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RESEARCH ARTICLE

Innovative Study of the Photogalvanics for Solar Energy Conversion and Storage Through Brilliant Yellow + NaLS + Ascorbic Acid System

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Abstract

Objective: A thorough analysis of the electrical output of PG cells has not piqued the research community's curiosity. The current study reports better findings of PG cell in order to accomplish this objective of providing the globe with pollution-free nature for sustainable development. The purpose of the study is to improve the conversion of solar energy into electricity and its storage utilizing PG cells for higher electrical output. **Methods:** The PG cell set-up consists of two electrodes, a digital pH metre, a resistance key, a carbon pot, and a micro-ammeter. Investigations into the specifically designed H-shaped PG cell were done for better electrical outcomes. The various solar parameters in a PG cell with a Brilliant yellow (BY) + NaLS + Ascorbic acid (AA) system was examined. The main effects of solar energy were examined by adjusting the PG cell's various parameters. For the PG cell, distilled water, alkali, and a mixture of surfactant, reductant, and dye were combined in a 25 ml solution. The PG cell has successfully experimentally demonstrated the efficient system that was the research's desired aim in terms of better electrical outcomes from renewable energy. **Findings:** For the BY+NaLS+AA, the observed photopotential, maximum photocurrent and fill factor were 924.00 mV and 630.00 μA, 0.3422, respectively. The PG cell Performance and conversion efficacy were found to be 140.00 minutes and 2.1562%, respectively. **Novelty:** As reported results (in BY+NaLS+AA system) are mentioned that work has new value to the existing literature. The obtained results are better innovative study of the PG for solar energy conversion and storage.

Keywords: Brilliant yellow; NaLS; Ascorbic acid; Photogalvanics; Photocurrent

1 Introduction

Fossil fuels like wood, coal, kerosene, etc. are getting closer to being entirely exhausted as a result of human consumption. Therefore, creating alternative sources is required.

The most practical alternative energy source is solar energy cells. The PG cell, which works on the PG effect, has the potential for both solar energy conversion and storage [1]. These fascinating photochemical reactions are the basis of the solar energy contents, such as water photolysis and photosynthesis. Studying the mechanism of electron transfer reactions in photoelectrochemical devices, such as PG cells, DSSC, semiconductor photo-catalysis, photoconductors, etc., is greatly aided by the photochemistry of dyes. In PG cells for solar power conversion and storage, oxizines (Brilliant Cresyl Blue and Nile Blue O) and thiazines (Azur A, Azur B, Azur C, Methylene Blue, and Toluidine Blue O) dyes have been widely employed as photosensitizers with and without surfactants [2]. Genwa and Prasad (2023) reported the PG cell having better dye-based storage capacity and as a result, the system is comparatively effective in the field of solar cell. The experimental results are as follows: 733.0 mV, 477.0 μA, 1.7984%, 0.2640 and 180.0 minutes [3]. Hung and Tuan (2020) reported better results for photodegradation mechanisms. The degradation efficiency of ZnO for Janus Green B in 10 min was 96.8%, it was 95.8% in 40 min for Congo Red [4]. Koli (2021) was studied on sudan-fructose based PG cells for solar energy conversion and storage at low and artificial sun intensity. The PP, SCF, OCP, and power storage capacity (as half time) has been observed to be of the order of 367.8 μW, 11.49%, 1014 mV, and 30 min, respectively [5]. Rathore et al. (2022) described the usage of surfactant with increased PG effect of dyes sensitizer for the transformation and conservation of solar energy. The PG cell was studied using different electrical outputs via photocurrent, photopotential, conversion efficiency, fill factor and cell performance. These were 385.0 μA, 1130.0 mV, 0.7965%, 0.5357 and 120.0 minutes, respectively [6]. Rathore et al. (2022) studied tartrazine dye with various parameters on improved and simplified PG cells for solar energy harvesting. They obtained results as photocurrent, photo potential, conversion efficiency, fill factor and cell performance. These were 388.0 μA, 1141.0 mV, 0.7995%, 0.5389 and 129.0 minutes, respectively [7]. The mixed surfactants (NaLS+Brij-35) have experimentally proved the efficient system as the desired object of research with special reference to enhancing electrical output and storage of solar energy [8]. The photo potential and photocurrent were observed 684.00 mV and 230.00 μA, respectively. Several scientists have studied the photodegradation of organic compounds and concluded the ideal conditions for the photo catalytic disintegration of organic compounds [9]. The PG cells have demonstrated through experiments the efficient system as the intended objective of the research, especially with regard to improved electrical production and solar energy storage. Many surfactant-dye-reducing agents (SDR) have been used across the solar system, but none of those mentioned parties have given Brilliant Yellow (BY) any thought as an alternative way of enhancing electrical production. As a result, work on the current PG cell (BY+NaLS+AA system) began. The solar cells that have undergone the most in-depth investigation are photogalvanic (PG) cells. In addition to unsafe operations and a polluted environment, non-renewable energy sources have their own disadvantages.

