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Study Of Photogalvanic Effect In Photogalvanic Cell Composed With Natural Dye Curcumin-Fructose-Brij-35 System For Solar Power Generation And Storage

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Abstract: Non-renewable energy comes from sources that will run out or will not be replenished in our lifetime or even in many lifetimes. Most of the non-renewable energy sources are fossil fuels, which influence the environment greatly and contribute to harmful global warming and climate change. Renewable energy is energy produced from sources that do not deplete or can be replenished or refilled within a human's life time. The most common examples of renewable energy sources include wind, solar, geothermal, biomass, and hydropower. Renewable energy is sustainable as it originates from sources that are inexhaustible (unlike fossil fuels). The aim of this study is to harness and store solar energy through natural dye Curcumin-Fructose-Brij-35 photogalvanic cell system. This cell based on photo-sensitizer natural dye Curcumin, surfactant Brij-35, reductant Fructose in alkaline medium has shown encouraging and very impressive improvement in solar energy conversion and storage. This combination of chemicals has shown harnessing of 120.50 μW maximum powers with a storage capacity of 100 min as half change time from the 10.4 $mWcm^{-2}$ artificial and low illumination intensity. In this study, the observed optimum cell performance in terms of the photopotential, maximum photocurrent, and short-circuit current is 918 mV, 824 μA, and 784 μA, respectively.

Keywords: Curcumin, fructose, Brij-35, maximum photocurrent, photopotential, fill factor, power point, and conversion efficiency.

1. **Introduction:** The world demand for energy is rapidly increasing and there is a need of energy to warm our homes, to cook our meals, to travel, communicate, to power our factories and other developmental processes. Today, global warming and the rapid decrease in energy resources caused by the large scale consumption of fossil fuels have become serious [1]. The conventional fuel is limited and their combustion is leading to increase in environmental pollution. In the era of energy crisis, there is an urgent need to find out alternative, non-conventional, harmless, inexhaustible source of energy, and, photogalvanic cell has these qualities. Developed and developing countries of the world are focussing on environmental damage observed due to conventional energy powers. Renewable energy sources occur in nature which is regenerative or inexhaustible like solar energy, wind energy, hydropower, geothermal, biomass, tidal and wave energy.The photogalvanic (PG) cells are photo-electrochemical systems based on the "photogalvanic effect’’. The PG cell is a device producing energy through the photochemical processes occurring inside the electrolyte solution on light absorption within a highly absorbing electrolyte and which give rise to high energy products on excitation by a photon. These energy products loose photo-energy electrochemically to generation the electricity. These cells are quite different from the other solar cells. Different kinds of dyes as light absorbing materials, organic/inorganic chemicals as reductant, and anionic/cationic/neutral surfactants as micelles have been exploited for the solar energy conversion and storage through the PG cell technology. The Nephthol blue black dye has some characteristics which make it as a good photosensitizer for use in the solar energy harvesting through the PG cells. Conversion of solar energy into Electrical energy through photogalvanic cell is the most importent and desirable route for obtaining electricity. Becquerel [2] was the first to observe the flow of current between the unsymmetrical illuminated metal electrodes in sunlight, and the photogalvanics were first reported by Rideal and Williams [3], but it was systematically investigated by Rabinowitch [4-5]. Later on Kaneko and Yamada [6], Murthy et al. [7], Rohatgi Mukherjee et al. [8], Folcher and Paris [9], Alfredo et al. [10], Dube et al. [11], Bayer et al. [12], Matsumoto et al. [13] and Shiroishi et al. [14] have studied some interesting photogalvanic systems. Bisquert et al. [15] have reviewed the physical–chemical principles of dyesensitized solar cells, whereas Mayer [16] has presented the molecular approaches to solar

