OPTIMIZATION OF DYE EXTRACTION FROM TURMERIC (CURCUMA LONGA L.) AND HENNA LEAVES (LAWSONIA INERMIS L.) IN DYE SENSITIZED SOLAR CELL

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Abstract.

Dye-sensitized solar cells (DSSC) are also known as photovoltaic solar cells. Basic component that used as sensitizers in DSSC was synthetic inorganic compound however in this research a natural dye extract from the plants were used to replace the crystalline silicon solar cell due to the high cost. In this study, the types of sensitizers used from a natural dye which were turmeric and henna leaves. Other than that, Doctor Blading technique or known as a tape casting was used to sinter TiO_2 powder at ITO glass. The extracted of these two dyes were immersed in the four different solvents which were ethanol (A), distilled water (B), a mixture of ethanol and distilled water 4:1 (C) and the other mixture was ethanol and distilled with different ratio 1:4 (D) successful investigated on DSSC. The efficiency of optimum sensitizers with the used of ethanol and distilled water were measured. FTIR was used to identify the carbonyl and hydroxyl groups that present in turmeric and henna. Meanwhile, UV-Vis was used to characterize the efficiency of these sensitizers by their ability to absorb light over a wide range of and the energy band gaps were recorded. The optimum dyes obtained the highest peak of absorption which was henna leaves that immersed in a mixture of ethanol and distilled water with ratio 4:1 solvent (C) due to the lowest energy band gap which was 1.89 eV. Moreover, the efficiency obtained was $1.32 \times 10^{-7}\%$ higher than other solvents. So, it can conclude that the mixture of ethanol and distilled water with ratio 4:1(C) gave the highest efficiency of DSSC. The implication from this research was henna leaves that extracted from mixture of ethanol and distilled water gave better efficiency compared to ethanol solvent that was frequently used from previous study.

Keywords: *Dye-sensitized solar cell, natural sensitizers, solvent, efficiency*

INTRODUCTION

The biggest challenge coming for living things especially humans is to discover and replace the non-renewable energy with energy sources which can be renewed as nowadays humans keep rely on this non-renewable energy as the main source. Due to the growing population and highly request from growing cities, the problem needs to solve with a low costing solution using profusely available materials which are easy to get and find. The solar energy is an absolute source that is cheap and clean energy. All the living things on Earth used solar energy. Hence, exploiting the power of the sun using photovoltaic solar cells is the one and sensible answer to solve this energy problem. In the Quran state that:

"It is He who made the sun a shining light and the moon a derived light and determined for it phases - that you may know the number of years and account [of time]. Allah has not created this except in truth. He details the signs for a people who know."

Surah Yunus: Verse 5

From verse 'Allah has not created this except in truth' shows that the Sun or all the things that had been created are useful for humans. Everything has its own function and benefits for humans. Nowadays, the photovoltaic technologies that are convenient are based on inorganic materials. This required an expensive cost. The using of an acceptor type and a donor in organic materials in photovoltaic devices form a heterojunction. This will favor the separation of the excitation into two carriers is known as conventional organic [1].

A dye-sensitized solar cell (DSSC) has emerged as a replacement to the p-n junction photovoltaic device. From the previous study, it was found that electricity can be generated through illuminated organic dyes in electrochemical cells. DSSCs are classified as third-generation organic solar cells as they offer additional functionalities such as flexibility and transparency. These functions are not available in the first and two-generation devices that built using single crystalline silicon (first generation) or thin films (second generation). The DSSCs are like photosynthesis process where the light absorbed from the sunlight by a green pigment, which known as chlorophyll and later photo-induced electron transfer generate fuel (starch).

There are many previous research that has been done identifying the best sensitizers for DSSC such as the using of silicon and other materials like cadmium telluride as the sensitizers in solar cells [2]. However, the material used is very harmful to the environment and the cost is high expensive [3]. Other than that, many researchers used the dye from another group such as beta carotene, and also another project just uses the dye that has been processed such as fruit juice. This may be contained or mix with other components that may lead to the low efficiency of DSSC. Previous research also used solvents such as methanol, acetic acid and acetone and these also may not improve the efficiency of DSSC.

