ORIGINAL ARTICLE

STUDY OF ELECTRICAL PARAMETERS AND ENERGY EFFICIENCY IN PHOTOGALVANIC CELL CONTAINING LISSAMINE FAST YELLOW DYE AS A PHOTOSENSITIZER

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ABSTRACT:
Photogalvanic effect was studied in cell containing Lissamine Fast Yellow as photosensitizer in ascorbic acid- NaLS System. The conversion efficiency of the cell, fill factor and the cell performance were observed as 1.0399%, 0.2681 and 160.0 min in dark respectively. The effect of different parameters on the electrical output of the cell was observed and current- voltage (i-V) characteristics of the cell were also studied.
Keywords: Lissamine Fast Yellow, ascorbic acid, Sodium Lauryl Sulphate (NaLS), Photogalvanic effect, fill factor.

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INTRODUCTION:
It is a need of today's world to concentrate on renewable energy source to satisfy the demand and conserve our finite natural resources for the generation to come. This is a try to present an overview of the concerns about energy demand and supply ratio and how to conserve energy as well how to maximum use of renewable energy. Although there is an increasing interest in alternate energy sources such as solar, wind, Biomass etc. a major of the energy comes from fossil fuel, oil and natural gas. Today, global warming and the rapid decrease in energy resources caused by the large scale consumption of fossil fuels have become serious. Accordingly, renewable energy resources are attracting a great deal of attention, and solar energy is one of the most promising future energy resources[1].
 Conversion of solar energy into Electrical energy through photogalvanic cell is the most important 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 dye-sensitized 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] and Genwa and Singh[21] 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 this system containing dye 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.

RESULTS AND DISCUSSION
Effect of variation of Lissamine Fast Yellow, ascorbic acid and NaLS concentration:
The results showing the effect of variation of Lissamine Fast Yellow, ascorbic acid and NaLS concentration are summarized in Table 1. Variation of dye concentration studied by using solution of Lissamine Fast Yellow of different concentrations. It was observed that the photopotential and photocurrent increased with increase in concentration of the dye [Lissamine Fast Yellow]. A maximum (at 858 mV and 370μA) was obtained for a

particular value of dye concentration (2.9×10^{-5} M), above which a decrease in electrical output of the cell was observed. Low electrical output observed at the lower concentration range of dye due to limited number of dye molecules to absorb the major portion 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 and photocurrent was found to increase till it reaches a maximum value at 1.4×10^{-3} M. These values are 858 mV and 370μA respectively. 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 [NaLS]. A maximum (858 mV and 370μA) result was obtained at a certain value (1.7×10^{-3} M) of concentration of NaLS. 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 NBB, ascorbic acid and NaLS concentrations
Light Intensity = 10.4 mW cm^{-2} , Temperature = 303 K , pH = 12.58

Concentrations	Photopotential (mV)	Photocurrent (μA)
[Lissamine Fast Yellow]× 10^{-5} M		
2.2	769.0	282.0
2.5	805.0	325.0
2.9	858.0	370.0
3.2	812.0	342.0
3.5	725.0	287.0
[Ascorbic acid] x 10^{-3} M		
1.0	745.0	276.0
1.2	805.0	322.0
1.4	858.0	370.0
1.7	812.0	338.0
1.8	735.0	282.0
[NaLS] x 10^{-3} M		
1.1	741.0	297.0
1.3	797.0	330.0
1.7	858.0	370.0
1.9	770.0	331.0
2.1	710.0	294.0

Effect of variation of pH

Photogalvanic cell containing Lissamine Fast Yellow – Ascorbic acid –NaLS system was found to be quite sensitive to pH of the solution. It was observed that there is an increase in the photopotential and photocurrent of the system with the increase in pH value (In the alkaline range). At pH 12.58 a maxima was obtained (858 mV and 370μA). On further increase in pH, there was a decrease in photopotential and photocurrent. 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 (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 a concequence, 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.