energy conversion. The problems encountered in the development of photogalvanic cells have been discussed from time to time. Krasnoholovets et al. [17], Madhwani et al. [18], Gangotri and Bhimwal [19], Genwa and Chauhan [20], Genwa and Singh [21], Rathode et al. [22-23] and Yadav et al. [24-26] have recently developed some photogalvanic systems for solar energy conversion and storage. The scientific community has successfully converted solar energy in electrical energy up to desired extent through various processes but storage capacity of solar energy is still not up to the mark to use it as and when required. Many of them have used different photosensitizers, surfactants, reductants in photogalvanic cells, but no attention has been paid to the use of system containing Curcumin dye, reductant arabinose and surfactant Tween-80 as energy material to enhance the electrical output and performance of the photogalvanic cell. Therefore, the present work was undertaken to achieve better performance and commercial viability of the photogalvanic cell.

2. Result and discussion

(a) Variation of potential and photocurrent with time:

The photogalvanic cell was placed in dark till it attained a stable potential and then the platinum electrode was exposed to light. It was observed that potential changes on illumination and it reached a constant value after a certain period. When the light source was removed, the direction of change in potential was reversed and a stable potential are again obtained after sometime. Figure 1 is a graphical representation of the variation of potential in the Curcumin-Fructose-Brij-35 system with respect to time. It was observed that there was a rapid rise in photocurrent of Curcumin-Fructose-Brij-35 system on illumination and it reaches a maximum value within few minutes. This value is denoted by i_{max} (maximum photocurrent). Then the current was found to be decrease gradually with the period of illumination finally reaching a constant value at equilibrium. This value is represented as i_{eq} (equilibrium Photocurrent). The variation of photocurrent in system with respect to time is represented in figure 2.

