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A study of Dye-sensitized solar cells using pomegranate dye as sensitizer with two different concentrations in terms of solar parameters

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Abstract

The human being is seeking luxurious life, therefore, using motor vehicles, industries, and household appliances as machinery which runs on fossil fuels i.e., gasoline, coal, diesel, gases, etc. These pieces of machinery burn fossil fuels and release toxic carbonaceous substances as a by-product in the form of pollutants and are nearly ending up. Solar energy is one of the best alternatives for producing clean and green energy to meet the energy demand. Over five decades, silicon solar cells have been commercially successful, but Dye-Sensitized Solar cells (DSSCs) are prioritized due to some limitations. In DSSC, ruthenium complex-based solar cells are the most efficient, but the high cost of the dye, toxicity and rarely available metal complex introduce organic dye. The organic dyes are cost-effective, abundantly available, and easy to process from extraction to fabrication. It can be extracted from different plant portions (fruit, flower, pulp, seeds, and peels). The current work used pomegranate dye with two different concentrations (5% and 10%), TiO_2 semiconductor, and iodine-triiodide electrolyte to fabricate two solar cells. Both cells were characterized under one sun intensity of 1000W/m^2 at 1.5 AM. Overall, both cells were efficient, but the solar cell with 10% dye solution provided better solar parameters. This study concluded that highly concentrated dye can have better adsorption with semiconductors resulting in better efficiency.

***Keywords*:** Dye Sensitised Solar Cell (DSSC), sensitizer, efficiency, TiO_2 and electrolyte

1. Introduction

The human population is increasing with the increasing energy demand daily. People are seeking a more luxurious and comfortable life; therefore, the number of motor vehicles, industries, and machinery have been lunching. This machinery uses current fossil fuels (non-renewable energy) and produces a lot of carbonaceous by-products. As a result, these are ecological districting balances [1]. One of the essential goals of scientists, governments, industries, and organizations all across the globe is to minimize pollution with the help of those devices which provide clean and green energy i.e., photovoltaic, hydrological energy, wind energy, etc. [2]. To cut off non-renewable energy such as gasoline, diesel, coal, and natural gases, solar energy is one of the best alternatives to fulfill energy demand which is environmentally friendly, cost-effective, non-toxic, and biodegradable [3]. Silicon solar cells have improved quality for five decades, and until now, these are highly efficient and successful commercially. Regardless, this solar has some limitations; therefore, other sorts of solar have gained attention for research and development. Dye-sensitized solar cell (DSSC) is the third generation solar has some advantages over silicon solar, such as ease of fabrication, cost-effective and abundantly available materials used for the fabrication [4]. The highest efficiency recorded for DSSC is 14.2% [5]. In DSSC, synthetic metal complex-based dyes, i.e., Ruthenium dyes, are highly successful in terms of efficiency and stability. Still, due to earth rare metal ruthenium, high processing cost, and toxicity, these are replaced by organic dyes extracted from plants [6].

In addition, DSSCs are being constructed with the help of semiconductors, counter electrodes (CE), sensitizers, and electrolytes [7–8]. Mostly TiO_2, Nb_2O_5, and ZnO are used as wide bandgap Nanocrystalline semiconductors to enhance solar parameters such as open-circuit voltage(Voc), short circuit current density(Jsc), fill factor(FF), and efficiency (դ) the doping and composite structure of the semiconductor are also applied by many research groups [9]. The TiO_2 semiconductor accepts the light with a bandgap nearby the ultraviolet (UV) region, which interacts with the molecular structure of the dye or sensitizer.

Dyes are key components extracted from various portions of plants such as flowers, fruit, pulp, peels, and root that absorb sunlight due to light-harvesting pigments [10]. These pigments are anthocyanin, carotene, chlorophyll, flavonoid, and betalains that absorb light in the visible region of the solar spectrum in the wavelength range of 200-800 nm [6]. The two molecular orbitals, HOMO and LUMO (highly occupied molecular orbital and lowest unoccupied molecular, respectively), are present in the molecular structure of the dye. These molecular orbitals are responsible for the transportation of electrons from the electrolyte to the working electrode (WE) (front side with semiconductor coated on conductive electrode) even in low intensity of light [7,11]. Furthermore, the iodine-triiodide liquid (I^-/I_3^-) electrolyte in the interface of WE and CE. is accountable for the overall performance of the solar cell. At the anode, dye molecules are reduced by iodide then the dye molecule gets regenerated. At the cathode, the oxidizing electrons of the electrolyte (tri-iodide) get reduced by the mass of electrons collected through the external load to the CE. Thus, it completes a circuit [3].