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Table 2: Table showing effect of variation of pH

(Lissamine Fast Yellow] = 2.9 x 10⁻⁵ M [Ascorbic acid] = 1.4 x 10⁻³ M [NaLS] = 1.7 x 10⁻³ M	Light Intensity = 10.4 mW cm⁻² Temperature = 303 K	
pH	Photopotential (mV)	Photocurrent (µA)
12.20	717.0	275.0
12.40	780.0	333.0
12.58	858.0	370.0
12.76	762.0	317.0
12.96	710.0	280.0

Table 3: Effect of Diffusion Length and electrode area

(Lissamine Fast Yellow] = 2.9 x 10⁻⁵ M Light Intensity = 10.4 mW cm⁻²
[Ascorbic acid] = 1.4 x 10⁻³ M Temperature = 303 K
[NaLS] = 1.7 x 10⁻³ M pH = 12.58

Diffusion length D_L (mm)	Maximum photocurrent i_{max} (µA)	Equilibrium photocurrent i_{eq} (µA)	Rate of initial generation of current (µA min⁻¹)
35.0	433.0	386.0	15.46
40.0	438.0	378.0	15.64
45.0	447.0	370.0	15.96
50.0	451.0	364.0	16.11
55.0	459.0	360.0	16.39

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

Table 4: Effect of Electrode Area

(Lissamine Fast Yellow] = 2.9 x 10⁻⁵ M [Ascorbic acid] = 1.4 x 10⁻³ M [NaLS] = 1.7 x 10⁻³ M	Light Intensity = 10.4 mW cm⁻² Temperature = 303 K pH = 12.58	
Electrode Area (cm²)	Maximum photocurrent i_{max} (µA)	Equilibrium photocurrent i_{eq} (µA)
0.70	428.0	382.0
0.85	434.0	375.0
1.00	447.0	370.0
1.15	453.0	368.0
1.30	460.0	365.0

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
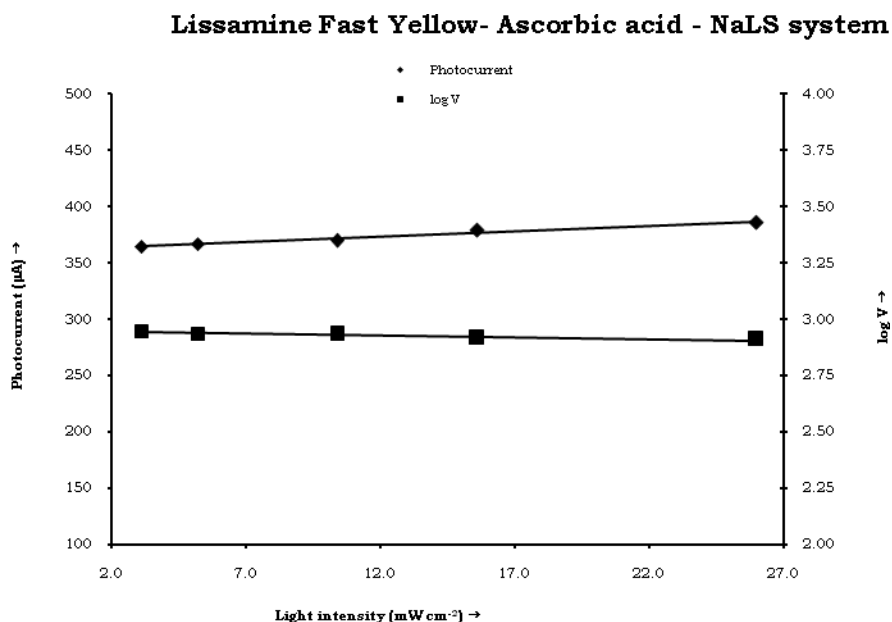
Lissamine Fast Yellow- Ascorbic acid - NaLS system

Figure 1: Variation of photocurrent and log V with light intensity

i-V Characteristics:

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

The short circuit current (i_{sc}) and open circuit voltage (V_{oc}) 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 Lissamine Fast Yellow –Ascorbic acid –NaLS system is graphically shown in Fig. 2. 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 and potential was maximum. With the help of i-V curve, the fill-factor was calculated as 0.2681 using the formula:

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

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 Lissamine Fast Yellow - Ascorbic acid - NaLS can be used in dark for 160.0 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 1.0399% using the formula. The results are graphically represented in time-power curve (Fig. 3).

