration were also studied by using solution of Curcumin at different concentrations. It was observed that the photopotential, photocurrent and power increased with increasing in concentration of the Curcumin. Maximum values of electrical output were obtained for a particular value of Curcumin concentration (1.9×10^{-5}M), above which a decrease in electrical output of the PG cell was observed. Low electrical output observed at the minimum concentration range of dye due to limited number of Curcumin molecules to absorb the major part of the light in the path, while higher concentration of Curcumin again resulted in a decrease in electrical output because intensity of light reaching to those dye molecules which are near to the electrode decreases due to absorption of the major portion of the light by the Curcumin molecules present in the path. Therefore corresponding fall in the electrical output.

With increasing the concentration of the Arabinose, photopotential, current and power were found to increase till it reaches a maximum value at 1.4×10^{-3} M. These values are 846.0 mV, 825.0 µA and 697.95 µW respectively. On further increase in concentration of Arabinose, a decrease in the electrical output of the cell was observed. The fall in power output was also resulted with decrease in concentration of Arabinose due to less number of molecules available for electron donation to the Curcumin dye. On the other hand, the movement of dye molecules hindered by the higher concentration of the Arabinose to reach the electrode in the desirable time limit and it will also result into a decrease in electrical output.

The electrical output of the cell was increased on increasing the concentration of Brij-35. A maximum (846.0 mV, 825.0 µA and 697.95 µW) result was obtained at a certain value (1.7×10^{-3} M) of concentration of Brij-35. On further increasing the surfactant concentration it react as a barrier and major portion of the surfactant photobleach the less number of dye molecules so that a down fall in electrical output was observed.

Table -1. Effect of variation of Curcumin, Arabinose and Brij-35 System concentrations

Light Intensity = 10.4 mW cm^{-2} , Temperature = 303 K , pH = 11.64

Concentrations	Photopotential (mV)	Photocurrent (µA)	Power (µW)
[Curcumin]×10^{-5} M			
1.5	653.0	619.0	404.20
1.7	752.0	684.0	414.36
1.9	846.0	825.0	697.95
2.1	753.0	699.0	526.34
2.3	666.0	597.0	397.60
[Arabinose] x 10^{-3} M			
1.0	668.0	543.0	362.72

1.2	767.0	664.0	509.29
1.4	846.0	825.0	697.95
1.6	757.0	653.0	494.32
1.8	673.0	549.0	369.48
[Brij-35] x 10^{-3} M			
1.3	647.0	619.0	400.49
1.5	746.0	732.0	546.07
1.7	846.0	825.0	697.95
1.9	744.0	753.0	560.23
2.1	625.0	636.0	397.50

(b) Effect of variation of pH

PG cell containing Curcumin-Arabinose-Brij-35 System was found to be quite sensitive to pH of the solution. It was studied that there is an increase in the electrical output of the system on increases the pH. At pH 11.64 a maxima was obtained in photopotential, photocurrent and power (846.0 mV, 825.0 µA and 697.95 µW). On further pH increases, there was a decrease in electrical output. The optimum electrical output was obtained at particular pH value; it may be due to better availability of ascorbic acid in donar form at that pH value. The impact of pH is shown in figure 1.

