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The optimum conversion efficiency in nile blue arabinose system by photogalvanic cell

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Abstract. The Nile blue has been used as a photosensitizer with Arabinose as a reductant in photogalvanic cell for optimum conversion efficiency and storage capacity. Reduction cost of the photogalvanic cell for commercial utility. The generated photopotential and photocurrent are 816.0 mV and 330.0 μA respectively. The maximum power of the cell is 269.30 μW where as the observed power at power point is 91.28 μW. The observed conversion efficiency is 0.6095% and the fill factor 0.2566 has been experimentally found out at the power point of the photogalvanic cell, whereas the absolute value is 1.00. The photogalvanic cell so developed can work for 120.0 minutes in dark if it is irradiated for 200.0 minutes that is the storage capacity of photogalvanic cell is 60.00%. The effects of different parameters on the electrical output of the photogalvanic cell have been observed. A mechanism has also been proposed for the photogeneration of electrical energy.

Keywords: conversion efficiency; photogalvanic cell; power point; fill factor; nile blue; arabinose

1. Introduction

The Sun is the most powerful sources of energy. Photogeneration of electricity has been attracted of the scientists as viable media for solar energy conversion with bright future prospects. The energy is the key of driving force economic developments of any country. The renewable energies are eternally available, cheap and environmental friendly sources along with high potential to provide energy with almost zero emission. Solar energy is the most abundant of the readily available renewable energy sources. So far, the high cost of conventional solar power relative to fossil fuel alternatives has impeded its wide spread use in grid-tied locations. Many approaches are being taken to reduce the cost of the solar power. Photogalvanic cells (PGC) were studied immensely in 1980s as a cheap solar energy harvesting system.

In the world without energy nothing could be happen. Energy is required for nation's growth. Energy can be obtained by two types of sources renewable and non renewable. Non renewable sources are fossil fuels, coal, crude oil etc. Renewable sources are Sun, wind and biomass etc. Non renewable sources are limited and pollutants. Becquerel (1839) first observed in the flow of current between two unsymmetrical illuminated metal electrodes in the sunlight. The

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photogalvanic cells have higher storage capacity than the photovoltaic cells but lower conversion efficiency. Many scientists are continuously working on this field and trying to achieve good value of conversion efficiency. The photogalvanic effect was first observed by Redial and Williams (1925) but it was systematically reported by Rabinowitch (1940). Later by various other workers Kaneko and Yamada (1977), Murty *et al*. (1980), Mukherjee *et al*. (1983), Ameta *et al*. (1985, 1989), Gangotri *et al*. (1996, 1997) have reported some interesting photogalvanic cell systems. Jana and Bhowmik (1999) showed that enhance the power output of solar cell consisting of mixed dyes. Pan *et al*. (1993), Balzani *et al*. (2007), Dennis *et al*. (2007), Bolton and Hall (1979), Gratzel and Kalyanasundaram (2008), Murthy and Reddy (1979), Lichtin (1976) have been also reported of photochemical conversion of solar energy and remarkable storage capacity of photogalvanic cells. Gangotri and Meena (2001) have used as Oxalic acid as a reductant and Methylene blue photosensitizer in the photogalvanic cell for solar energy conversion and storage. Gangotri and Lal (2000) have reported the enhancement in power output of solar cell containing mixed dyes. Gangotri and Regar (1998), Genwa and Khatri (2007) have been studied the photogalvanic effect of heterocyclic azine dyes. The effects of micelles in photogalvanic cell have been observed by Ameta *et al*. (1990), Gangotri and Pramila (2007), Gangotri and Gangotri (2009), Groenen *et al*. (1984) have been given in various interesting photogalvanic cell for solar energy conversion . Recently Genwa and Mehaveer (2008) have reported the remarkable amount of storage capacity of photogalvanic cell. Ameta *et al*. (1993), Genwa and Chouhan (2006) have studied the photogalvanic effect of heterocyclic dyes Azur-A as a photosensitizer in photogalvanic cell for solar energy conversion and storage. Genwa *et al*. (2009) have comparatively studied the photogalvanic effect by using Toluidine blue -Arabinose-NaLS and Malachite Green-Arabinose-NaLS system. Sustainable energy action plan of medium sized municipalities in north Greece reported by Kanstantinos *et al*. (2015) and Copper industry improvised technique developed by Sankar *et al*. (2015). The detailed survey of literature reveals that the role of Arabinose as reductant with Nile blue as photosensitizer in photogalvanic cell has not been studied so far in order to get the better results in the photogalvanic cell. The aim of investigation is enhancing the efficiency in photogalvanic cell for solar energy conversion and storage.