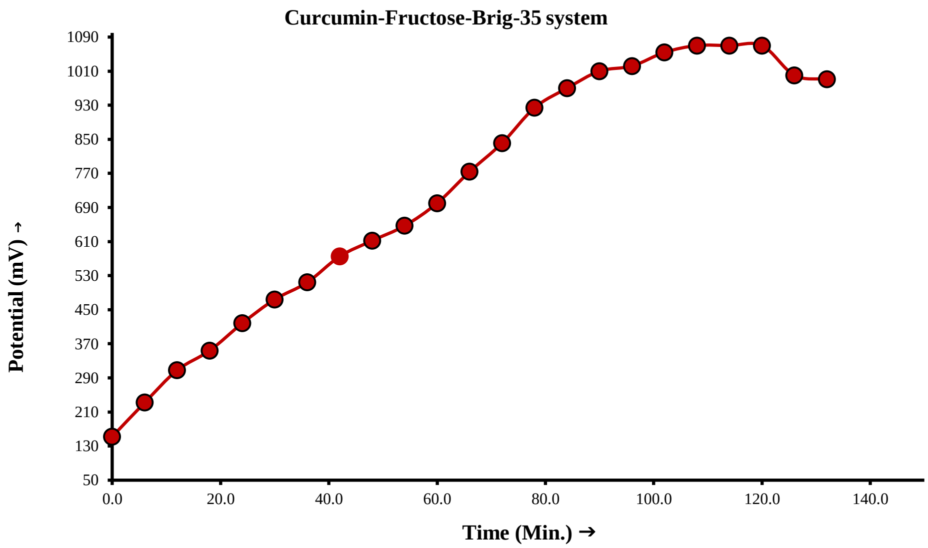


Fig. 1 VARIATION OF POTENTIAL WITH TIME

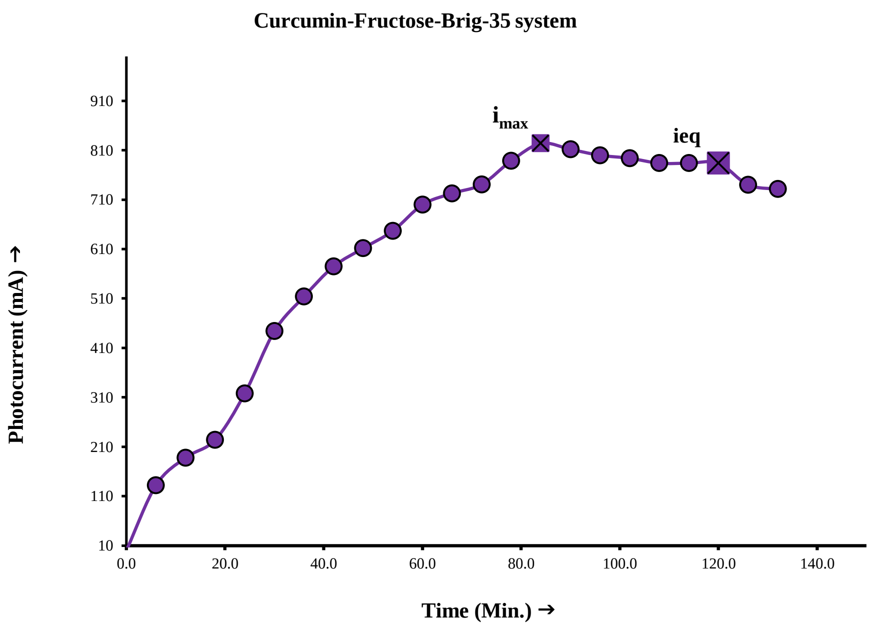


Fig. 2 VARIATION OF PHOTOCURRENT WITH TIME

(b) Effect of variation of Curcumin, Fructose and Brij-35 concentration:

The impact of variation of Curcumin, Fructose 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 dye concentration (1.8×10^{-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 fructose, photopotential, current and power were found to increase till it reaches a maximum value at 1.6×10^{-3} M. These values are 918.0 mV, 784.0 μA and 719.71 μW respectively. On further increase in concentration of fructose, a decrease in the electrical output of the cell was observed. The fall in power output was also resulted with decrease in concentration of fructose 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 fructose 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 result was obtained at a certain value (1.8×10^{-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, fructose and Brij-35 concentrations

Light Intensity = 10.4 mW cm^{-2} , Temperature = 303 K , pH = 11.84

Concentrations	**Photopotential(mV)**	**Photocurrent (μA)**	**Power (μW)**
[Curcumin]×10^{-5} M			
1.4	657.0	604.0	396.82
1.6	823.0	693.0	570.33
1.8	918.0	784.0	719.71
2.0	833.0	683.0	568.93
2.2	667.0	586.0	390.86
[Fructose] x 10^{-3} M			
1.2	754.0	574.0	432.80
1.4	857.0	693.0	593.90
1.6	918.0	784.0	719.71
1.8	844.0	684.0	577.30
2.0	763.0	587.0	447.88
[Brij-35] x 10^{-3} M			
1.5	732.0	613.0	448.72
1.6	847.0	712.0	603.06
1.8	918.0	784.0	719.71
1.9	859.0	701.0	602.16
2.0	741.0	600.0	444.60

(c) Effect 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 figure 3.