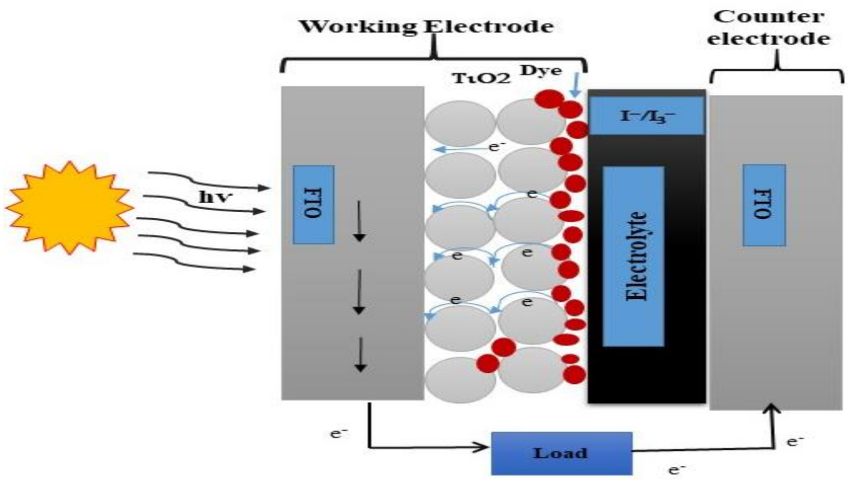

Figure 1: The pictorial representation of the working mechanism of DSSC

Over a decade, liquid electrolytes were promising for successfully fabricating DSSC. It joints the anode and cathode, enhances the durability of the cell, performance, protection, price, and ecological effect, and converts and storage electrochemical energy [12]. The (CE.) is the supporting constituent of the DSSC, which accepts the electron from the external circuit and then diffuses toward the electrolyte. Nowadays, researchers are applying various techniques to improve the movement of an electron from CE. to the electrolyte. These techniques include coating fluorine-doped tin, graphite, graphene, carbon nanotubes, and other polymeric nanomaterials on a glass substrate [13]. The pictorial representation of DSSC is shown in Figure (1).

This work used commercially available TiO2 nanoparticles (metal-oxide nanoparticles) as a semiconductor to constructal photoanode or WE for DSSC. The dye was extracted from a raw Pomegranate seed with two different concentrations of dye solution (5% and 10 %) and examined with optical instruments. The current-voltage (I-V) characterization was done for both cells dipped into the solutions of the dye two concentrations.

2. Experimental Methods

2.1 Materials

Commercially available Titanium dioxide nanoparticles (TiO_2) powder (photocatalyst 7 nm) was purchased from Sigma-Aldrich, India. Iodine tri-iodide electrolyte, Fluorine doped tin oxide(FTO) for both CE and WE with the sheet resistance 18Ω/cm^2 purchased from Sigma chemical Banglore, India. Raw pomegranate was collected from the nearby market: binder clips, scotch tape, dil. HNO_3 0.1 M, ethanol, etc., chemicals are used without further purification.

2.2. Extraction of natural dye

The fresh pomegranate was slashed, and the seeds separated from the peels. The seeds of weight 0.5 gm were measured and crushed with the help of a mortar and pestle. Finally, the solid residue was filtered out, and the juice was used as a dye [14]. From the stock solution, both 5 % and 10% (%v/v) dye solutions were prepared in the absolute ethanol solution.

2.3 Preparation of Working Electrode (Photoanode) and Counter Electrode

Initially, 0.3 g of TiO_2 powder (photocatalyst 7 nm) was taken into the mortar to prepare TiO_2 paste. Add 1 mL of dil. HNO_3 solution to the powderedTiO_2 dropwise until the consistency of the paste is thinner than toothpaste and thicker than water, then mixed with a pestle. For electrical contact with the cell, the conductive side of the FTO faces upward. Paste the scotch tape on FTO to make a rectangular border [14]. After that, the paste was applied on the FTO having a conductive side with the help of the Doctor blade technique. Finally, the cell was sintered at 400 ˚C temperature in a furnace.

The FTO was used as a CE. and liquid iodine tri-iodide (I^-/I_3^-) as an electrolyte. Although, the TiO_2-coated electrodes were cooled at room temperature and immersed in the dye solution of two different concentrations for 24 hours [15]. These electrodes are taken out from the solutions and then washed first with water and ethanol to remove the dye molecules weakly attached to the surface of the semiconductors. Both electrodes were sealed with the help of binder clip, and placed the electrolyte between the electrode uniformly [16].