2. Experimental method

An H-shaped glass tube completely blackened except a window in one limb was used containing a known amount of the solutions of photosensitizer-Nile blue (Ases) with reductant-Arabinose (Loba) and sodium hydroxide (Merck) were used in the present work. The total volume of the mixture was always kept at 25.0 ml by making up with doubly distilled water. All the solutions were kept in amber colored containers to protect from sunlight. A platinum 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 of the H-tube. The terminals of the electrodes were connected to a digital pH meter (Systronics Modal-335) and the whole system was first of 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) as the light source. Employing lamps of different wattages varies the light intensity of the system. A water filter was placed between the illuminated chamber and the light source to cut off thermal infrared radiations. On illumination, The Photochemical bleaching of the Nile blue was studied potentiometrically. The photopotential and photocurrent generated by the system were measured by the help of the digital pH meter and microammeter

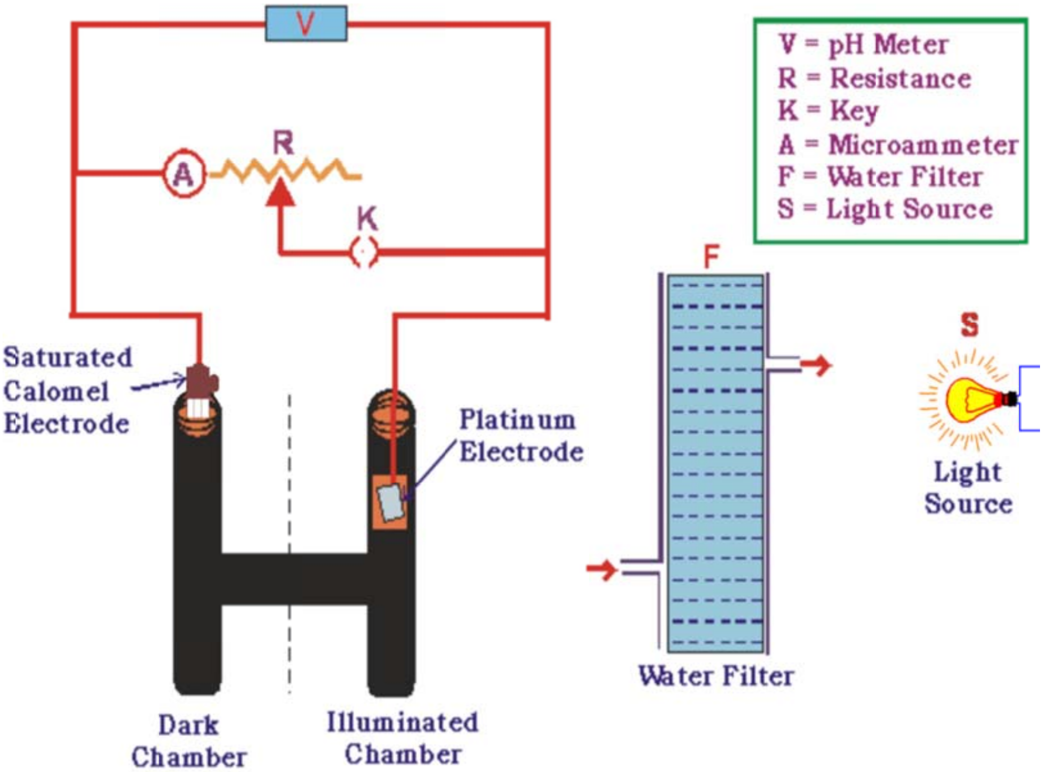
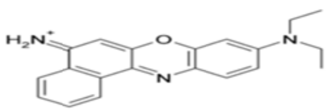


Fig. 1 Photogalvanic cell setup

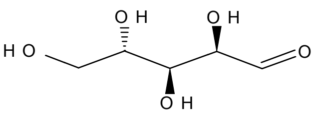
(Ruttonsha Simpson), respectively. The current-voltage characteristics of the photogalvanic cell have been studied by applying an external load with the help of a carbon pot (log470) connected in the circuit through a key to have close circuit and open circuit device. The system setup of the photogalvanic cell is given in Fig. 1.