2 Methodology

2.1 Solution preparations

All of the experiment's approaches, including sodium hydroxide, brilliant yellow, and ascorbic acid, were made with distilled water (DW) in order to produce results that were relevant. In each series of tests, oxalic acid was employed to standardize the solution containing sodium hydroxide. All of these solutions are kept in amber-colored bottles to shield them from radiation.

2.2 Methodology

The special designed H-shaped photogalvanic system (PGS) was studied by using resistance key, carbon pot, micro-ammeter and digital pH meter [10]. A 25 ml H tube was filled with sodium hydroxide (01 ml), surfactants (NaLS, 07 ml), reductant (AA, 05 ml), and dye (BY, 12 ml) solutions (Figure 1). In the experiment, the resistance key, micro-ammeter, 200 W electric lamp (which had a W filament), and both ends of the electrodes were connected to complete the solar circuit. The experiment's light sources and radiation protection were set up using the water filter. Photopotential, photocurrent, and power were all measured in the presence of illumination. For PG cells, the electrical findings were assessed in terms of the Vpp (575.00 mV), I_{max} (630.00 μA), I_{SC} (585.00 μA), i_{pp} (390.00 μA), and P_{pp} (224.25 μW). The uncertainty of metres (such as microammeters and pH metres) was related to the handling (errors) and calibration factors of scientific instruments. During the experiment, a very diluted solution of the dye (BY = 3.4 X 10^{-5} M), reductant (AA=2.8X10^{-3} M), and surfactant (NaLS=5.2X10^{-3} M) were used. The temperature in the system was 303 K, and the cell illumination time was 160.00 minutes during the experimental process. The experimental setup for BY+NaLS+AA system is shown in Figure 1.

