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Visible light absorption and photosensitizing characteristics of natural yellow 3 extracted from *Curcuma Longa L.* for Dye-Sensitized solar cell

N Sofyan^{1,2}, F W Situmorang¹, A Ridhova¹, A H Yuwono^{1,2} and A Udhiarto³

¹ Department of Metallurgical and Materials Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia

² Tropical renewable Energy Center, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia

³ Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia

E-mail : nofrijon.sofyan@ui.ac.id

Abstract. Curcumin has known to have a long intense wavelength absorption in the visible region ranging from 420-580 nm. Because of that, curcumin is a promising material for use in dye sensitized solar cells. In this work, curcumin was extracted from turmeric (*Curcuma longa L.*) through a simple extraction technique using different organic solvents, i.e. acetone, methanol, and ethanol. The results from the extraction were applied as a sensitizer in dye sensitized solar cell applications. Suitable solvent for extraction that could give high efficiency in DSSC device were analysed. Characterization of the dye was performed using Fourier transform infrared (FTIR) and ultra violet-visible (UV-Vis), while the performance of DSSC was analysed through a simple current and potential different (I-V) curve analyser. The infrared results showed that all of the turmeric extracted dyes have the same tendency with the characteristic of curcumin. UV-Vis absorbance characteristics of the curcumin natural dye extracted using acetone, ethanol and methanol has the same tendency with plateau-like absorbance peak at around 490, 492, and 505 nm, respectively. The maximum power conversion efficiency (PCE) is found to be 7.88% obtained from the solvent of ethanol whereas the PCE obtained from other natural dyes extracted using acetone and methanol are found to be low, 2.23% and 1.25%, respectively. This finding is convincing in terms of efficiency in which the value from the dye extracted using ethanol has higher efficiency than that of the commercial organic dye RK1 with a PCE of 4.02%.

1. Introduction

Dye sensitized solar cells (DSSCs), a third generation of solar cells, have attracted considerable attention due to their environmental friendliness, non-toxicity and low cost of production [1–3]. The principle of DSSCs is based on the photovoltaic effect that converts the sun-light photon into electrical energy through photo-electrochemical principle of band gap semiconductor and sensitization of the dye solution [4]. A DSSC is generally composed of conducting electrode, electrolyte, sensitizer and a counter electrode. Conducting electrode is usually in the forms of fluorine doped tin oxide (FTO) or indium doped tin oxide (ITO), semiconductor layers such as TiO₂, ZnO, CdSe, CdS, WO₃, Fe₂O₃, SnO₂, Nb₂O₅, and Ta₂O₅ [5]. The electrolyte is needed in process of reduction and oxidation reaction



such as triiodide solution. The sensitizer dye will act as photon energy absorber such as anthocyanin, chlorophyll, carotenoid, and flavonoid that can so easy to be attained. The counter electrode will function to collect the electrons and at the same time to catalyse the reduction of electrolyte. Considering its function, the sensitizer dye is indeed one of the important elements that plays a significant role to enhance the performance of DSSCs in which it absorbs light spectrum and thus works as an anchoring group to improve the injection of electron into conduction band of TiO_2 .

Some of inorganic compound such as porphyrins, platinum complex, phthalocyanines, and fluorescent dye have been used as a sensitizer. However, their availability is rather limited and difficult to be synthesized, making these compounds expensive in price. In order to overcome this problem, natural dyes are the best solution. They are not only abundance and easy to be attained, but also cheap, easily synthesized, biodegradable, and environmentally friendly. Interestingly, the use of curcumin derived dyes as sensitizers in dye sensitized solar cells has not attracted significant research attention [1]. In this paper, curcumin is used as a sensitizer. Curcumin can be extracted from turmeric or *Curcuma longa* Linn.

Turmeric is a rhizomatous herbaceous perennial plant (*Curcuma longa* Linn) of the ginger family. It is widely used as a spice, colouring agent in food processing industries, household medicine and insect repellent [6]. Moreover, under in vitro and in vivo studies, it has been confirmed that turmeric extracts have powerful biological activities, such as anti-inflammatory [7], antibacterial [8], antidepressant [9], antidiabetic [10], antitumor [11], immunomodulatory [12] and gastroprotective properties [13]. Turmeric or *Curcuma longa* is cultivated extensively in south and southeast tropical Asia, such as Bangladesh, China, Taiwan, Pakistan, Sri Lanka, Myanmar, and Indonesia. Turmeric or *Curcuma longa* is not only abundance but also easy to be attained. In 2014, Indonesia produced about 112,088.181 Kg of turmeric to be used as a spice and colouring agent in food processing industries. The bio-active polyphenol component of turmeric is curcumin, also known as C.I. 75300 or Natural Yellow 3. The scientific chemical name of this active component is known as (1E, 6E)-1, 7-bis (4-hydroxy-3-methoxyphenyl)-1, 6 heptadiene-3, 5-dione [14, 15].