Structure and IUPAC name of the chemical compounds used-

- **Nile Blue** (9-(Diethylamino)-5H-benzo[a]phenoxazin-5-iminium chloride)



- **L (+) Arabinose** (2R,3S,4S)-2,3,4,5-tetrahydroxypentanal)



- **Sodium hydroxide**

NaOH

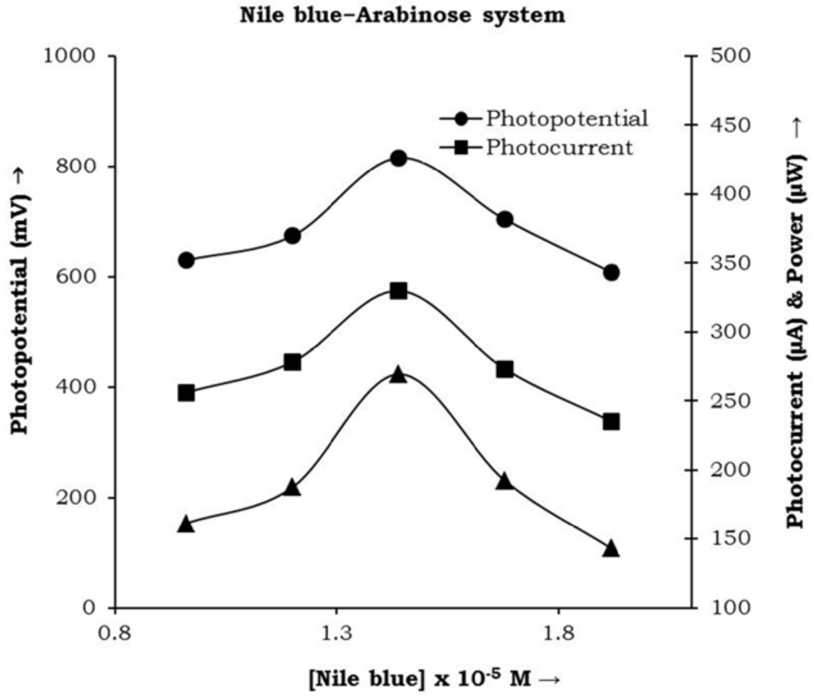


Fig. 2 Variation of photopotential, photocurrent and power with [Nile blue] concentration

3. Results and discussion

3.1 Effect of variation of photosensitizer (Nile blue) concentration on the system

The increase in concentration of the dye the photopotential and photocurrent were found to increase until it reaches a maximum. On further increase in concentration of dye decrease in electrical output of the cell was found. The effect of variation of Nile blue concentration on photopotential and photocurrent is reported in the Table-1 and graphically represented in Fig. 2. On the lower side of the concentration range of dye, there are a limited number of dye molecules to absorb the major portion of the light in the path. Therefore, there is low electrical output, whereas higher concentration of the dye does not permit the desired light intensity to reach the molecules near the electrodes and hence, there is corresponding fall in the power of the cell.

3.2 Effect of variation of reductant (Arabinose) concentration on the system

The increase in concentration of the reductant-Arabinose, the photopotential was found to increase till it reaches a maximum value. On further increase in concentration of reductant, a decrease in the electrical output of the cell was observed. The effect of variation of reductant concentration on the photopotential and photocurrent of system is given in Table 2. The fall in power output was also resulted with decrease in concentration of reductant due to less number of molecules available for electron donation to the cationic form of dye on the other hand, the movement of dye molecules may be hindered by the higher concentration of reductant to reach the

Table 1 Effect of variation of dye (Nile Blue) concentration

Nile blue-Arabinose System	[Nile blue] $\times 10^{-5}$ M				
	0.96	1.2	1.44	1.68	1.92
Photopotential (mV)	630	674	816	704	608
Photocurrent (μA)	256	278	330	273	235
Power (μW)	161.28	187.4	269.3	192.2	142.9
Conversion efficiency (%)	**0.4767**	**0.582**	**0.61**	**0.593**	**0.522**