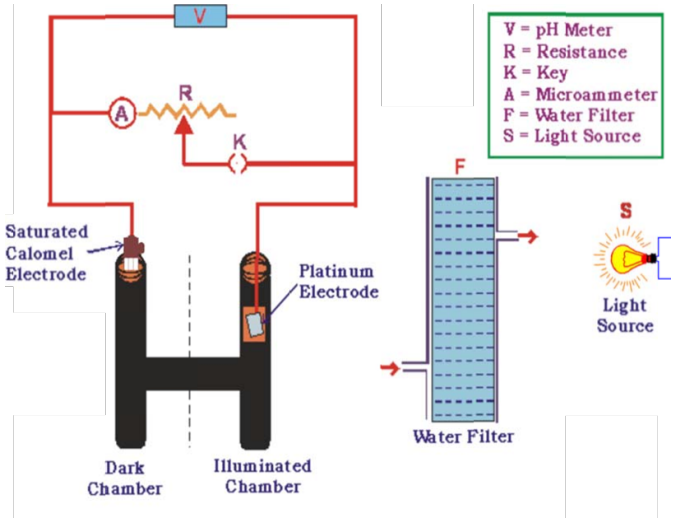

Fig 1. Methodology for PG cell

3 Results and Discussion

3.1 Variation of BY concentration

The change of dye concentration for BY+NaLS+AA has been investigated in the current study. The electrical output increases in presence of a particular surfactant, due to increase in solubilization and stabilization properties of dye molecules in the water [11]. The electrical results in the BY+NaLS+AA system increase with an increase in BY concentration, peaking at 3.4 X 10^{-5} M, and then begin to decline. Due to the hydrophobic character of dye, which results in a lower nature of BY for the absorption of light, the electrical output is comparably low (BY= 2.4 X 10^{-5} M). When BY molecules are present in higher concentrations (BY > 4.3 X 10^{-5} M), a substantial number of them crowd the surface of the absorbent. The best molecules are present when the BY concentration is in the middle (BY = 3.4 X 10^{-5} M), allowing the best light source to reach the molecule closest to the electrode and trigger photochemical reactions. For BY variation on the PG system, the Open circuit voltage (V_{oc}), photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. In Table 1 and Figures 2, 3 and 4, all outcomes that were observed are reported.

3.2 Variation of AA concentration

The change of AA concentration for BY+NaLS+AA has been investigated in the current study. The observed results rise as AA concentration increases. The comparatively lesser amounts of reductant are available for electron donation to dye to form the ionic nature whereas, at much more concentration of reductant there are a higher amounts of reductant molecules being available for photophysical change to dye to form the ionic form which hinders the dye molecules [12]. When AA concentration is increased, the electrical output also progressively rises to a maximum value at 2.8 X 10^{-3} M before falling off in the BY+NaLS+AA system. Comparatively less amounts of reductant EDTA are available for electron donation to BY to produce the ionic nature at lower concentrations of AA. The quantity of AA molecules accessible for photophysical conversion to AA to create the cationic form, which inhibits the AA molecules, is larger at much higher concentrations of ethylene dimethyl tetraacetic acid (AA > 3.20 X 10^{-3} M). The reductant concentration is an intermediate range where satisfactory results are obtained. This can be explained by the presence of the ideal number of reductant molecules, which open up advantageous paths for semi- or leuco-forms of dye BY molecules. The results showed that the deep sleep mode consumed only 10 μA of current, which is often far less than the system's current usage. For AA variation on the PG system, the V_{oc}, photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. In Table 1 and Figures 2, 3 and 4, all outcomes that were observed are provided.

3.3 Variation of NaLS concentration

The good precipitation may occur in surfactant mixture over individually precipitate of a single surfactant in PG cells for individual surfactants, the observed results in terms of the open circuit voltage, photopotential, maximum photocurrent, and short circuit current are 870.00 mV, 635.00 mV, 175 uA, and 90.0 uA, respectively [13]. The PG cell with the BY+NaLS+AA system tested the photo reactivity of NaLS with electrical power. It was found that if the concentration of NaLS was increased, the result would rise until a particular point before falling after that. For photophysical processes on the surface, the solubilization of the molecules was reduced at lower NaLS concentrations (surfactants 4.4 X 10-3 M). Higher surfactant concentrations (NaLS > 6.00 X10-3 M) may reduce the electron carrier because there are significantly more surfactant molecules available for photophysical reactions in hydrophobic contact. The considerable electrical output was recorded at a surfactant concentration of 5.2 $X10^{-3}$ M NaLS, which is an intermediate range. For NaLS variation on the PG system, the V_{oc}, photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. Table 1 and Figures 2, 3 and 4 present all of the outcomes that were observed for the system.

Table 1. Variationof BY, AA, NaLS , and pH

	Light Intensity = 10.4 $mWcm^{-2}$, Temperature = 303 K		
Parameters	**Photopotential (mV)**	**Photocurrent (μA)**	**Power (μW)**
[BY] $\times 10^{-5}$ M			
2.4	758	392	297.13
2.9	870	473	411.51
3.4	924	585	540.54
3.8	862	468	403.41
4.3	753	390	293.67
[AA] $\times$ 10^{-3} M			
2.4	741	386	286.02
2.6	862	468	402.55
2.8	924	585	540.54
3.0	856	472	404.03
3.2	738	381	281.17
[NaLS] $\times$ 10^{-3} M			
4.4	762	388	295.65
4.8	851	480	408.48
5.2	924	585	540.54
5.6	848	476	403.64
6.0	757	383	290.69
pH			
11.28	744	382	284.20
11.32	862	460	396.52
11.36	924	585	540.54
11.40	859	456	391.70
11.44	738	380	280.44

