Effect Of Various Extraction Solvents on Efficiency of Natural Pigment Based Dye-Sensitized Solar Cell

Abstract. Natural dye has been utilized as a substitute for ruthenium-based dyes in Dye-Sensitized Solar Cell (DSSC). Natural dye was successfully extracted from Ficus benjamina using ethanol, methanol and double distilled water as a solvent. And the effect of solvents on the efficiency of prepared DSSCs has been studied extensively. Results revealed that pigment extracted with methanol has demonstrated the highest efficiency(η) of 0.198%, open-circuit voltage (V_{OC}) 61.6 mV and short circuit current (I_{SC}) 0.424 mA for F. benjamina. It has been observed that methanol has enhanced the efficiency of DSSC by 15.67% compared to double distilled water and 11.05% compared to ethanol for F. benjamina. Further, UV spectrophotometer is used to analyze the absorption characteristics of prepared natural dyes.

Keywords: DSSC, Natural Dye, Solvents, Ficus benjamina, Biosolar

1. Introduction

Every growing energy demand at a global scale on one side of the equation and global warming on the other side of the equation does not balance very well. Renewable energy sources can bring the balance we are looking for. They must meet certain criteria, such as low costs of production and high biodegradability and sustainability. These renewable sources can replace high carbon dioxide emissions production methods like natural coal, gas and oil [1–4]. Solar cells technology has demonstrated the harvesting of solar energy with significantly good efficiencies [5, 6], and the technology has constantly been evolving by making iterative improvements to the power conversion efficiency of the cell. Solar Photovoltaics (PV) technology is a well-established technology, but factors like the production cost complexity of manufacturing make it difficult to use PV cells for various applications [7, 8]. Therefore, several PV designs were explored to overcome these challenges. Dye-Sensitized Solar Cells (DSSC) has attracted substantial attention over the past decade for their straightforward manufacturing method, high cost to efficiency ratio, and ability to deform their shape [9–11]. However, DSSCs struggle to maintain stability and photoconversion efficiencies are lower than that of the crystalline silicon-based PV cells [12–15]. Over the years, several techniques were adopted to improvise the efficiency of DSSCs, noticeably interested in developing photoanode capable of photocatalytic dye degradation [16–18]. DSSCs use dye molecules as sensitizers to harvest light energy and convert it into electrical energy. The dye molecules are often loaded on wide bandgap semiconductor material such as titanium dioxide (TiO$_2$) or zinc oxide (ZnO) nanostructures.

Transparent Conductive Oxide (TCO), such as Indium tin oxide or Fluorine doped tin oxide (FTO), is used as a substrate for electrodes. Platinum has been widely used as a counter electrode for DSSCs due to its very good catalytic ability. This is important because the reaction rate at the counter electrode has to be twice as fast as that of the working
electrode. Iodine-based redox couple (I/\text{I}_3) is used as an electrolyte. When DSSC is illuminated with sunlight, the dye molecules readily absorb the light and excite electrons from Highest Occupied Molecular Orbital (HOMO) to Lowest Unoccupied Molecular Orbital (LUMO) shown in Figure 1. The excited electron jumps to the conduction band of the TiO\textsubscript{2} working electrode and flows through the external circuit to reach the counter electrode. In the meantime, electrolytes lend one electron to dye molecules to restore them and undergo reduction. Whereas electron from the counter electrode restores the electrolyte to keep the reaction going [19–21]. Copper complexes based redox electrolytes has been reported to achieve the highest efficiency of 13.1% under 100 mW/cm\textsuperscript{2} conditions and the efficiency goes even higher up to 32% for photon flux of 1000 lux using indoor light [22].

This study investigates the effects of solvents such as ethanol, methanol, and double-distilled water (dd-water) as an extraction solvent for natural dyes extracted from *Ficus benjamina* leaves. Pigment concentrations of as prepared natural dye were estimated and studies in correlation with the photoelectric performance of the prepared DSSCs. In addition, UV-Vis Spectrophotometer is employed to study the absorbance characteristics of the prepared dye solution.

![Figure 1 Schematic of Dye-Sensitized Solar Cell.](image)

## 2. Materials and Methods

Chemicals such as ethanol (99.99%), acetonitrile (99.99%), potassium iodide (99.99%), ethylene glycol (99.99%), surfactant (Tween 20), acetic acid (99.99%), and iodine and titanium dioxide (99.99%) were purchased from Union Science. The Fluorine-doped Tin Oxide (FTO glass) with a resistance of 10 ohms/sq. meter was purchased from Hangzhou, Zhejiang, China.

### 2.1 Dye Extraction

Natural dye extract was prepared using *F. benjamina* leaves, commonly known as Weeping Fig. The leaves were collected and washed to remove any visible contaminants and then dried in the dark to avoid chlorophyll being exposed to sunlight. The leaves are then weighted and blended with ethanol. The blended solution is kept in a dark and dry place for a few minutes until the ethanol reacts with the leaves. Later this mixture is vacuum filtered with filter paper using a rotatory pump. The filtrate containing pigment is then stored in a dark and
cool place to avoid the disintegration of chlorophyll. This extraction method has been adopted by Sumanta et al. [23].

![Figure 2](a) Leaves of *F. benjamina* (weeping fig). Dye extract prepared using (b) Ethanol, (c) Methanol (d) double distilled Water (dd-water).

### 2.2 Photoanode Preparation

Mesoporous TiO$_2$ thin film photoanode was prepared by grinding the TiO$_2$ powder with a magnetic stirrer until it became fine powder and then acetic acid and surfactant were added and mixed thoroughly. Then the prepared TiO$_2$ paste is deposited into the FTO glass using Doctor’s Blade method and sintered to form the mesoporous layer.