[Arabinose] = 1.0×10^{-3} M Light Intensity = 10.4 mW cm^{-2}
Temperature = 303 K pH = 12.77

Table 2 Effect of variation of reductant [Ababinose] concentration

Nile blue-Arabinose System	[Arabinose] $\times 10^{-3}$ M				
	0.6	0.8	1	1.2	1.4
Photopotential (mV)	625	720	816	730	632
Photocurrent(μA)	232	260	330	280	255
Power(μW)	145	187.2	269.3	204.4	161.2
Conversion efficiency (%)	**0.4867**	**0.564**	**0.61**	**0.594**	**0.589**

[Nile blue] = 1.44×10^{-5} M Light Intensity = 10.4 mW cm^{-2}
Temperature = 303 K pH = 12.77

Table 3 Effect of variation of pH

Nile blue-Arabinose System	pH				
	12.64	12.71	12.77	12.83	12.88
Photopotential (mV)	610	680	816	688	618
Photocurrent (μA)	245	275	330	295	240
Power (μW)	149.45	187	269.3	203	148.3
Conversion efficiency (%)	**0.4036**	**0.594**	**0.61**	**0.539**	**0.479**

[Nile blue] = 1.44×10^{-5} M Light Intensity = 10.4 mW cm^{-2}
[Arabinose] = 1.0×10^{-3} M Temperature = 303 K

electrode in the desired time limit and it will also result in to a decrease in electrical output of the system.

3.3 Effect of variation of pH (NaOH) on the system

The electrical output of photogalvanic cell containing Nile blue-Arabinose system was found to be quite sensitive to pH of the solution. The system shows an increase in the photopotential and photocurrent of the cell with increase in pH value (in alkaline range). At pH 12.77 a maxima was achieved. On further increase in pH, there was a decrease in photopotential and photocurrent. The effect of variation of pH on photopotential and photocurrent is given in Table 3.

3.4 Effect of variation of diffusion length on the system

The effect of diffusion length (distance between the two electrodes, i.e., SCE and Platinum electrode) on the current parameters of the photogalvanic cell has been studied using H-shaped cell of different dimensions. It was observed that there was a sharp increase in photocurrent (i_{max}) in the first few minutes of illumination and then, there was a gradual decrease to a stable value of photocurrent of the system. This photocurrent at equilibrium is represented as (i_{eq}). This kind of photocurrent behavior is due to an initial rapid reaction followed by a slow rate-determined step at a later stage. On the basis of the effect of diffusion path length on the current parameters it may be concluded that the leuco or semi reduced from of dye and the dyes itself are the main electro active species at the illuminated and the dark electrode, respectively. The reducing agents and their oxidized products behave as the electron carriers in the cell diffusing through the path of the cell. The results are represented in graphically formed in Fig. 3.

3.5 Effect of light intensity on the system

The light intensity on the electrical output of the cell was studied by using light sources of different intensities (lamps of different wattages). It was found that the photocurrent varies linearly with increase in the light intensity, whereas the light intensity was measured in term of $mWcm^{-2}$ with the help of solarimeter (CEL Model SM 203). The results are graphically formed in Fig. 4.