Curcumin is not easily dissolve in water. For this reason, the solvent used to extract the curcumin from the turmeric would be an important consideration. Previous investigation has used various types of solvents such as ethanol and acetonitrile. The result showed that ethanol has an efficiency of around 0.60% and acetonitrile 0.41% [1, 16]. In the current investigation, three different solvents, *i.e.* ethanol, methanol, and acetone were used to extract the curcumin or Natural Yellow 3 from the turmeric. The dyes resulted from the extraction were investigated in terms of their absorption spectra, functional groups, and their performance in the fabricated DSSC device. The results are presented and discussed detail in this article.

2. Experimental Setup

The natural material *Curcuma longa* L. was purchased from traditional market in Jakarta. The chemicals were titanium dioxide (TiO_2) nanoparticle (P-25 Degussa), platinum paste (Platisol, Solaronix), electrolyte (Iodolyte, Solaronix), ethanol 99% and methanol 99% (Merck) acetone and fluorine-doped tin oxide glass (FTO, Solaronix).

One kg of fresh turmeric was thoroughly washed with tap water and dried under ambient condition. The dried turmeric was crushed in a blender and air dried at room temperature. The crushed dried turmeric was grinded into fine powders and further was subjected to separation through a vibrating sieving machine. The fine turmeric powders were collected and put in a seal bottle. Curcumin extraction was carried out by mixing the fine turmeric powder in each of acetone, ethanol, and methanol. All of the mixtures have the same ratio of turmeric powder and solvent of 1:10 w/v. The mixture was stirred for 24 hours at room temperature. The extracted dye solutions were filtered and stored in a dark glass bottles for further characterization and DSSC device fabrication. The extracted dye solution was characterized using attenuated reflectance Fourier transform infrared (ATR FTIR, PerkinElmer Spectrum 2) for functional groups and ultra violet-visible (UV-Vis, PerkinElmer Lambda

25) for the dye absorption characteristic. As a comparison, 2.5 mg commercial organic dye (Sensitizer RK1, Solaronix) dissolved in 100 mL ethanol was also examined.

The electrode was prepared by adding one gr of TiO_2 nanoparticle P25 into 10 ml ethanol and stirred. Two drops of TRITON X-100 (Sigma Aldrich) were added into the paste and stirred again until a homogeneous phase was obtained. This white paste was then deposited onto fluorine doped tin oxide (FTO) glass using doctor blade method. For this purpose, the Scotch tape was used to adjust the thickness of the TiO_2 paste deposit with an area of 1 cm by 1 cm. The paste was dried at 450°C for one hour and cool down before soaking it in the curcumin dye solution for 6 hours and air dried. As a comparison, the commercial RK1 dye (Sensitizer RK1, Solaronix) dissolved in ethanol was used. The counter electrode was prepared using platinum paste deposited on an FTO glass. After the deposition, counter electrode was air dried before sintering it at 450°C for 1 hour.

A double tape was used as an adhesive and to seal both electrode glasses. It also functions as a spacer to avoid the electric contact between the anode and the cathode. Further, electrolyte solution was dropped in the gap between the anode and the cathode. Finally, a binder clip was used to attach the electrodes together. Cell activity was then measured using a simple ammeter whereas the cell performance was examined using a Semiconductor Parameter Analyzer (SPA, Agilent 4155A) with a standard illumination of about 100 mW/cm^2 .

3. Results and Discussion

Fourier transform infrared (FTIR) characterization was carried out to examine the functional group characteristic contained in the turmeric extracted dye. These specific functional groups are expected to be adsorbed onto TiO_2 layer in order to function properly. The dyes spectra were obtained at wavenumber $4000 - 400\text{ cm}^{-1}$ and the results are given in figure 1. The characteristic of pure commercial RK1 dye is given for a comparison.