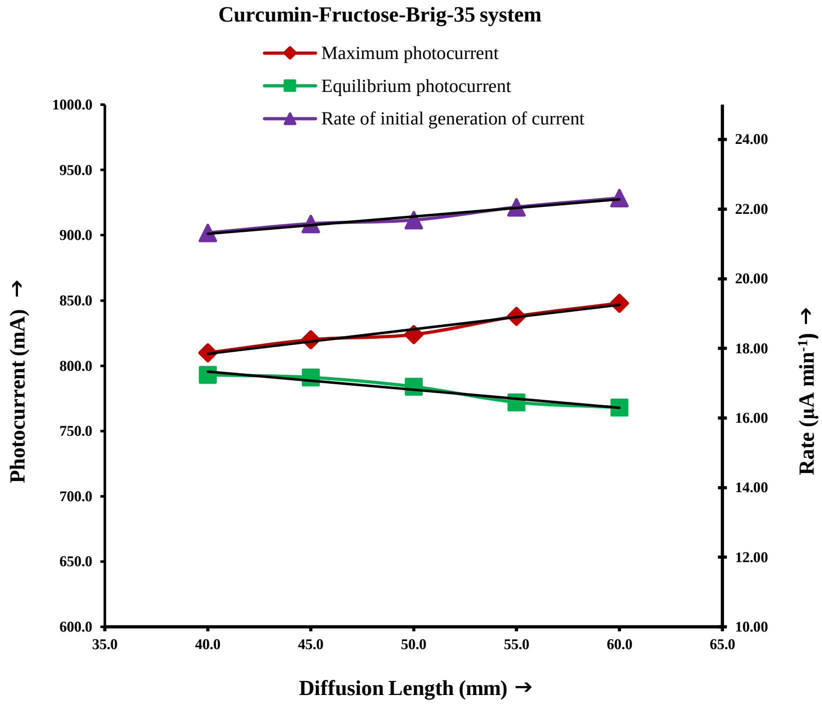


Fig. 3 VARIATION OF CURRENT PARAMETERS WITH DIFFUSION LENGTH

(d) Effect of temperature:

With an increase in the temperature, the photocurrent of the PG cell was found to increase with a corresponding rapid fall in potential. The effect of temperature on total possible power output in the Curcumin-Fructose-Brij-35 system was also studied and it was observed that with the increase in temperature (temperature range under observation) the power output of the cell increase slowly irrespective of the rapid fall in photopotential. The results are reported in table 2.

Table- 2

Variation of photopotential and photocurrent with temperature

Curcumin-Fructose-Brij-35 System	**Temperature (K)**				
	298.0	**300.0**	**303.0**	**310.0**	**315.0**
Photopotential (mV)	930.0	924.0	918.0	907.0	900.0
Photocurrent (μA)	772.0	777.0	784.0	798.0	809.0

(e) Current-Voltage (i-V) properties of the cell:

The short circuit current (i_{sc}) 784 μA and open circuit voltage (V_{oc}) 1070 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, fructose and Brij-35 chemicals are graphically shown in figure 4. 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}) 250 μA and potential (v_{pp}) 482 mV was maximum. With the help of i-V curve, the fill-factor was reported 0.1436 by using the formula:

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

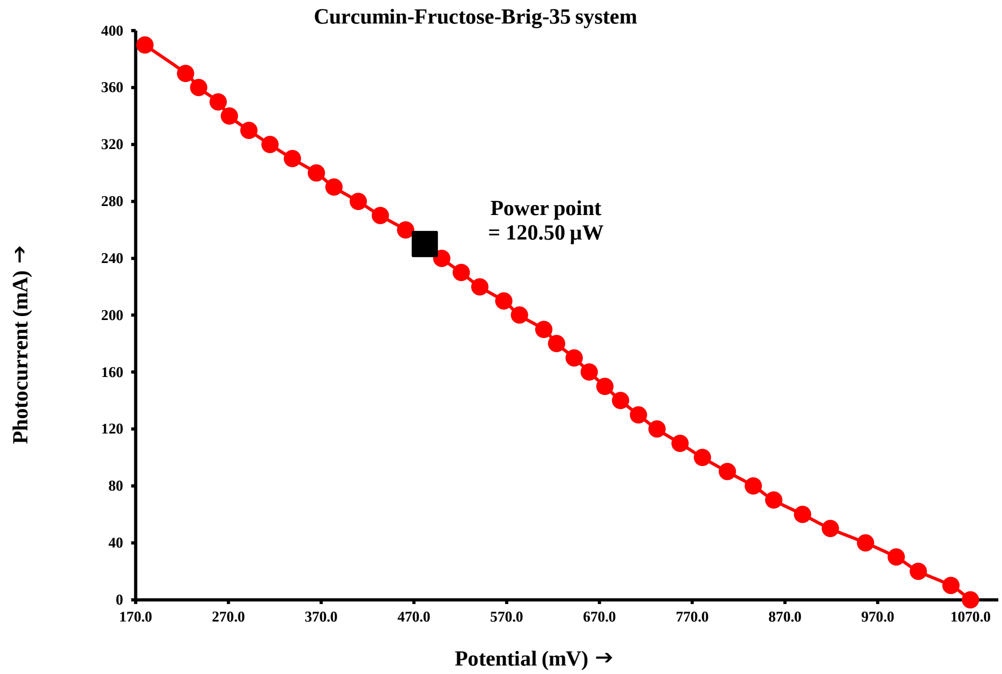


Fig. 4 CURRENT VOLTAGE (i-V) CURVE OF THE CELL

(f) 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-fructose-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 1.15 % using the formula.

The results are graphically represented in time-power curve (figure 5).

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

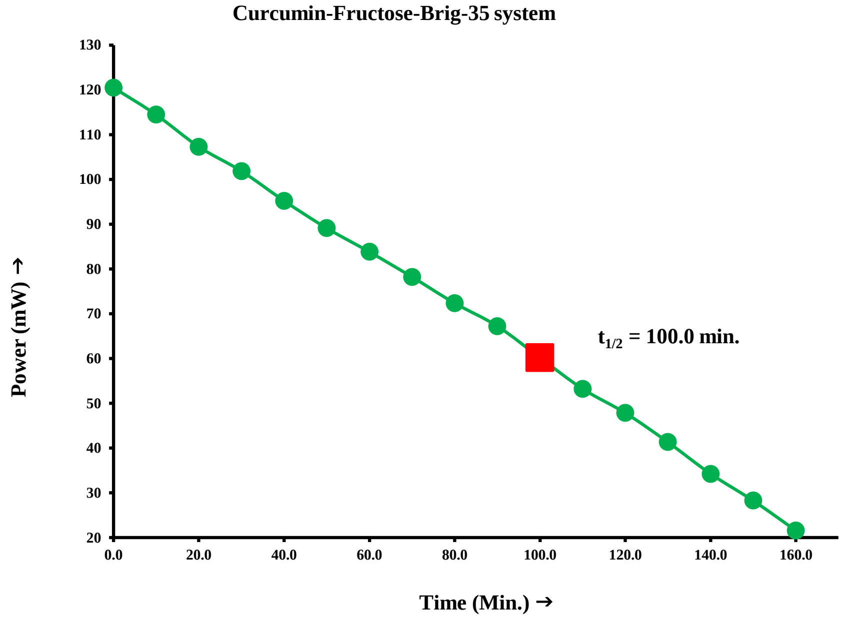


Fig. 5 TIME-POWER CURVE OF THE CELL

3. Mechanism

When the dye molecule is excited by the light in the presence of electron donating substance (fructose), 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 6.

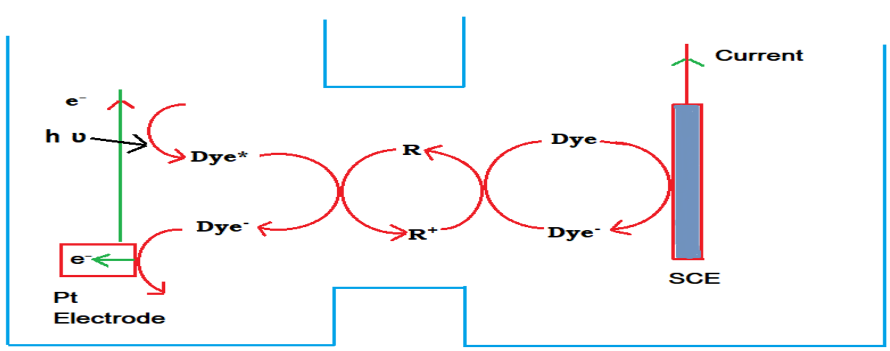


Fig. 6 Scheme of mechanism

SCE = Saturated calomel electrode D = Dye (Photosensitizer)

R = Reductant D = Semi & Leuco form

4. Materials and methods

Curcumin, fructose, Brij-35 and NaOH of Loba Chemie were used in the present work. Solutions of Curcumin, fructose, 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, fructose, 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 7.