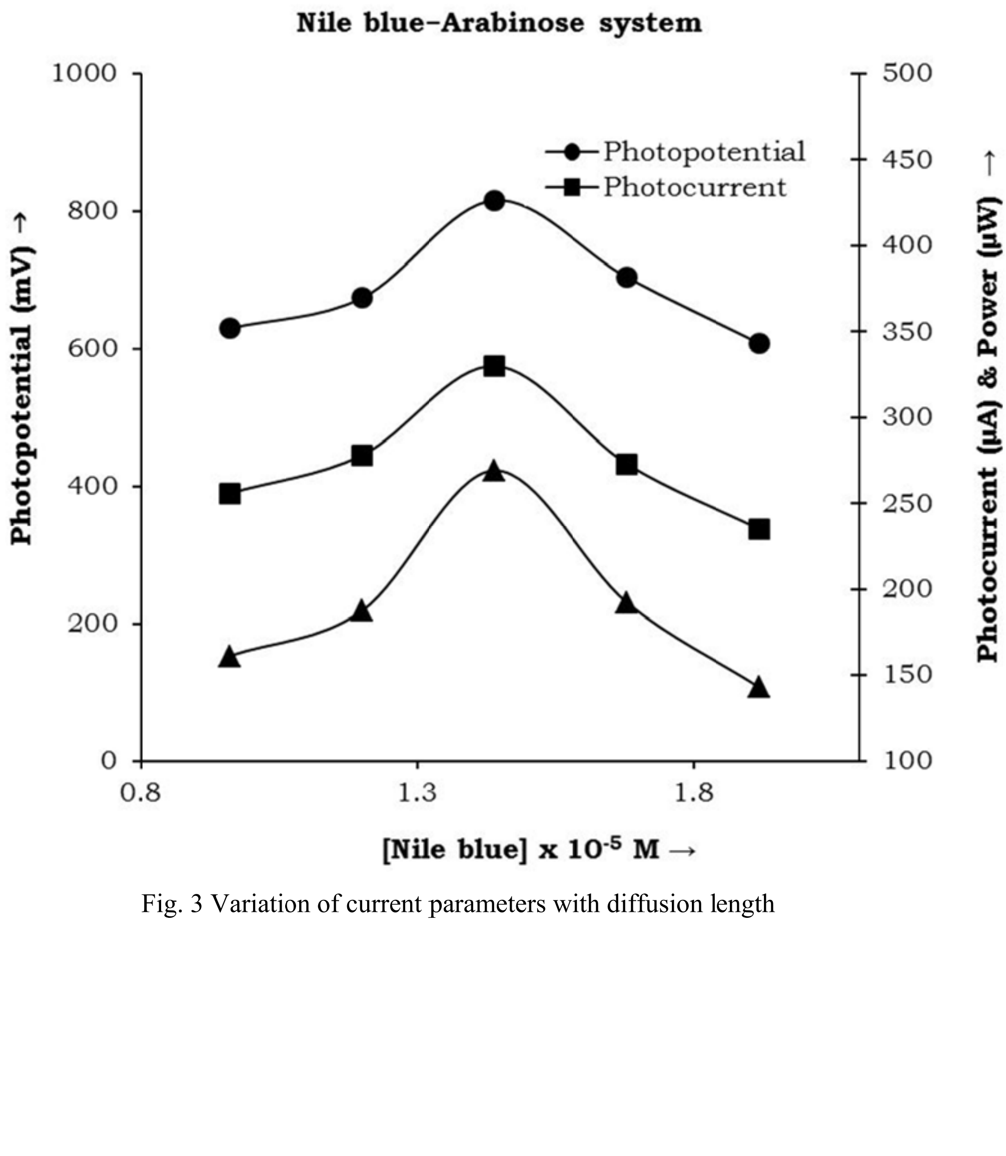


Fig. 3 Variation of current parameters with diffusion length

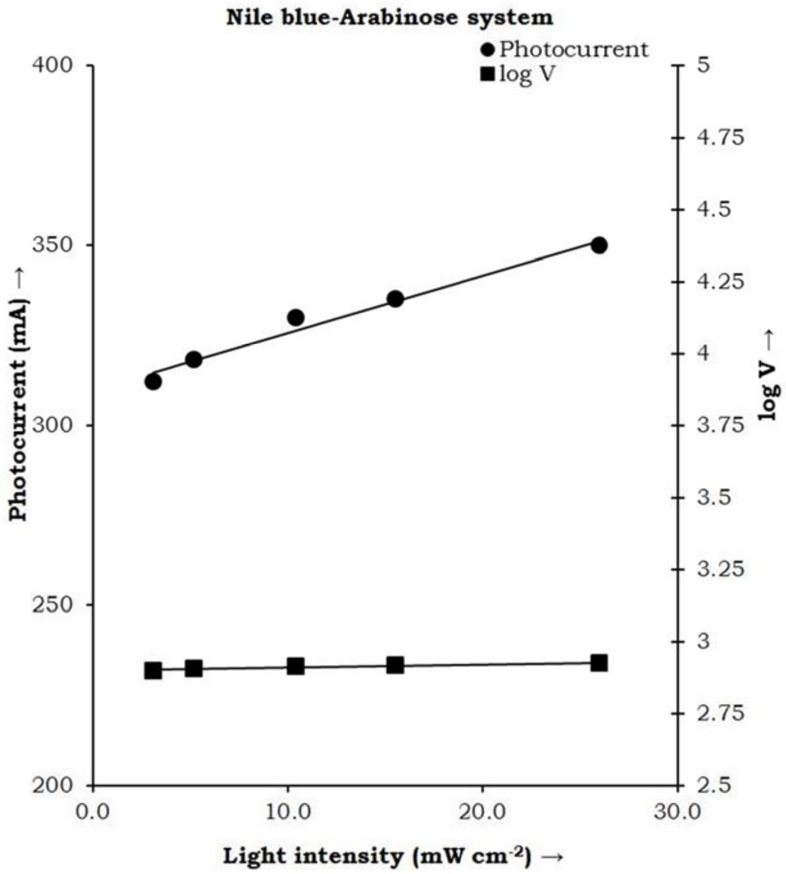


Fig. 4 Variation of photocurrent and log *v* with Light Intensity

An increase in light intensity leads to a corresponding increase in the number of photons per unit area striking the photosensitizer molecules around the platinum electrode leading to an increase in the electrical output of the cell. On the other hand, an increase in the light intensity increases the temperature of the cell and hence, a water filter was placed between the illuminated chamber and the light sources to nullify the effect of thermal radiation. The source of light was tungsten lamp used.

