Punica granatum Dye Based Photogalvanic Cell for Solar Energy Conversion and Electrical Storage Using Fructose and Tween 80.

Abstract

The present investigation focuses on the development of a photogalvanic solar cell employing natural dye extracted from *Punica granatum* along with fructose and Tween 80 in alkaline medium for simultaneous solar energy conversion and storage. The prepared photogalvanic system exhibited significant enhancement in electrical output under artificial illumination of 10.4 mW cm⁻². The fabricated cell produced an open circuit voltage of 969 mV and a short circuit current of 928 µA. Maximum power output of 119.52 µW was observed at the power point conditions of 498 mV and 240 µA. The conversion efficiency and fill factor of the cell were calculated as 1.1492% and 0.1184 respectively. The system also demonstrated appreciable storage capability with a half decay time of 165 minutes in dark conditions. The influence of fructose concentration, Tween 80 concentration, pH, electrode area, diffusion length and light intensity on cell performance has been systematically examined. The study indicates that naturally available dye sensitizers can be effectively utilized for low-cost and environmentally sustainable photogalvanic energy devices.

Keywords: Photogalvanic cell, solar energy conversion, natural dye sensitizer, Punica granatum, fructose, Tween 80.

1. Introduction

The increasing global demand for renewable energy resources has stimulated extensive research on solar energy harvesting systems. Among the various photoelectrochemical devices, photogalvanic cells have gained attention due to their capability to simultaneously convert and store solar energy. Unlike conventional photovoltaic cells, photogalvanic cells possess an inherent energy storage mechanism and therefore do not require separate storage units.

The phenomenon of photogalvanic effect was initially described by Rabinowitch in 1940 during studies on thionine-iron systems. Since then, a large number of photogalvanic systems containing different photosensitizers, reductants and surfactants have been explored for improved solar energy conversion. Researchers have employed dyes such as methylene blue, toluidine blue, phenosafranine, azur dyes and acridine orange in combination with various reductants and surfactants to enhance photocurrent generation and storage characteristics.

Natural dyes have recently attracted considerable interest because of their eco-friendly nature, easy availability and low cost. Plant-derived pigments possess excellent light absorption characteristics and can serve as efficient photosensitizers in photoelectrochemical devices. Previous studies involving spinach extract and curcumin-based systems have demonstrated promising performance in photogalvanic applications.

In the present work, extract obtained from *Punica granatum* has been utilized as a natural photosensitizer. Fructose acts as the reductant, whereas Tween 80 serves as the surfactant in alkaline medium. The study aims to evaluate the suitability of this combination for efficient solar energy conversion and electrical energy storage.

2. Experimental Methodology

2.1 Chemicals Used

The photogalvanic system was prepared using the following materials:

- *Punica granatum* extract as photosensitizer
- Fructose as reductant
- Tween 80 as surfactant
- Sodium hydroxide as alkaline medium

All solutions were prepared in double distilled water and stored in coloured bottles to prevent photodegradation.

2.2 Experimental Setup

An H-shaped glass photogalvanic cell was employed for the experimental studies. One arm of the cell was illuminated while the other was maintained in dark conditions. A platinum electrode was immersed in the illuminated chamber and a saturated calomel electrode (SCE) was placed in the dark chamber.

Artificial illumination was provided using a 200 W tungsten lamp. Electrical measurements were carried out using a digital multimeter, while external resistance was controlled using a carbon potentiometer.

The cell was first allowed to attain equilibrium in dark conditions. After illumination, the generated photocurrent and photopotential were measured at different external loads.

2.3 Determination of Cell Parameters

The fill factor (FF) was calculated using the relation:

$$FF = (Vpp \times ipp) / (Voc \times Isc)$$

where:

- Vpp = potential at power point
- ipp = current at power point
- Voc = open circuit voltage
- Isc = short circuit current

The conversion efficiency (CE) was evaluated using:

$$CE = [Vpp \times ipp / (10.4 \times A)] \times 100$$

where A represents electrode area in cm^2.