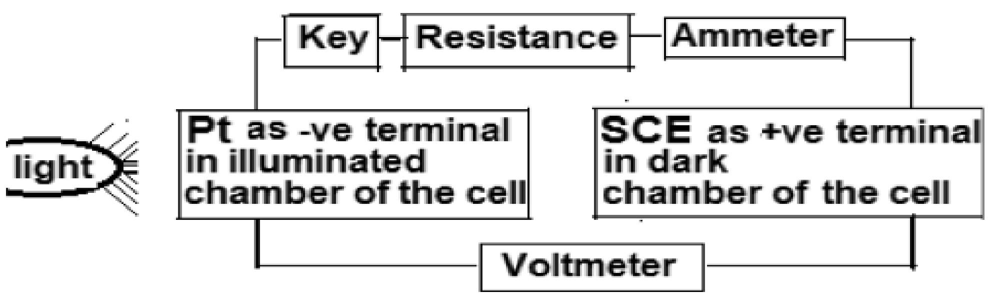
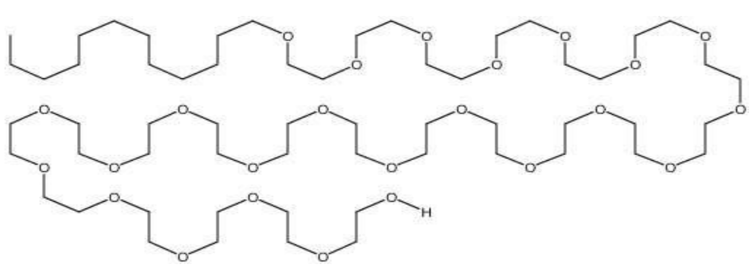
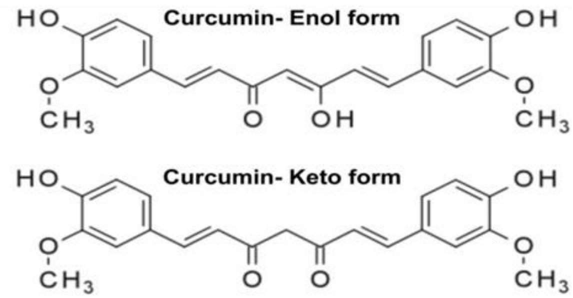


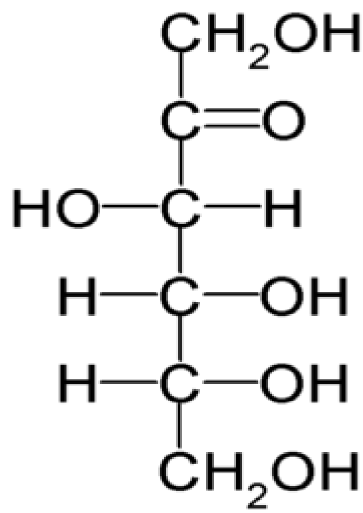
Fig.7 Photogalvanic Cell Set-up



Brij-35



Curcumin



Fructose

Structures of chemicals

5. Conclusions

The Curcumin is a water soluble dye having good photo-sensitizer property. These characteristics of the dye make it a good light absorbing candidate for the use in dye sensitized PG cells. In present study, this dye has responded favourably to the use of good reductant fructose in the presence of small Pt working electrode, combination electrode as counter electrode and Brij-35 as surfactant at very high pH to show abruptly enhanced photogalvanics (current 784 μA, power 120.50 μW). This study revalidates efficacies of the small Pt working electrode, combination electrode, surfactant, and high pH for having the increased solar power generation and storage from any dye sensitizer through the PG cells. Therefore, the Curcumin, fructose and Brij-35 chemical combination with small Pt electrode will be an option for construction of highly efficient PG solar cells.

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