In this research, natural dye pigments are used which are henna leaves and turmeric as the sensitizers for the main aim of solving a solution for affordable energy and not harsh to the environment. Lawsone and curcumin dyes that extracted from henna and turmeric are used to carry out the efficiencies of both dyes as photosensitizers on a titanium dioxide, TiO_2 photoelectrode. The cost to construct the DSSC is also cheap. Other than that, henna leaves contain chlorophyll pigment and turmeric contains anthocyanin which these two groups will contribute to give the highest efficiency for DSSC.

Ethanol and distilled water are used as the solvent because ethanol gives the highest efficiency compared to another solvent meanwhile distilled water is used to compare the result with ethanol. The dye extracted from henna and turmeric are immersed in ethanol (A), distilled water (B), a mixture of ethanol solvent and distilled water 4:1 (C) and the other ratio of ethanol solvent and distilled water is 1:4 (D). The large range of absorption peak of a wavelength that will be obtained in this study. Meaning that the energy band gap will be smaller and produce high efficiency that will be observed by V-I characteristics.

METHODOLOGY

2.1 ITO Glass Preparation

Firstly, indium tin oxide (ITO) was used as the substrate. The ITO glasses were already in small pieces which 2.0 cm by 2.0 cm square. Next, the glasses were cleaned using acetone and distilled water. After that, the glasses were placed into a drying cabinet at 70 ℃. When the surface dried, the part of ITO conductive glasses which are two edges was covered with adhesive tape to prevent the film for being thickness.

2.2 TiO_2 Preparation and Deposition

Initially, 3.0 mL of concentrated acid was mixed with 1.0 g of the titanium dioxide (TiO_2) powder. Then, mortar and pestle were used to grind the mixture. The TiO_2 paste was obtained when a pasty, fine and homogeneous white substance was produced. TiO_2 was deposited on the ITO glass using a screen printing technique (Doctor Blading).

2.3 Solvent Preparation

The 100 mL solvents that had been used were ethanol and distilled water. However, this research consisted of four different solvents which were ethanol (A), distilled water (B) and the other two were the mixture of ethanol solvent and distilled water in ratio 4:1 (C) and ratio 1:4 (D). The 10 mL and 100 ml of measuring cylinders were used to measure the volume of the solvents.

For 100 mL ethanol and 100 mL distilled water, the solvents were measured by using 100 mL of measuring cylinder. The solvent A and solvent B were prepared.

The calculation to make the mixture of ethanol solvent and distilled water was,

1 ratio = 20 mL of solvent

For ratio 4:1 (4 denoted for ethanol and 1 denoted for distilled water),

4 ratio = 4 $\times$ 20 mL of ethanol

= 80 mL of ethanol

1 ratio = 1 $\times$ 20 mL of distilled water

= 20 mL of distilled water

Solvent C (4:1) = 80 mL + 20 mL

= 100 mL

For ratio 1:4 (1 denoted for ethanol and 4 denoted for distilled water),

1 ratio = 1 $\times$ 20 mL of ethanol

= 20 mL of ethanol

4 ratio = 4 $\times$ 20 mL of distilled water

= 80 mL of distilled water

Solvent D (1:4) = 20 mL + 80 mL

= 100 mL

2.4 Dye Preparation

After the preparation of the turmeric and henna dyes, these dyes were immersed in the 4 different solvents which are ethanol (A), distilled water (B), a mixture of ethanol solvent and distilled water for ratio 4:1 (C) and mixture of ethanol solvent and distilled water for ratio 1:4 (D).

2.4.1 For Turmeric Roots

First and foremost, took and weight 15 g of turmeric roots using analytical balance and washed using distilled water for a few minutes. Next, dried using drying cabinet for 15 minutes at room temperature. Used mortar and pestle to crush the turmeric roots into small pieces. Then, the turmeric roots that had been crushed were immersed overnight in 100 ml of 4 different solvents; A, B, C and D. After that, the impurities were filtered out using Whatman filter paper and the dyes were obtained.