3.6 *The current-voltage (i-V) characteristics, storage capacity, conversion efficiency and performance of the photogalvanic cell*

The short circuit current (i_{sc}) and open circuit voltage (V_{oc}) of the 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 cell containing Nile blue-Arabinose system are graphically represented in Fig. 5. It was observed that *i-V* curve deviated from their regular rectangular shapes. A point in *i-V* curve, called power point

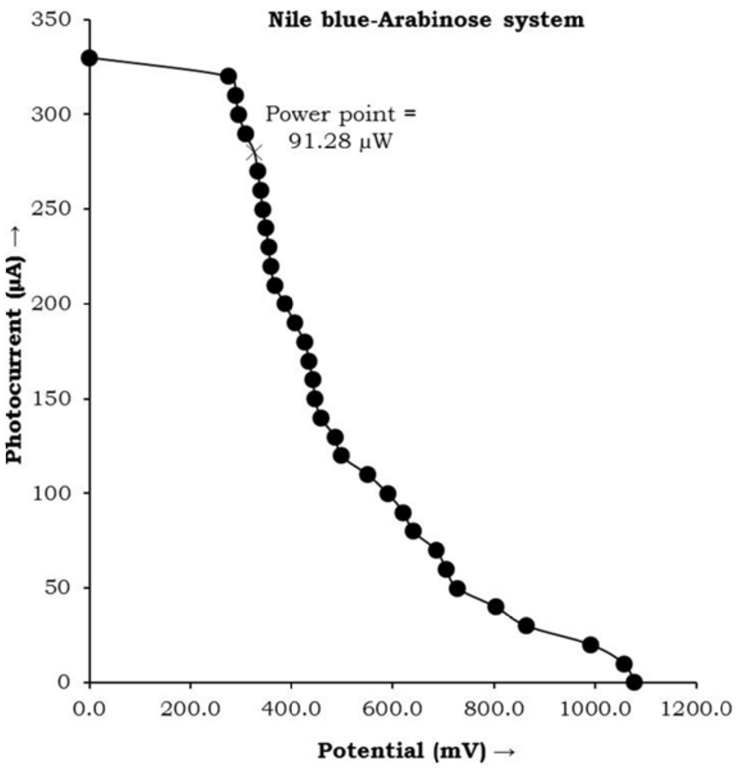


Fig. 5 Current voltage (*i*-*v*) curve of the cell

(pp) was determined where the product of current and potential was maximum and the fill factor was calculated as 0.2566 using this formula