3.4 Variation of pH range

The pH of the system can be adjusted by adding the desired volume of standard NaOH solution [14]. pH of the reactive system was measured by a digital pH meter (Systronics model 335). In the current investigation, the concentration of hydrogen ions was recorded. As the basic nature (pH) increased, the current parameters were also gradually increased and reached a maximum value of a certain range (pH=11.36 at max.), after which the BY+NaLS+AA system decreased. Poor results are observed on a pH range between 11.28 and higher (pH > 11.44). In contrast, better outcomes are observed at the intermediate range (pH = 11.36). This is because dye molecules (BY) have a nature that makes them superior for photochemical processes. For pH variation on the PG system, the V_{oc}, photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV,

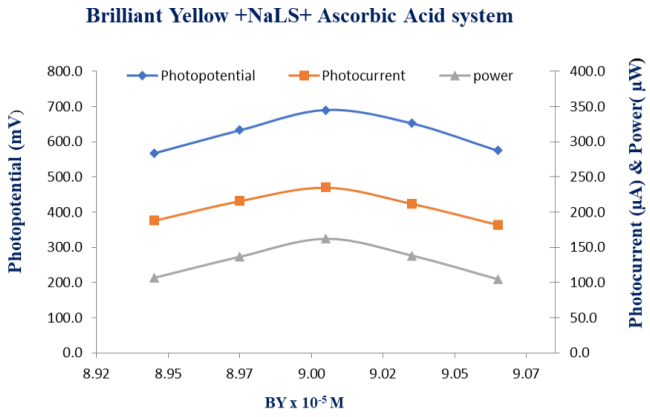

Fig 2. Variation of photopotential , photocurrent and power

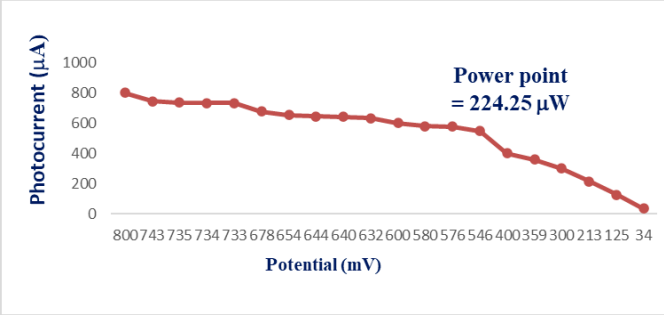

Fig 3. Current voltage (i-V) curve of cell

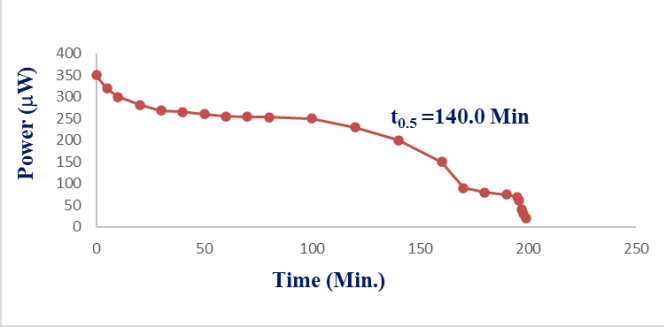

Fig 4. Performance of the PG cell

924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. The pH variation in the BY+NaLS+AA system is shown in Table 1.

3.5 Variation of diffusion length on the PG system

The cell was utilised for experiments with diffusion lengths ranging from 40 mm to 60 mm. In the BY+NaLS+AA system, the current parameters of the PG cell were studied. The rate of photocurrent's initial generation is accelerated by increasing diffusion length. At 50.00 mm, very positive results are attained, with values of maximum photocurrent (630.00 μA) and equilibrium photocurrent (585.00 μA), respectively. Ram et al. reported on electrical output about decreasing in the uniform pathway of

PG cell[15]. The photocurrent is acquired in a corresponding way because dye molecules cannot absorb the light source at lower and higher diffusion lengths (40 mm and 60 mm), respectively. For diffusion length variation on the PG system, the V_{oc}, photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively.