2.4.2 For Henna Leaves

Initially, after washed the henna leaves were dried at room temperature but open in the laboratory for several days to get the variant weight. Then, took and weighed 15 g of henna leaves using an analytical balance. The henna leaves were crushed into tiny bits using mortar and pestle technique then immersed into 100 mL of 4 different solvents; A, B, C and D for overnight. After that, the impurities were filtered out using the Whatman filter paper and the dyes were obtained.

2.5 Full Assembly of DSSC

The TiO_2 film was spread on the ITO glasses. The glasses were heated on the hot plate at 450 °C for 2 hours to produce a mesoporous layer. Next, the samples were cooled down at room temperature to avoid from obtained any cracks on the TiO_2 film. After that, the films were immersed in the natural dye solution for one day to let the film absorbs the dyes. For electrolyte preparation, composed the iodide electrolyte by mixing the 1.3 g of iodine (I_2), 2 g of potassium iodide (KI) and 40 Ml of distilled water. The dropper was used to drop the iodide electrolyte in a range of one to two drops on the photoanode electrode. Then, for another electrode known as a counter electrode, the carbon soot was used to coat them. Attached the counter electrode with a photo anode glass plate. Lastly, clipped the two sides of photoelectrodes by using binder clips to complete the assembly of DSSC. Figure 1 shows the sequence of the full assembly of DSSC.

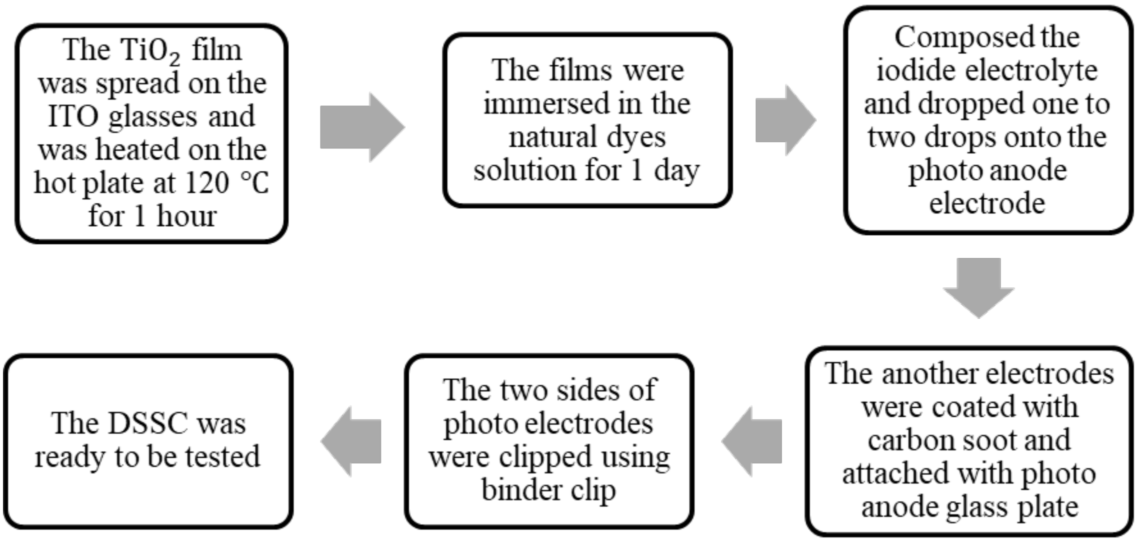

Figure 1: Full assembly of DSSC

2.6 Characterization of Natural Dye Sensitizers and DSSC

To characterize the dyes, there are three steps involved in this experiment. First and foremost, the UV-Vis spectrometer and FTIR spectrometer were used to observe the optical properties and absorbance of each dye. Then, the I-V characteristics were calculated to get the efficiency of DSSC.