3. Results and Discussion

3.1 UV-Visible absorbance analysis of pomegranate dye

The Pomegranate dye with 5% and 10% solution was prepared in ethanol. The optical characterization was done with the help of UV-Vis spectrophotometry in the range of 200- 800 nm. Both dyes have shown the maximum absorbance at 500-600 nm. The absorbance of pomegranate dye in the visible range confirms the light-absorbing pigment, i.e., anthocyanin. Anthocyanin is the significant light-harvesting pigment present in the most coloured plant. The dye solution with 5% concentration shows a broader absorbance peak, whereas the dye solution with 10% concentration shows sharp peaks in the 500-600 nm range, as shown in Figures 2(a) and 2(b) [16-18].

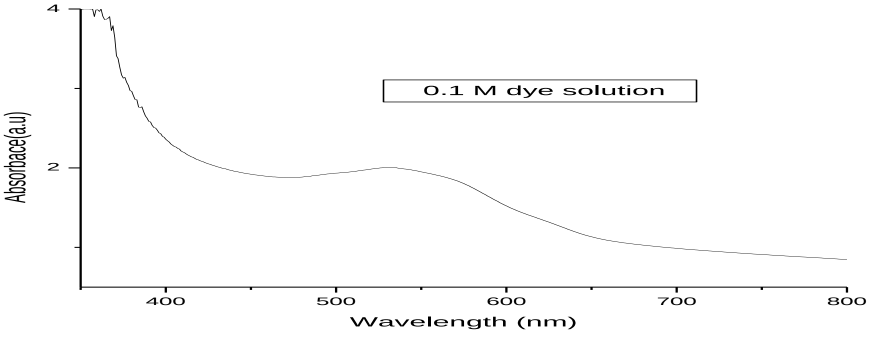

Figure 2 (a): The UV-Vis absorbance of 5% concertation of pomegranate dye

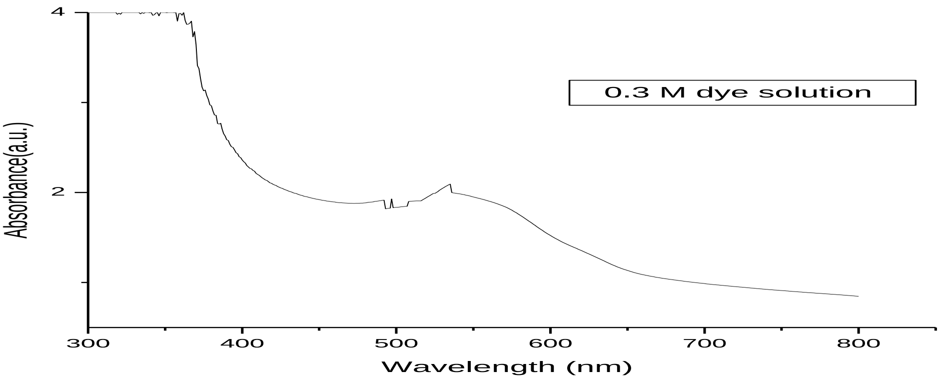

Figure 2(b): The UV-Vis absorbance of 10% concertation of pomegranate dye

3.2 Current -Voltage (I-V) characterization of the dye-sensitized solar cell (DSSC)

The photo current-voltage (I-V) characterization of a DSSC cell without modification of the electrodes is shown in Figures 3 (a) and (b). The cells with two different dye concentrations were characterized by a solar simulator where both are found efficient. These cells were illuminated under 1 sun intensity of 1000W/m^2 at AM 1.5 [16]. Though the first cell with 10 % dye solution provides solar parameters Voc, Isc, FF, and η are 120 mV, 0.00157 mA.cm^{-2}, 20 and 0.00376 %, respectively. In the second cell with 5% dye solution provided the solar parameters Voc, Isc, FF, and η are 100 mV, 0.0010 mA.cm^{-2}, 10 and 0.00102 % respectively. These solar parameters are presented in tabular form in Table 1. The current and voltage can also be observed at dark, where Voc and Isc were found negligible. The solar cell efficiency was calculated with the help of standard formula [17].