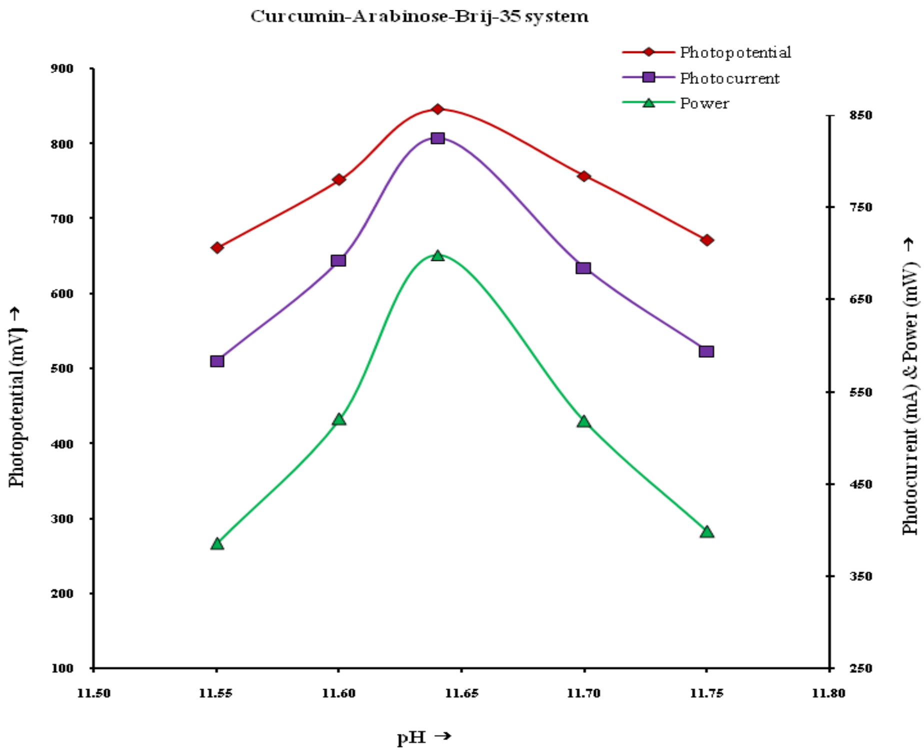


Fig. 1 VARIATION OF PHOTOPOTENTIAL, PHOTOCURRENT AND POWER WITH pH

(c) Impact of diffusion length

The impact 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 glass 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 experimently 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 ascorbic acid and its oxidation product act only as electron carriers in the path. The results are given in table 2.

Table- 2 Effect of Diffusion Length

Diffusion Length D_L (mm)	40.00	45.00	50.00	55.00	60.00
Max^m Photocurrent in µA	842.0	844.0	847.0	849.0	852.0
Equilibrium Photocurrent in µA	830.0	828.0	825.0	822.0	820.0
Initial Gen. Current Rate (µA min^{-1})	22.16	22.21	22.29	22.34	22.42

(c) Impact 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 photo potential increases in a logarithmic manner. The impact of change in light intensity on the photo potential and current is graphically represented in figure 2.

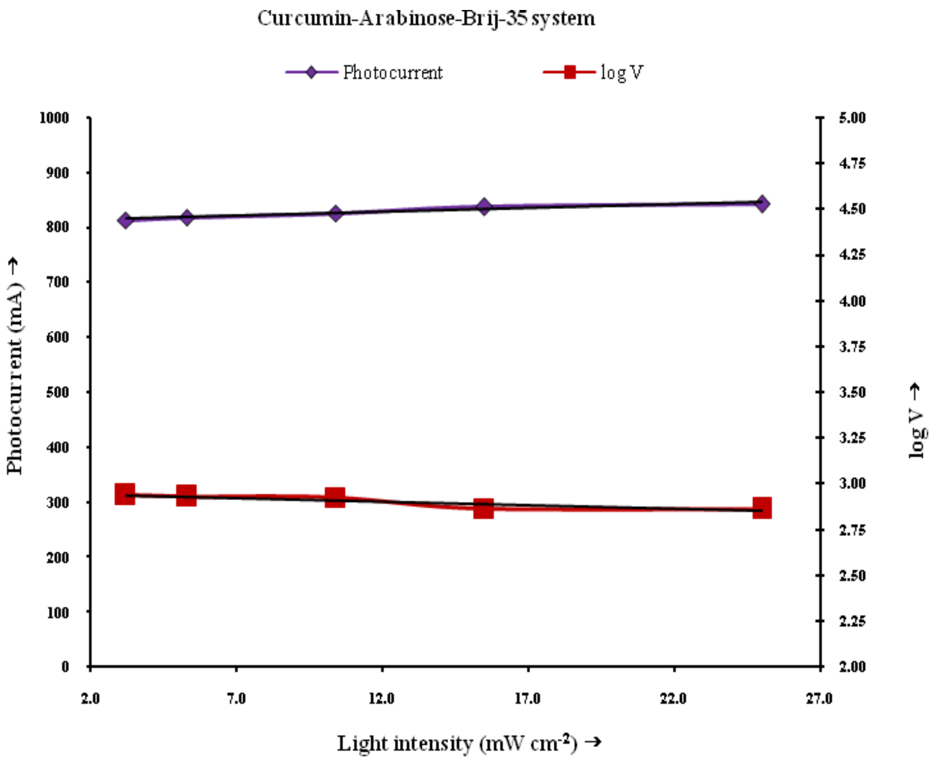


Fig. 2 VARIATION OF PHOTOCURRENT AND log V WITH LIGHT INTENSITY

(d) Current-Voltage (i-V) properties of the cell

The short circuit current (i_{sc}) 825 µA and open circuit voltage (V_{oc}) 1024 mV of the PG 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 photo 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 properties of the PG cell containing Curcumin-Arabinose-Brij-35 System is graphically shown in figure 3. It was observed that i-V curve deviated from its regular rectangular shape. A point in the i-V curve, called power at point (pp), was determined where the product of photo current (i_{pp}) 240 µA and potential (v_{pp}) 510 mV was maximum. With the help of i-V curve, the fill-factor was reported 0.1448 by using the formula:

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

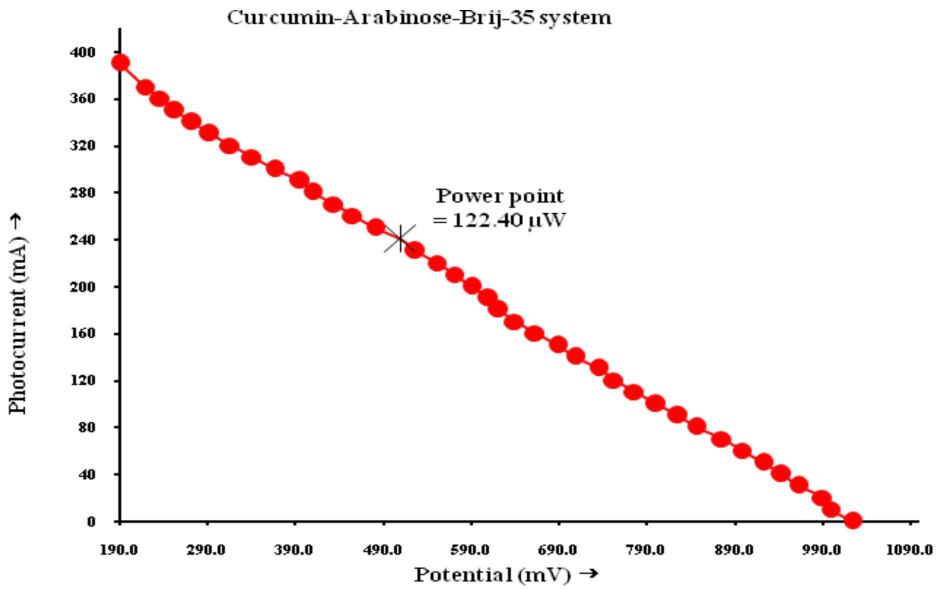


Fig. 3 CURRENT VOLTAGE (i-V) CURVE OF THE CELL

(e) Cell performance and conversion efficiency

The performance of the PG cell was observed by applying an external load (necessary to have current at power point) after terminating the light source as soon as the potential reaches at a constant value. The performance was determined in terms of $t_{1/2}$, i.e., the time required in fall of the power output to its half at power point in dark. It was observed that the cell containing Curcumin-Arabinose-Brij-35 system can be used in dark for two hours. With the help of photo current and potential values at power point and the incident power of radiations, the conversion efficiency of the cell was determined as 1.17 % using the formula.

The results are graphically represented in time-power curve (figure 4).

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

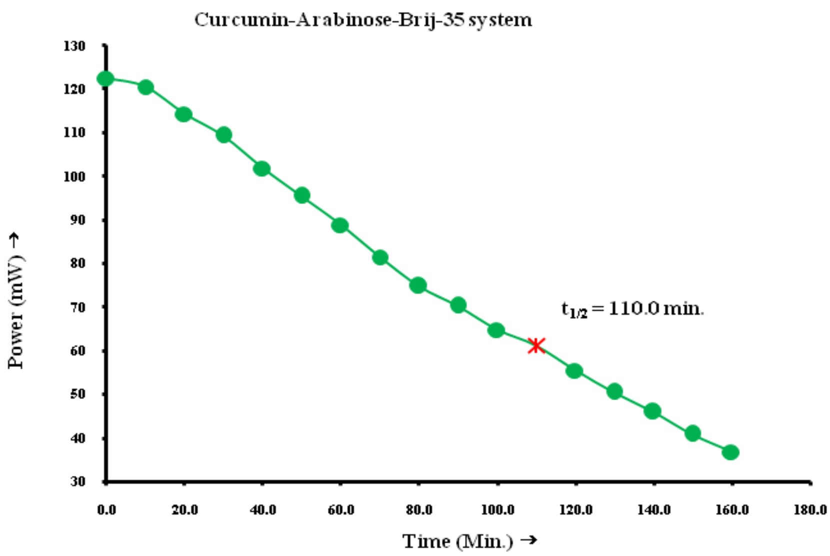


Fig. 4 TIME-POWER CURVE OF THE CELL

3. Mechanism

When the dye molecule is excited by the light in the presence of electron donating substance (ascorbic acid), the dye 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 PG cell shown in figure 5.