2.6.1 Ultraviolet-Visible (UV-Vis) Spectrometer

UV-Vis spectrometer works by passing light through the sample and the absorbance will be obtained from the transmittance of light [4]. The absorbance of each sample was determined by using UV-Vis Varian 50 Conc with the range of wavelength 200 nm to 800l nm. Other than that, the main aim to get the optical properties of each dye was to calculate the energy bandgap. The energy band gap was calculated using the formula,

$$E = \frac{hc}{\lambda} \quad (1)$$

Where $h, Planck\ constant = 6.63 \times 10^{-34} Js$

$$c, speed\ of\ light = 3.0 \times 10^{8} ms^{-1}$$

$$1eV = 1.60 \times 10^{-19} J$$

2.6.2 Fourier Transform Infrared (FTIR) Spectrometer

Basically, the working principle of FTIR is by using the infrared beam that directly passed through the chamber of a sample and measured the transmittance at each of the wavelengths [5]. Other than that, the functional group of the organic and inorganic samples can also be detected using FTIR by observing at a specific wavelength. The optical properties of each sample were observed by using Varian 3100 FTIR.

2.7 Efficiency of DSSC

The efficiency of DSSC can be obtained from the V-I graph. Initially, the experiment was set up under the sunlight. The surface of the sandwich ITO glasses for each sample was exposed to sunlight to make sure the photon can be absorbed by the dyes. Then, the resistor and the multimeter were connected to the solar cell using crocodile clips. To get efficiency, the voltage of each dye was recorded after each of the samples was been tested. After that, the current was calculated using formula Ohm's Law. Then, the current obtained was used to calculate the efficiency by using the equation,

$$\eta = \frac{P_{cell}}{P_{const}} \times 100 \qquad (2)$$

RESULT AND DISCUSSION

Table 1 shows the summarization colours of each dyes after extract in four different solvents.

Table 2: The summarization color of the dyes in four different solvents

Henna Leaves	Types of Solvents	Turmeric
Very deep dark brown	A	Very bright orange
Light red	B	Cloudy yellow
Dark brown	C	Bright orange
Red	D	Light orange

Figure 2 and figure 3 shows the FTIR analysis for henna leaves and turmeric in four different solvents.