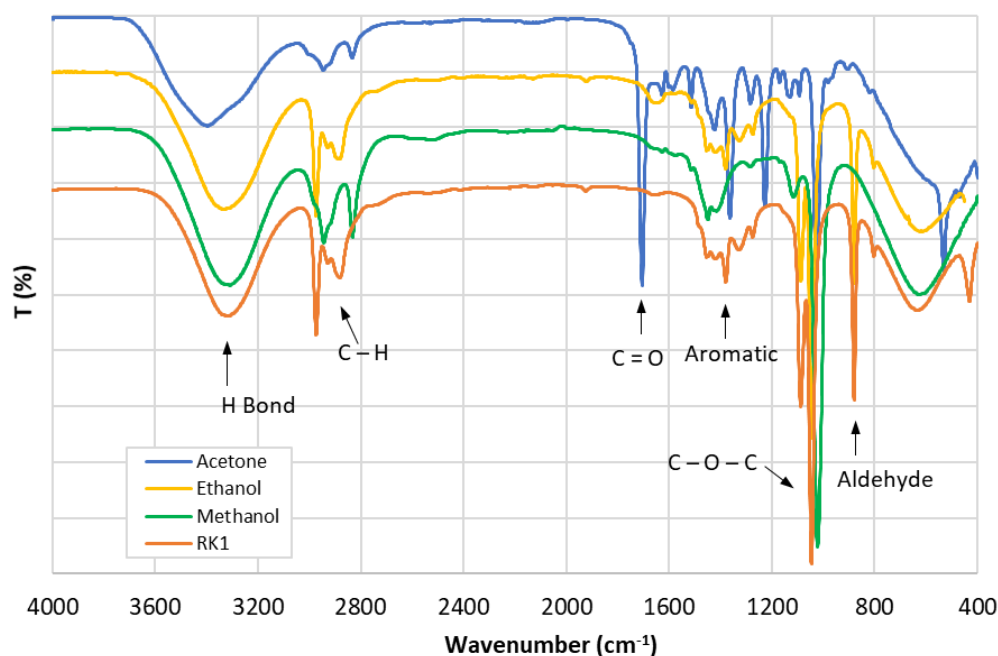


Figure 1. Fourier transform infrared transmittance characteristics of the commercial dye and the turmeric dye extracted using various solvents at wavenumber $4000 - 400\text{ cm}^{-1}$

As seen in figure 1, except for the dye extracted using acetone, all of the spectra show the same tendency with that of the RK1 dye. In the case of the dye extracted using acetone, the absorption intensities of C = O and aromatic bands are higher than that of the other dyes. The absorption intensity of C – H band, however, is shorter than that of the other dyes. Nonetheless, all of the spectra show the appearance of hydrogen bonded OH stretching bands ranging from 3250 to 3450 cm^{-1} . The bands around 2878 to 2973 representing C-H groups stretching [17] are also present. The band at 1640 cm^{-1} indicates C=O stretching vibration. This band, as has been mentioned previously, except for the natural dye extracted using acetone, all are small. The small peak at 1450 cm^{-1} belongs to C – N, whereas the bands at 1423-1274 cm^{-1} belong to aromatic compound. Further, the band at 1045 belongs to C – O, while the stretching vibration of C–O–C esters is found at 1046 cm^{-1} . Due to inherent properties of the organic base natural dye, the aldehydes are also found in the wavelength between 880 cm^{-1} and 800 cm^{-1} .

The presence of carboxyl and hydroxyl group in the natural dye is expected to trigger the interaction with the semiconductor, in this instant to strongly bind onto TiO_2 surface [18]. The interaction between TiO_2 nanoparticle and functional groups of the dye would then will drive the electron transfer from the dye molecules to the conduction band of the semiconductor TiO_2 [19]. UV-Vis spectroscopy was used to examine the absorption spectrum of the dye in the visible range at wavelengths from 400 – 700 nm and the results are given in figure 2.

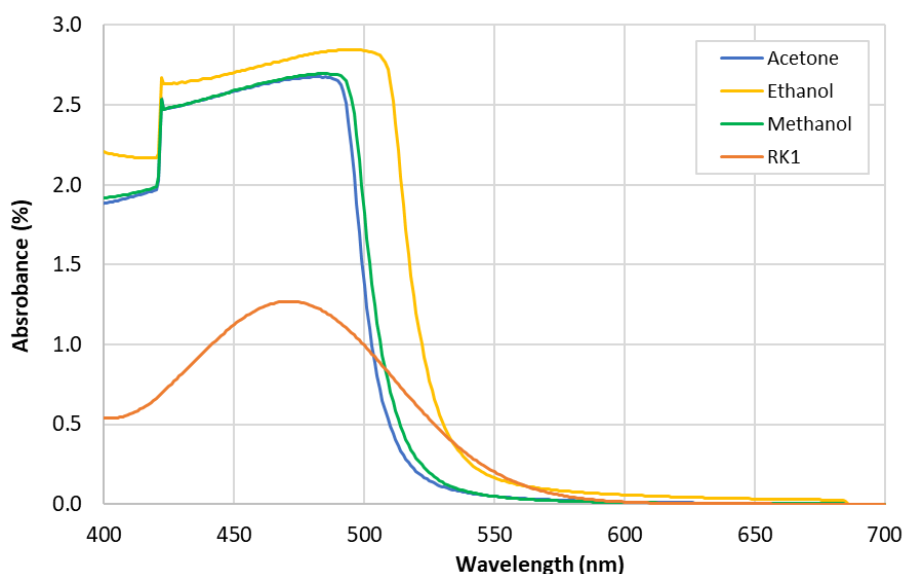


Figure 2. Ultraviolet-visible absorbance characteristics of the commercial RK1 dye and the curcumin natural dye extracted using various solvents at wavelength from 400 – 700 nm

As seen in figure 2, UV-Vis absorbance characteristics of the RK1 commercial dye has a specific absorbance peak at around 474 nm, whereas the curcumin natural dye extracted using acetone, ethanol and methanol has the same tendency with plateau-like absorbance peak at around 490, 492, and 505 nm, respectively. This absorption peak indicates at which the presence of the yellow 3 dye that would absorb high number of photon energy from the visible light source. It can also be noted from the spectra that the absorption characteristic of the dye has a broader absorption wavelength compared to that of the synthetic RK1 dye.