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

V_{pp}, i_{pp} represent the values of photopotential and photocurrent at power point and V_{oc}, i_{sc} represent the values of open circuit voltage and short circuit current respectively. The value of fill factor=0.2566 was obtained and the power point of cell=91.28 μW was determined on the system. Many researcher almost Gangotri and Lal (2013, 2014) have been reported some photogalvanic cells uses of various dyes as Trypan blue, methylene blue to improvement the system. Mahmoud and Mohamed (2015) study on Rose Bengal Oxalic acid and CTAB system but not attention to Nile blue system enhancement to electricity. Meena and Gangotri (2015) have been reported to EDTA-TB-Cetyl pyridinium chloride system in photogalvanic cell but not attractive results have been found. Meena *et al.* (2015) Role of photosensitizer Orange-G in photogalvanic cell these results are poor with Trypan blue system. Ruud (2014) studies on sustainable energy system changes required to transform our global, regional and local energy systems. Saini *et al.* (2015) reported on methyl violet NaLS and EDTA system, but not attention to this photogalvanic cell system. Tanwar (2015) use of surfactant in photogalvanic cells for solar energy conversion and storage: A sodium lauryl sulphate- mannitol- methylene blue system but no more good efficiency and fill factor were achieved. In Nile blue arabinose system found a good conversion efficiency

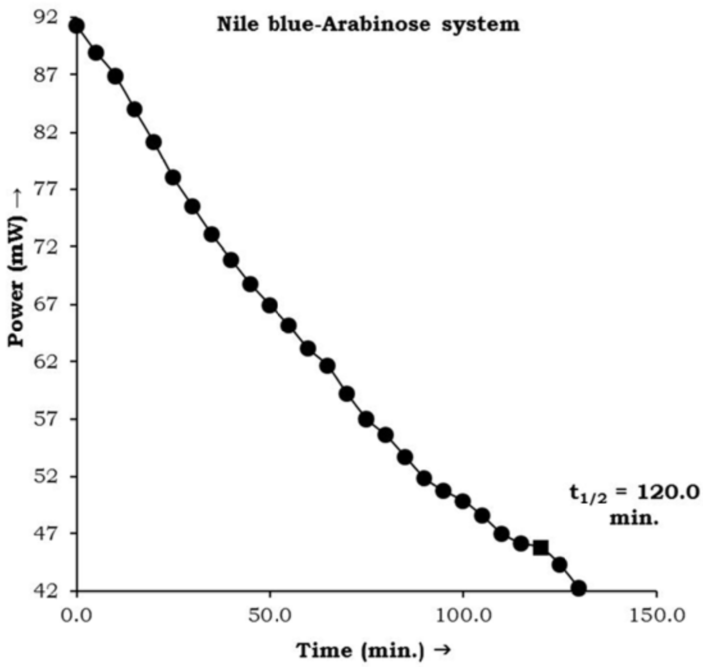


Fig. 6 Performance of the cell

and fill factor to enhancement to performance of the cell. These results are better than other previous work done. The optimum conversion efficiency of this photogalvanic cell is effective to others.

Storage capacity of the cell was observed by applying an external load after termination of the illumination as soon as the photopotential reaches a constant value. The storage capacity was determined in term of the $t_{1/2}$ that is the time required in fall of the electrical output to its half at power point in dark. It was observed that the photogalvanic cell can be used in dark for 120.0 minutes. After irradiation of 200.0 minutes, Hence, observed storage capacity is 60.00%. The results are graphically represented in Fig. 6.

The conversion efficiency of photogalvanic cell system containing Nile blue, Arabinose and sodium hydroxide were calculated using the electrical output at power point and the power of incident radiations. The conversion efficiency of the photogalvanic cell was determined as 0.6095% using this formula:

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

The system (at the optimum conditions) was also exposed to sunlight and conversion efficiency and sunlight conversion data for this system are reported.

The performance of overall photogalvanic cell was observed and reached remarkable level with respect to electrical output, initial generation of photocurrent, conversion efficiency and storage capacity of the photogalvanic cell. The results so obtained in Nile blue-Arabinose system are summarized in Table 4.