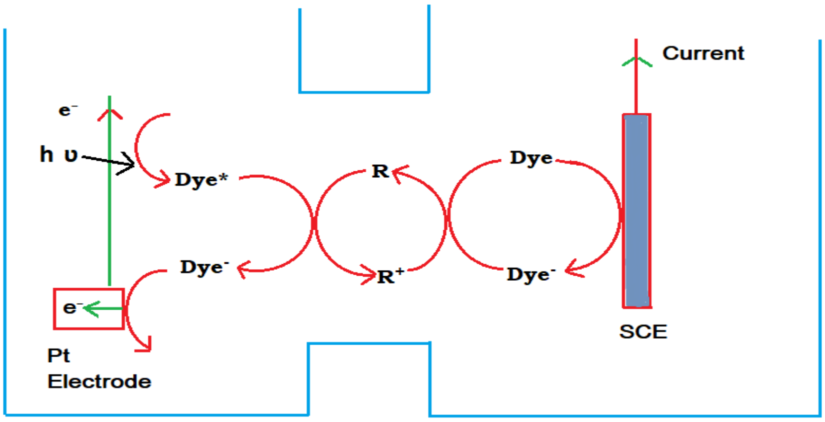
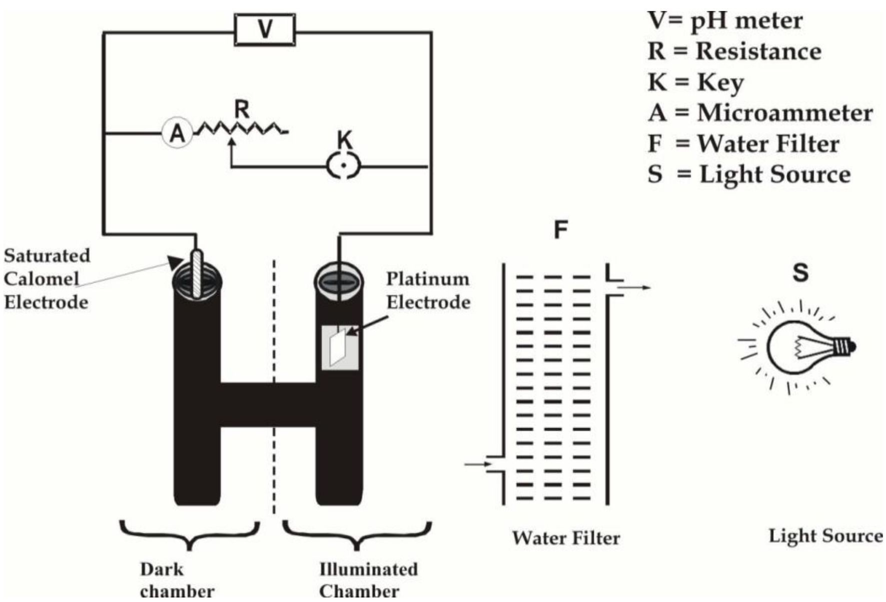


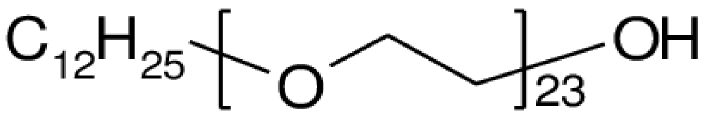
Fig. 5 Scheme of mechanism

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

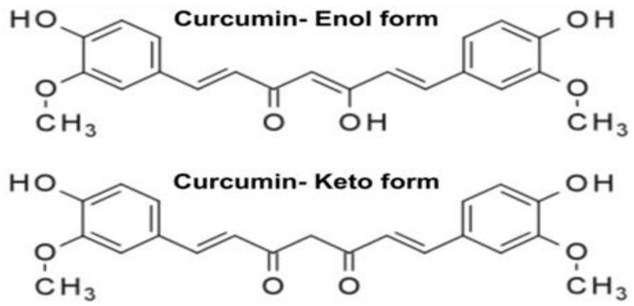
4. Materials and methods

Curcumin, Arabinose and Brij-35 and NaOH of Loba Chemie were used in the present work. Solutions of Curcumin, Arabinose, Brij-35 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 solution of Curcumin, Arabinose and Brij-35 and NaOH was taken in an H–type glass tube which was blackened by black carbon paper to protect from sun light. A shiny Pt 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. Pt-electrode acts 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 Pt-electrode was exposed to a 200 W tungsten lamp (Philips). A water filter was used to cut off thermal radiation. A digital multimeter (HAOYUE DT830D Digital Multimeter) was used to measure the photo potential and current generated by the system respectively. The i-V 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 6.

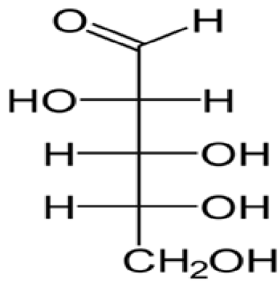




Brij-35



Curcumin



Arabinose

Fig.6 Photogalvanic Cell Set-up Structures of chemicals

5. 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 this system. The conversion efficiency, storage capacity, power at power point and fill factor are recorded as 1.17 %, 110 minutes, 122.40 µW and 0.1448 respectively in Curcumin-Arabinose-Brij-35 system.

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