3.6 Variation of electrode area of the cell

The current characteristics of the PG cell were calculated using electrode areas ranging from 0.36 cm^2 to 1.96 cm^2. Genwa and Prasad reported on a sensitizer-reductant couple for enhanced simultaneous solar energy conversion and storage by photogalvanic cells at the low and artificial sun intensity and Low-power early forest fire detection and warning system[16]. The study was conducted on the photocurrent and photocurrent for better results. For electrode area variation on the PG system, the Open circuit voltage (V_{oc}), photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. Maximum photocurrent of 630.00 μA and equilibrium photocurrent of 585.00 μA were obtained and recorded at 1.0 cm^2 of electrode area, which are comparatively better electrical outputs in the BY+NaLS+AA system.

3.7 (i-V) characteristics of the PG cell

The fill-factor (FF) and power point (PP) were calculated (Equation (1)):

$$\text{Fill factor } (\eta) = \frac{V_{pp} \times i_{pp}}{V_{oc} \times i_{sc}} \tag{1}$$

$$Power\ Point\ (pp)\ =\ V_{pp}\, x\, i_{pp} \tag{2}$$

Where

V_{pp} is value of potential, i_{pp} is current at power point, V_{oc} is open circuit voltage, I_{sc} is short circuit current.

The value of FF of the cell circuit was calculated as 0.3422 and the Ppp was obtained as 224.25 μW for the PG cell. Table 2 displays the observed results for the (i-V) characteristics of the PG cell for BY+NaLS+AA system. Figure 4 shows the power point of a cell in BY+NaLS+AA System.

Table 2. Current Voltage (I-V) Characteristics of the PG Cell

Photopotential (mV)	Photocurrent (μA)	Power (μW)	Fill Factor (n)
1120	0	0	
1085	15	16.275	
1014	95	96.330	
985	130	128.050	
935	168	157.080	
890	180	160.200	
842	215	181.030	
798	232	185.136	
720	285	205.200	
680	308	202.440	
612	360	220.320	
575	390	224.250	0.3422
540	405	218.700	
482	445	214.490	
385	490	188.650	
255	525	133.875	
185	551	101.935	
45	574	25.830	
0	585	0	

3.8 Cell performance and conversion efficiency of the PG system

The determined performance is in terms of $t_{1/2}$ and the observed value was 140.00 minutes in dark. PG cell conversion efficiency (CE) was determined as 2.1562 % (Equation (3)).

$$\text{Conversion efficiency} = \frac{V_{pp} \times i_{pp}}{A10.4mCm^{-2}} \times 100\% \quad (3)$$

Where $V_{pp,}$ is photopotential at power point of cell, i_{pp} is photocurrent at power point of cell, A is electrode area of cell. Table 3 displays the observed results for the performance of the PG cell for BY+NaLS+AA system.

Table 3. Performance of the PG Cell

Time (Min.)	Power (μW)
0	224.250
10	210.21
20	196.34
30	189.72
40	182.61
50	175.36
60	168.20
70	161.58
80	154.82
90	147.40
100	140.13
110	133.24
120	126.53
130	119.46
140	112.08
150	105.28
160	98.60
170	91.22
180	84.56

3.9 Effect of variation of light intensity

The light intensity of the PG cell was calculated using electrode areas ranging from 3.1 $mWcm^{-2}$ to 26.0 $mWcm^{-2}$. The study was conducted on the maximum photocurrent (i_{max} in μA) and equilibrium photocurrent (i_{eq} in μA). at 10.4 $mWcm^{-2}$, very positive results are obtained, Table 4 displays the observed results for the change in electrode area on the BY+NaLS+AA system.

Table 4. Effect of Variation o f Light Intensity

BY-NaLS-AA System	Light Intensity ($mWcm^{-2}$)				
	3.1	5.2	10.4	15.6	26.0
Photopotential (mV)	914	919	924	929	934
Photocurrent (uA)	577	581	585	589	593
Log V	2.96094	2.96331	2.96567	2.96801	2.97034

3.10 Mechanisms

The following chemical process manifests in a laboratory environment, showing the movement of electrons within the cell circuit.