As a sensitizer in the DSSC device, the dye will establish bonds between the oxygen site of TiO_2 semiconductor and the functional groups of the natural dye such as carbonyl (C = O) and or hydroxyl (O-H) groups. Photocurrent activity could then be observed when an incident photon is absorbed by

the natural dye during the service. In this instant, any successful bonding between TiO₂ semiconductor and the natural dye will promote electrons from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) state [21]. Photocurrent-voltage activity of the extracted dye on TiO₂ nanoparticle assembled in DSSC device was examined through a J-V curve characteristic using a semiconductor parameter analyzer and the results are given in figure 3.

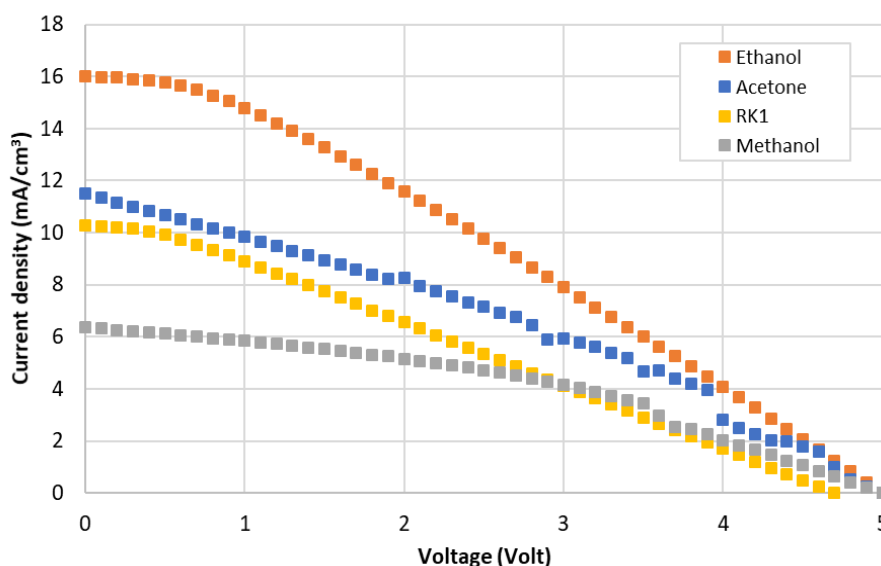


Figure 3. Photocurrent characteristic of the DSSC device sensitized using the commercial dye RK1 and the curcumin natural dyes extracted with various solvents

This J-V curve characteristic was then analyzed to obtain the power conversion efficiency [20]. Based on this analysis, the maximum power conversion efficiency (PCE) was found to be 7.88% obtained from the solvent of ethanol. The PCE obtained from other natural dyes extracted using acetone and methanol are found to be low as seen detail in table 1. This finding is convincing in terms of the PCE in which the value from the dye extracted using ethanol has higher efficiency than that of the commercial organic dye RK1 (4.02%) [22].

Table 1. Power conversion efficiency (PCE) of the DSSC device sensitized the curcumin natural dyes extracted with various solvents and the commercial dye RK1 as a comparison

	Acetone	Ethanol	Methanol	RK1*
V _{oc} (volt)	5.00	5.00	5.00	4.80
I _{oc} (mA)	11.49	16.01	6.37	10.28
V _{max} (volt)	0.20	0.50	0.20	0.40
I _{max} (mA)	11.16	15.76	6.27	10.06
FF	0.04	0.10	0.04	0.08
PCE (%)	2.23	7.88	1.25	4.02

*Source: Ref [22]

4. Conclusion

The results from infrared characterization showed that all of the turmeric extracted dyes indicate to have the same tendency with the characteristic of curcumin. All of the results from UV-Vis examination showed that the dyes have a visible light absorption with a plateau-like at a wavelength of 490, 492, and 505 nm, respectively. The maximum power conversion efficiency (PCE) is found to be 7.88% obtained from the solvent of ethanol. The PCE obtained from other natural dyes extracted using acetone and methanol are found to be low, 2.23% and 1.25%, respectively. This finding is convincing in terms of efficiency in which the value from the dye extracted using ethanol has higher efficiency than that of the commercial organic dye RK1 with a PCE of 4.02%.

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