### 2.3 Dye Loading

The photosensitizer was absorbed onto the photoanode by carefully applying the prepared dye solution dropwise and dried in the dark for a few hours. Moreover, this process is repeated two more times to produce better adsorption of dye molecules onto the photoanode.

### 2.4 Preparation of Counter Electrode

The counter electrode was prepared by mixing activated carbon powder with ethanol, and the paste was then deposited onto aluminum foil using Doctor’s Blade method and then dried at high temperature.

### 2.5 Electrolyte

I$^-$/I$_3^-$ redox couple used as a liquid electrolyte and prepared using a simple one-step method adopted from Gu et al. [24] for small-scale DSSC preparation. Among other liquid electrolytes, iodine-based redox couple electrolyte has been reported to perform better than others and have been studied widely by researchers [24].

### 2.6 Fabrication of DSSC

Cell assembly starts by attaching copper contacts to FTO glass deposited with TiO$_2$ photoanode. Then polyethylene membrane soaked in iodide electrolyte is sandwiched
between a photoanode and a counter electrode made of aluminum foil coated with a thin layer of activated carbon.

Figure 3 Schematic of DSSC Cell Assembly.

2.7 Photoelectric Characterization of DSSC

The prepared cells’ photoelectric conversion efficiency (PCE) was measured using the solar simulator. The DSSCs with an active area of 3 cm² were placed under the simulator with a power of 190 mW cm². MCP41010 microcontroller was programmed to increase resistance in a step-wise manner while the voltage and current response of the cell was recorded. The PCE was determined using the equation (1):

\[
\eta = \frac{J_{SC} \times V_{OC} \times FF}{P_{in}}
\]  

where \( J_{SC} \), \( V_{OC} \), \( FF \), and \( P_{in} \) are the Short-Circuit Current Density, Open-Circuit voltage, Fill Factor, and Incident Power. Then, the ratio of maximum power produced by the cell to the theoretically maximum power for the given cell is given by Fill Factor (FF) and calculated using equation (2):

\[
FF = \frac{P_m}{(I_{SC} \times V_{OC})} = \frac{I_m \times V_m}{(I_{SC} \times V_{OC})}
\]

2.8 Statistical Analysis

The experiment was conducted with three replicates. Hence, the data were presented as mean ± standard deviation (SD).

3. Results and Discussion

3.1 Photovoltaic Performance of Cell

The PV efficiency of DSSCs can be calculated using the voltage-current (I-V) line. The parameters for the output PV of DSSCs include short-circuit current (Isc) and the open circuit...
potential (Voc) as well as Fill factor (FF) along with the power conversion rate (e). The photovoltaic efficiency of the as-prepared cells proved the presence of F. benjamina dye is a key component. The PV performance of DSSCs is estimated from the current–voltage (I–V) curve. The output PV parameters of DSSCs are short-circuit current (Isc), open-circuit potential (Voc), fill factor (FF), and power conversion efficiency (η). The photovoltaic performance of as-prepared cells showed that F. benjamina dye-based DSSCs could attain steady-state operation in converting solar energy to electrical energy. Table 1 captures critical photovoltaic parameters of DSSCs and the results indicate methanol solvent for dye extraction has the highest power conversion efficiency (η) of 0.198% for F. benjamina based dye extract.

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<th>Table 1 DSSC Performance Comparison</th>
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<td><strong>Dye</strong></td>
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<td><strong>Verdant-turmeric</strong></td>
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**3.2 UV-Vis Characterization**

UV-Vis is a different low-cost, rapid, and easy method of characterization that is typically used to NMs research. Certain MNMs possess optical properties which are sensitive to size, shape of the agglomeration, state of agglomeration concentration, shape and the refractive index close to the surface of the NM which makes UV-Vis spectroscopy an important method to study these materials. The absorption characteristics of natural dye extracted using different solvents are studied using a UV-Vis photo-spectrometer and the results are shown in Figure 4. Absorbance spectra show peaks in 400 - 550 nm and 600 - 750 nm. This absorbance range indicates the signature of chlorophyll pigment [30], [31]. Further, the line shape of absorbance peaks for chlorophyll are in close conjunction with the literature [32, 33]. The spectra depict maximum absorbance λmax at 440, 470 and 480 nm for dd-water, methanol and ethanol, respectively; this shows lower concentrations of chlorophyll in dd-water. On the other hand, ethanol and methanol showed similar absorbance characteristics, whereas methanol with strong absorbance at 480 nm.
Figure 4 UV-Vis absorption spectra of dye extracted from *F. benjamina* using ethanol, methanol and dd-water as a solvent.

Figure 5 captures Mortar and piston, plant extract and dye solution used for grinding plant leaves with solvent, which is later used to estimate pigments in the solution. The solvent is added to the raw plant extract solution to make it up to 100ml. The solution in the cuvette represents the sample used for UV characterization.

4. Conclusion

The photochemical performance of DSSCs with *F. benjamina* based natural dye extract has been studied extensively. The effects of three different extraction solvents on the cell's performance have been carefully analyzed. The pigment analysis of the extracted dye revealed that the carotenoid to chlorophyll concentration ratio plays a crucial role in the light harvestability of the natural dye. Photochemical studies have revealed that methanol has shown high performance compared to other solvents with an efficiency of 0.198% and
Current Density of 0.0447 mA/cm², Maximum Power Density of 0.0113 μW/cm², Fill Factor (FF) of 31.72% and open-circuit voltage of 0.0616 V. Methanol has acted as anti-aggregation agent for dye molecules which enhanced the overall efficiency of the DSSC. In summary, methanol as a solvent has performed better than ethanol and ethanol has performed better than dd-water.

References