- **Illuminate Chamber:** In the photophysical and photochemical reactions process (Equation (4)) the BY molecules (Dye) capture quantum photons and are stimulated as follows. In the secondary phase (Equation (5)), excited BY absorbs electrons from reductants and transfers its energy to various other molecules.

$$BY \xrightarrow{hv} BY* \tag{4}$$

$$BY^* + AA \longrightarrow BY + AA^+ \tag{5}$$

- **Photochemical reaction at Pt electrode:** During the secondary reaction; however, the semi- or leuco-form of BY (Equation (6)) donates an electron to an electrode and transforms back into the initially formed BY molecules.

$$BY^- \longrightarrow BY + e^- \tag{6}$$

- **Photochemical reaction at dark Chamber:** At the counter electrode, the Dye (BY molecules) gains an electron from the counter electrode and changes into a semi- or leuco-form of BY as a fellow (Equation (7)). Finally, the BY (leuco/semi-form) and the reductant (oxidized form) combine to produce the original BY dye and AA molecules (Equation (8)), and the photochemical cycle is completed.

$$BY + e^- \longrightarrow BY^- \tag{7}$$

$$BY^- + AA^+ \longrightarrow BY + AA \tag{8}$$

Where: BY is Brilliant yellow dye, BY* is excited form of Brilliant yellow, BY^- is semi or leuco form of Brilliant yellow, AA is Ascorbic acid, AA^+ is oxidized form of reductant (Ascorbic acid).

4 Conclusions

4.1 Novelty, Prospectus and Recommendation

The project's main objectives were to reduce the price of PG cells while simultaneously enhancing electrical performance. The objective has been attained by taking into account the BY+NaLS+AA system's good amount of storage capacity. The existing PG cells on the market may be replaced, and these efficient systems may be able to supply all of humanity's electrical demands if the price and general efficiency are reduced to the necessary level.

4.2 Importance of work

We found better PG cell results that the BY+NaLS+AA surfactants have enhanced the PG cell's electrical output as well as its capacity to convert energy based on the findings of the observed experiments. The BY+NaLS+AA cell's open circuit voltage is 1120.00 mV, compared to an earlier reported value of 895.00 mV (Published work in International journal of energy research, Lal and Gangotri, 2022). The BY+NaLS+AA good photocurrent is 585.00 uA, compared to an earlier reported value of 150.00 uA (Published work in Indian Journal of Science and Technology, Gangotri and Meena, 2023). In conclusion, the findings of the observed PG cell are higher than those of recently reported PG systems published by Lal and Gangotri in 2022, Rathore et al. 2022 and Gangotri and Meena, 2023. The BY+NaLS+AA PG system, the Open circuit voltage (V_{oc}), photopotential, I_{sc}, I_{max},V_{pp}, i_{pp},and P_{pp} are measured; the resulting values are 1120 mV, 924 mV, 585.00 μA, 630.00 μA, 575mV, 390.00 μA, and 224.25 μW, respectively. The value of Fill Factor is 0.3422 and the Ppp is 224.25 μW for the PG cell. Maximum photocurrent of 630.00 μA and equilibrium photocurrent of 585.00 μA were obtained at 1.0 cm^2 of electrode area, which are comparatively greater electrical outputs in the BY+NaLS+AA system. The effects will be used to create a PG cell with a larger electrical output than the results that have already been published (see references [5,8,13]). If efficient systems are sufficiently advanced, they might take the place of the solar cells that are currently available on the market and have the ability to supply the necessary electricity for environmentally friendly growth.

5 Abbreviations

PGS = photogalvanic system; PG cell = photogalvanic cell; BY = Brilliant Yellow; NaLS = Sodium lauryl sulphate; AA = Ascorbic Acid; i_{eq} = photocurrent at equilibrium; I_{sc} = short circuit current; i_{pp} = photocurrent at power point; mV = millivolt in cell circuit; ml = milliliter for PG cell; V_{oc} = open circuit voltage; $t_{1/2}$ = storage capacity of cell; pp = power point of cell; M = molarity of solution used; V_{pp} = photopotential at power point; μA = microampere in cell circuit; h = fill factor for PG cell; i_{max} = maximum photocurrent; μW = microwatt in cell circuit

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