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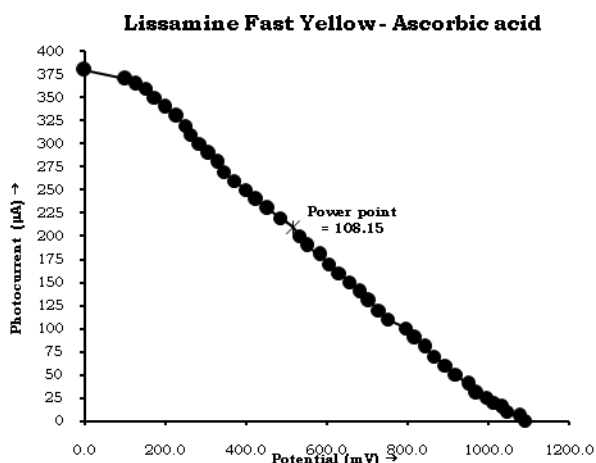
$$(2)$$

Lissamine Fast Yellow - Ascorbic acid

Figure 2.: Current voltage (I-V) curve of the cell

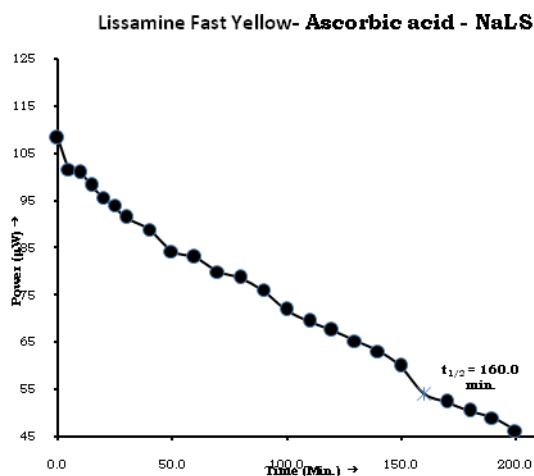**Lissamine Fast Yellow- Ascorbic acid - NaLS**

Figure 3: Time-power curve of the cell

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.

$$Dye \xrightarrow{h\upsilon} Dye^* \quad (i)$$
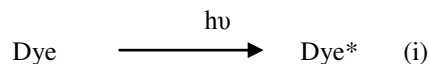
The excited dye molecules accept an electron from reductant and converted into semi or leuco form of dye, and the reductant into its excited form.

$$Dye^* + R \longrightarrow Dye^- (semi\ or\ leuco) + R^+ \quad (ii)$$

At platinum electrode:

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

$$Dye^- \longrightarrow Dye + e^- \quad (iii)$$
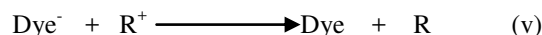
Dark Chamber:

At counter electrode:
$$Dye + e^- \longrightarrow Dye^- (Semi\ or\ leuco) \quad (iv)$$

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.