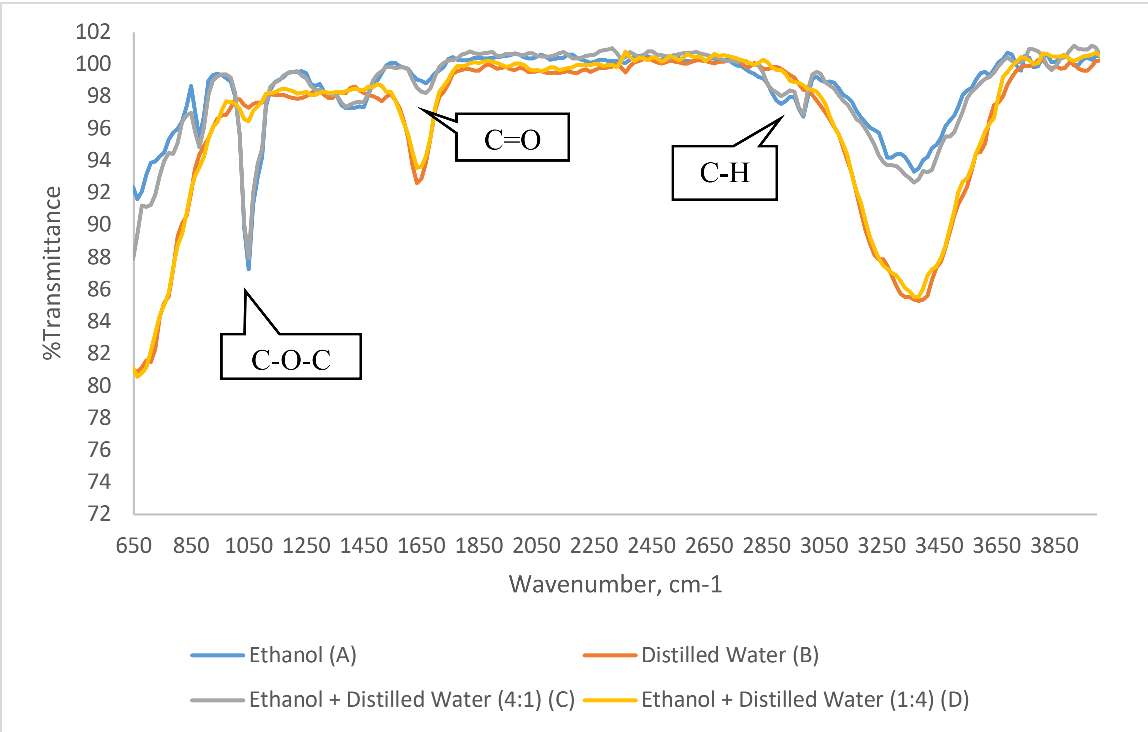

Figure 2: FTIR analysis for henna leaves in four different solvents

Figure 2 above shows the FTIR analysis for henna leaves in four different solvents. The analysis was done in a range of 650 cm^{-1} to 3850 cm^{-1}. As can be seen from the graph, the results obtained were slightly similar and just have some differences in the range of wavenumber and size of peaks. For henna leaves that immersed in ethanol (A) and mixture ethanol and distilled water with ratio 4:1 (C), there were two strong stretching peaks at 880 cm^{-1} for solvent A and 879 cm^{-1} in solvent C which contributed to the C-H of the group for alkene. For the two strong peaks at 1049 cm^{-1} were C-O-C of the ester group. Besides, there were also medium stretching bands of C-H which was alkane at the range of 1435 cm^{-1} to 1450 cm^{-1} and range of 2850 cm^{-1} to 3000 cm^{-1} in two solvents. Next, for stretching bands at the range of wavenumber of 1650 cm^{-1}, there were C=O which was carbonyl group that presence in solvent A and C. After that, the broadband at the range of 3286 cm^{-1} to 3363 cm^{-1} for solvent A and 3251 cm^{-1} to 3363 cm^{-1} for solvent C were stretching bands to O-H which was a hydroxyl group. For henna leaves in distilled water (B) and a mixture of ethanol and distilled water 1:4 (D), there was carbonyl group, C=O at a wavenumber of 1635 cm^{-1} for solvent B and 1651 cm^{-1} for solvent D. However, for solvent D the small shoulder band was present due to the existence of ester, C-O-C. The strong, broad stretching band at the range of 3000 cm^{-1} to 3650 cm^{-1} allocated for O-H functional group.