$\eta = Pout/ Pin$

$\eta = VocIsc\ FF / Pin$

From the above obtained solar parameters data, it can be seen that the overall solar parameters are increased with an increase in dye concentrations. The concentration of the dye solution increased from 5% to 10%, then the Voc was increased by 20%. In addition, the current was increased slightly while the FF was increased by two times than the solar cell with a 5% dye solution. However, the efficiency of the second cell increased three times more than that of the first cell. The dye with a high concentration may be more favorable to interact with nanocrystalline semiconductors than less concentrated dye due to better efficiency. Overall, the concentration of the dye increases with an increase in the solar parameters because the higher concentrated dye contains more light-harvesting pigments than the less concentrated dye [17].

Table 1. I-V characterization of pomegranate-based solar cell illumination at 1000 W/m^2.

S. N	(%v/v) of dye solution	Voc (mV)	Jsc (mA.cm^{-2})	FF (%)	η (%)
1	5	100	0.0010	10	0.00102
2	10	120	0.00157	20	0.00376

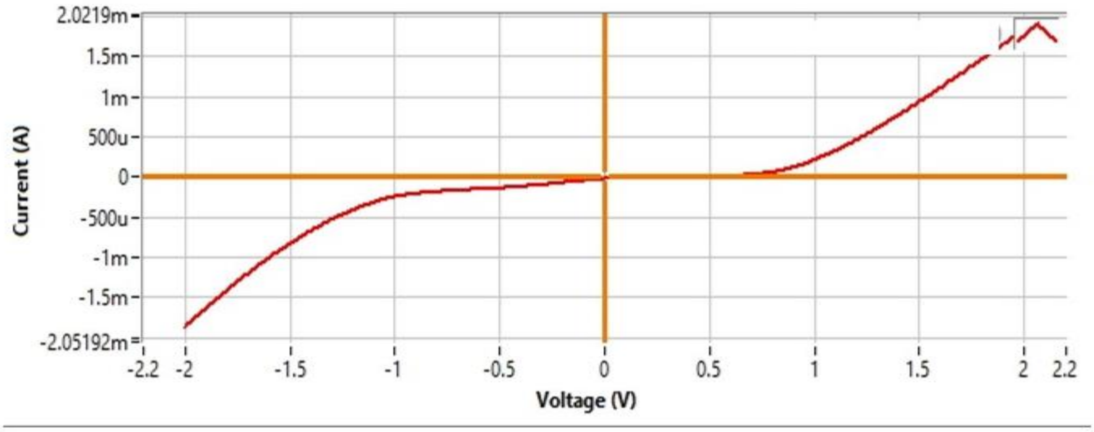

Figure 3 (a): I-V characterization of the solar cell with 5% pomegranate dye solution

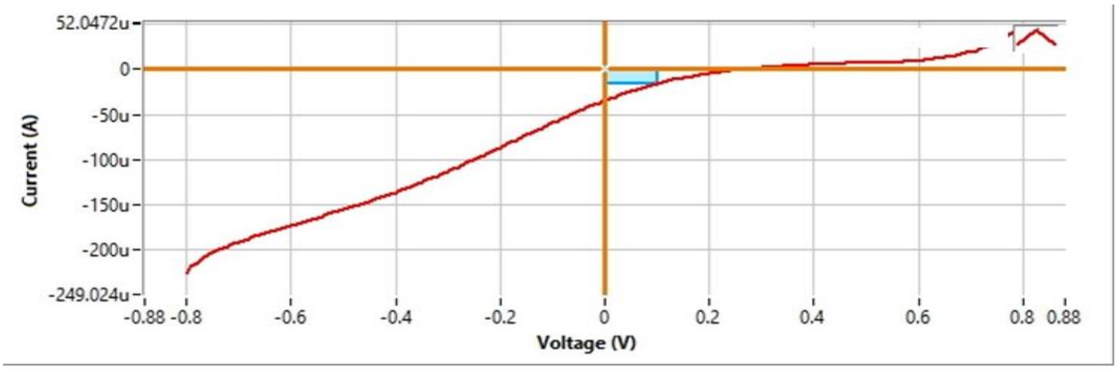

Figure 3 (b): I-V characterization the solar cell with 10% pomegranate dye solution

4. Conclusion

This study provides the characteristics of pomegranate-based DSSC. The TiO_2-coated photoanodes were immersed in two different concentrations of 5% and 10% dye in ethanol solution. At 24 hours, the photoanode absorbed a sufficient amount of dye, and both electrodes were illuminated under 100 mW cm^{-2} of 1 sun (AM 1.5) and found efficient. An electrode with 10% concentration has shown higher solar parameters (efficiency 0.00376%) than 5%. However, this study clearly shows that the concentration of dye molecules affects the overall solar parameter and a higher concentration provides better efficiency.

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