Table 4 The electrical output, conversion efficiency and storage capacity of the photogalvanic cell

S. N0.	Parameters	Observed Values
1	Maximum photocurrent (i_{max})	440.0 μA
2	Equilibrium photocurrent (i_{eq})	330.0 μA
3	Short circuit photocurrent	330.0 μA
4	Rate of initial generation of photocurrent	29.33 μA min^{-1}
5	Rate of generation of photocurrent	1.9412 μA min^{-1}
6	Maximum power of the cell at power point	269.28 μW
7	Power of the cell at power point	91.28 μW
8	Fill factor	0.2566
9	Solar conversion efficiency	4.8760%
10	Conversion efficiency	0.6095%
11	Storage capacity $t_{1/2}$	120.0 minute
12	The time of illumination (Charging time)	200.0 minute

[Nile blue] = 1.44×10^{-5} M Light Intensity = 10.4 mW cm^{-2}
[Arabinose] = 1.0×10^{-3} M Temperature = 303 K
pH = 12.77

4. Mechanism

The basis of these observations, a mechanism is suggested for the generation of photocurrent in the photogalvanic cell as:

4.1 Illuminated chamber

On illumination the photosensitizer (Dye) molecules get excited form-

$$NB \xrightarrow{h\upsilon} NB^* \quad \text{(Excited form)}$$

The excited dye molecule accepts an electron from reductant and converts into semi or leuco form of dye and the reductant into its oxidized form-

$$NB^* + R \longrightarrow NB^- \text{ (Semi or leuco)} + R^+$$

4.1.1 At platinum electrode: The semi or leuco form of dye loses an electron to electrode and converts into original dye molecule

$$NB^- \longrightarrow NB + e^-$$

4.2 Dark chamber

4.1.2 At counter electrode: dye molecule accepts an electron from electrode and converts into semi or leuco form

$$NB + e^- \longrightarrow NB^- \text{ (semi or leuco)}$$

Finally, leuco/ semi form of dye and the oxidized form of the reductant combine to give original dye and reductant molecules and the cycle continues.

$$NB^- + R^+ \longrightarrow NB + R$$

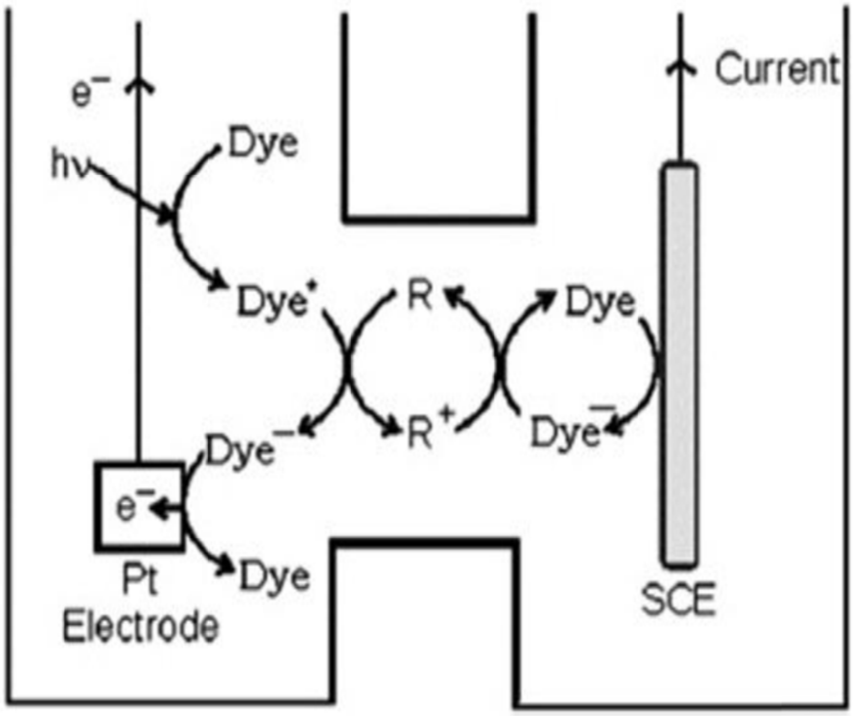


Fig. 7 Mechanism in photogalvanic cell

Where NB, NB*, NB^-,R and R^+ are the Nile blue, Nile blue excited form, semi or leuco form of Nile blue, reductant and oxidized form of the reductant, respectively. The process of mechanism in photogalvanic cell is represented in Fig. 7.

5. Conclusions

Conclusion of the selected redox couple along with the used concentrations and volumes are efficient enough to enhance the electrical output, conversion efficiency and storage capacity of the photogalvanic cell. The efforts are also successful in reducing the cost of construction of the photogalvanic cells. Though, the field of research has enough scope still to enhance the results by exhaustive efforts.

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