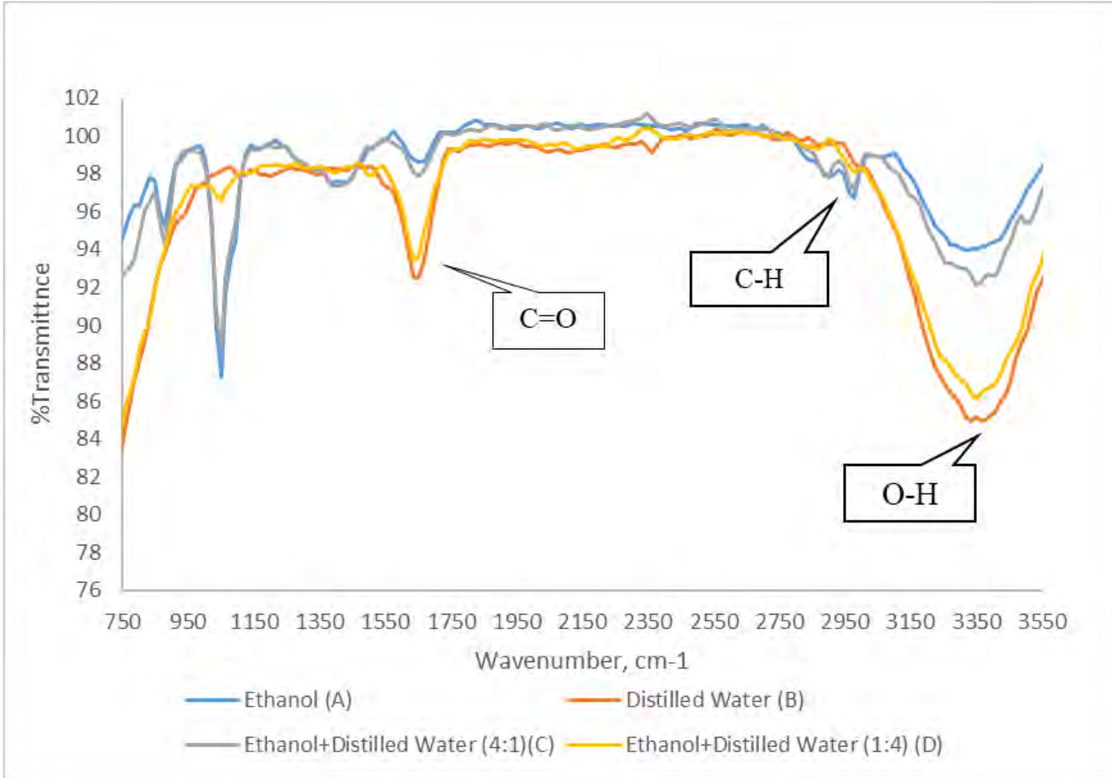

Figure 3: FTIR analysis for turmeric in four different solvents

Turmeric dyes were tested in FTIR at the range of 750 cm^{-1} to 3550 cm^{-1}. As can be seen from the graph in figure 3, the results for each dye were quite the same but there still have some differences. At the stretching bending 879 cm^{-1}, the two peaks attributed to solvent A and C were C-H functional group for alkene was presence. For sharp stretching band at the same wavenumber 1049 cm^{-1} for solvent A and solvent C but small shoulder band for solvent D, the peak allocated for C-O-C which was ester. There was the existence of C-H that appeared in stretching bending at 1388 cm^{-1} for solvent A and 1404 cm^{-1} for solvent C represented alkane. The C=O existed in these four solvents at strong stretching bands of 1651 cm^{-1} for solvent B and 1635 cm^{-1} in solvent D. However, the small shoulder band were presence for C=O in wavenumber 1666 cm^{-1} for solvent A and 1651 cm^{-1} for solvent C. Other than that, the medium peaks of C-H that illustrated in the figure above which at the range of 2750 cm^{-1} to 2950 cm^{-1} for both solvent A and C represented alkane. The strong broad stretching bands of O-H was presence in four solvents in a range of wave number 3000 cm^{-1} to 3550 cm^{-1}.

Table 2 shows the summarization of energy bandgap and efficiency for each dye. Solvent A is for ethanol solvent, Solvent B is for distilled water, Solvent C is for a mixture of ethanol and distilled water (4:1) and Solvent D is for a mixture of ethanol and distilled water (1:4). As can be seen from the table below, the low energy bandgap obtained the highest efficiency compared to the highest energy bandgap. Henna leaves that immersed in solvent C gave the highest efficiency compared to other dyes.

Table 3: The summarization of energy bandgap and efficiency for each dye

Dyes	Energy Bandgap, eV	Efficiency, %
Henna + Solvent A	1.9	7.02×10^{-8}
Henna + Solvent B	2.41	1.45×10^{-8}
Henna + Solvent C	1.89	1.32×10^{-7}
Henna + Solvent D	2.36	4.7×10^{-8}
Turmeric + Solvent A	2.86	3.72×10^{-8}
Turmeric + Solvent B	4.29	5.14×10^{-9}
Turmeric + Solvent C	2.87	2.85×10^{-8}
Turmeric + Solvent D	4.3	2.34×10^{-9}

CONCLUSION

To conclude, the henna leaves and turmeric were accomplished synthesize to be used as sensitizers in dye-sensitized solar cells (DSSC). Other than that, the effect of ratio variation between ethanol and distilled water used as solvents gave different results for each dye. The optical properties that have been analyzed using UV-Vis and FTIR were proved that each dye can be used as sensitizers in DSSC and all at once can enhance the efficiency of the solar cell.

The optimization of dyes used can be seen from UV-Vis result which was henna leaves in a mixture of ethanol and distilled water with ratio 4:1 (C) yielded 659 nm wavelength compared to other solvents. Other than that, the highest efficiency for henna leaves in a mixture of ethanol and distilled water with ratio 4:1 (C) obtained 1.32×10^{-7} %, higher than other solvents due to the lowest energy band gap which was 1.89 eV. Other than that, henna leaves especially those extracted in a mixture of ethanol and distilled water with ratio 4:1 (C) were the best and suitable dyes compared to turmeric because henna leaves contain chlorophyll and can absorb a high amount of photon from sunlight.

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