$$Dye^- + R^+ \longrightarrow Dye + R \quad (v)$$

Here Dye, Dye*, Dye⁻, R and R⁺ are the dye, its excited form, leuco form, reductant and its oxidized form, respectively. The scheme of mechanism is shown in Fig.4
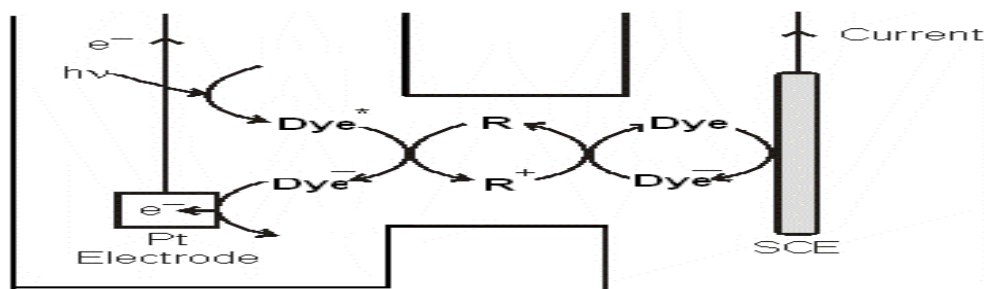

Figure 4: Scheme of mechanism

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

MATERIALS AND METHODS

Lissamine Fast Yellow (Loba Chemie, Mumbai), ascorbic acid (Ases Chemical, Jodhpur), NaLS (Sisco Research Laboratories, Mumbai) and NaOH (RFCL, New Delhi) were used in the present work. Solutions of ascorbic acid, Lissamine Fast Yellow, NaLS and NaOH (1N) were prepared in double distilled water (conductivity 3.5×10^{-5} Sm^{-1}) and kept in amber colored containers to protect them from sun light. Lissamine Fast Yellow dye (Scheme 1) is crystalline powder brown in colour, odourless, soluble in water and stable under normal temperature and pressure. Its molecular formula and molecular weight $C_{22}H_{14}N_6O_9S_2Na_2$ and 616.49 respectively.

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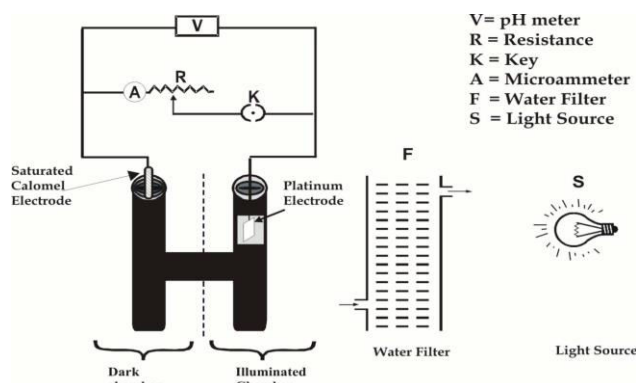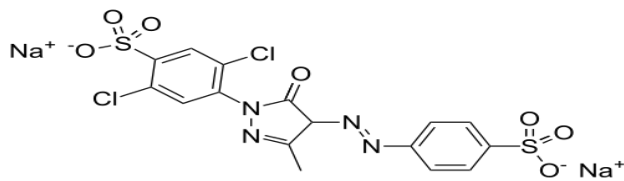F = Water Filter
S = Light Source

Figure 5: Photogalvanic Cell Set-up

Scheme 1: Lissamine Fast Yellow

A mixture of solutions of dye, 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 (1.0×1.0 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 pH meter (Systronics 335) was used to measure the potential and a microammeter (Nucon) used to measure the current generated by the system respectively. The current voltage characteristics were studied by applying an external load

with the help of a carbon pot (log 470 K) connected in the circuit the photogalvanic cell set-up is shown in Figure 5.

CONCLUSIONS:

The photogalvanic conversion of solar energy has attracted attention of scientists towards solar energy conversion and storage. This cell undergoes cyclical charging and discharging process. The charging of cell occurs only in presence of illuminating source. The discharging of cell takes place only when we apply the external circuit for electron transfer. As long as there is no external circuit, the cell will keep light energy stored. The photogalvanic cell have inbuilt storage capacity and stored energy can be used in absence of light whereas photovoltaic cells needs extra hardware as batteries for energy storage, photogalvanic cells are economic than photovoltaic cells because low cost materials are used in these cells. The conversion efficiency, storage capacity and fill factor are recorded as 1.0399%, $t_{1/2}$160.0 min and 0.2681 respectively in Lissamine Fast Yellow - Ascorbic acid – NaLS system.

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