3. Mechanism of Photocurrent Generation

Upon illumination, the molecules of *Punica granatum* dye absorb photons and attain an excited state. The excited dye molecules accept electrons from fructose, resulting in the formation of reduced dye species. These electrons are subsequently transferred to the platinum electrode, generating photocurrent in the external circuit.

The electrons flow through the circuit toward the saturated calomel electrode where the oxidized species are regenerated. The cyclic electron transfer process enables continuous generation and temporary storage of electrical energy.

The storage capability of the photogalvanic cell arises due to relatively stable intermediate species formed during photoexcitation.

4. Results and Discussion

4.1 Electrical Output of the Cell

The photogalvanic cell exhibited a gradual increase in photopotential upon illumination and attained a stable maximum value after a certain duration. The optimized cell produced the following electrical parameters:

Parameter	Observed Value
Open circuit voltage (Voc)	969 mV
Short circuit current (Isc)	928 µA
Maximum power output	119.52 µW
Fill factor	0.1184
Conversion efficiency	1.1492%
Half decay time (t1/2)	165 min

The maximum power output was obtained at a potential of 498 mV and photocurrent of 240 µA.

4.2 Effect of Fructose Concentration

The concentration of fructose strongly influenced the electrical characteristics of the photogalvanic cell. An increase in fructose concentration up to 2.6×10^{-3} M enhanced photocurrent and photopotential due to improved electron donation capability.

Beyond the optimum concentration, a decline in cell performance was observed. This decrease may be attributed to enhanced back electron transfer and hindrance in movement of electroactive species.

4.3 Effect of Tween 80 Concentration

Tween 80 improved the stability and mobility of dye molecules within the system. The optimum concentration of Tween 80 was found to be 3.2×10^{-3} M.

At lower concentrations, insufficient surfactant molecules limited efficient electron transfer, whereas higher concentrations restricted diffusion of electroactive species toward the electrode surface.

4.4 Influence of pH

The photogalvanic system performed efficiently in alkaline medium. Maximum electrical output was obtained at pH 12.65.

In acidic medium, protonation of dye molecules reduced their electron donating ability, leading to poor performance. Extremely high alkalinity also caused reduction in output due to interaction of hydroxide ions with oxidized reductant species.

4.5 Effect of Electrode Area

The photocurrent increased with increase in platinum electrode area. Larger electrode surface facilitated faster electron collection and improved charge transfer kinetics.

4.6 Effect of Diffusion Length

Diffusion length significantly affected the photocurrent characteristics of the system. Increasing the diffusion length increased maximum photocurrent due to enhanced photochemical reaction path.

However, equilibrium current showed comparatively smaller variation because longer diffusion pathways slowed the transport of electroactive species.

4.7 Effect of Light Intensity

The photocurrent increased linearly with increase in light intensity, while photopotential exhibited logarithmic behaviour. Higher illumination intensity promoted excitation of larger number of dye molecules, thereby increasing charge carrier generation.

5. Storage Behaviour and Cell Performance

The energy storage capability of the photogalvanic cell was evaluated by observing the decay in power output after terminating illumination. The cell continued to supply electrical energy in dark conditions for a considerable duration.

The half decay time of the optimized system was measured as 165 minutes, indicating appreciable storage capacity. This behaviour highlights the advantage of photogalvanic cells over conventional photovoltaic systems, which generally require separate batteries for energy storage.

6. Conclusion

The present investigation demonstrates that *Punica granatum* extract can serve as an effective natural photosensitizer in photogalvanic solar cells. The combination of *Punica granatum* dye, fructose and Tween 80 produced encouraging electrical output and storage behaviour under artificial illumination.

The optimized photogalvanic cell generated an open circuit voltage of 969 mV, short circuit current of 928 µA and maximum power output of 119.52 µW with conversion efficiency of 1.1492%. The system also displayed significant storage capability with a half decay time of 165 minutes.

The study confirms the potential of natural dye based photogalvanic systems as low-cost, sustainable and environmentally friendly alternatives for solar energy conversion and storage applications.

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Acknowledgement

The authors acknowledge the support and laboratory facilities provided by the Department of Chemistry, Government Dungar College, Bikaner, Rajasthan, India.