

## Potential of textile-dye extract as the sensitizer in dye-sensitized solar cells

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**Abstract:** A dye-sensitized solar cell (DSSC) is a device for converting photons from sunlight into electrical energy. In a DSSC, an important role is played by the dye sensitizer, which absorbs light and injects excitation electrons into the conduction band of a semiconductor oxide. As the sensitizer, complex ruthenium-based dyes provide high conversion efficiency but are expensive and scarce. As alternatives to Ru-based dyes, natural ones extracted from plants are environmentally friendly, inexpensive, and abundant. However, in DSSCs natural dyes are yet to offer higher conversion efficiency than that of complex Ru-based dyes, given low absorption in the visible range and low stability. High-purity textile dyes have been investigated as sensitizers in DSSCs, and dispersive azo dyes for textiles have been purified successfully by column chromatography, with a minimum purity of 97.3%. As such, textile-dye extract could be used as a dye in a DSSC by purifying the former using column chromatography. This article describes research on (i) DSSC fabrication and characterization, (ii) column chromatography for purifying dispersive azo dyes, (iii) the absorbance of several types of textile dye, (iv) the characteristics of the textile dye Remazol Red RB-133, and (v) the performance of a DSSC based on that dye.

**Keywords:** Absorbance, DSSC, Dye, Sensitizer, Textile dye

### 1. Introduction

Dye-sensitized solar cells (DSSCs) are third-generation solar cells comprising natural molecules and offer an alternative to silicon solar cells because DSSCs are lightweight, flexible, and simple to fabricate. The main components of a DSSC are its photoanode, electrolyte, and counter-electrode. An important element of the photoanode in a DSSC is the dye sensitizer, which plays a direct role in light absorption, photoelectron production, and electron transfer (Al-alwani et al., 2016).

The dyes that are commonly used in DSSC fabrication processes are ones based on transition metals, such as ruthenium (II) carboxylated polypyridyl complexes, because of

(i) their ability to absorb charge transfer in visible light and (ii) their high efficiency in metal-to-ligand charge-transfer transitions (Duffy, Peter, Rajapakse, & Wijayantha, 2000). Some dyes from the complex Ru group (Ru polypyridyl complexes) are used as charge-transfer sensitizers and have an incident-photon-to-current efficiency of up to 10% with AM 1.5 (the standard spectrum used in solar-cell testing); incident photons are converted into electric current over nearly all the spectrum from ultraviolet (UV) to infrared (Grätzel, 2003). A DSSC with a dye using Ru compounds based on TiO<sub>2</sub> semiconductor nanocrystals can achieve an efficiency of 11.1% with black dye (Chiba et al., 2006) and 11.20% with N719 dye (Grätzel, 2003).

Many natural organic dyes extracted from plants have been tested as low-cost materials to replace expensive and scarce Ru dyes (Al-alwani et al., 2016). Overall, in DSSCs natural dyes are yet to outperform Ru dyes because the former have weak binding energy with TiO<sub>2</sub> semiconductors, low absorption in visible light, and low stability due to photocatalytic degradation with TiO<sub>2</sub>, all of which results in decreased efficiency (Güzel et al., 2018). Other complex metals that can be used as substitutes and exist in large quantities are Fe, Co, Cu, and ditizone and dithizone metals. Complex gallic acids can be used as dyes because dithizone and complex metals have high absorption properties (Ünlü, Çakar, & Özacar, 2018), and waste dyes from textiles contain some heavy metals such as Pb, Cu, Ni, Cr, Fe, and Si as tested by inductively coupled plasma spectroscopy (Yousef et al., 2019).

Azo textile dye has the potential to act as a dye in DSSCs. The initial parameter for assessing the performance of azo-group textile-dye extract is the absorbance peak. As studied by Abdou et al. (2013), the  $J-V$  (current-density–voltage) characteristics of DSSCs with Remazol Red RB-133 (RR-133) textile dye show that textile-dye with advanced purification could be used as a dye sensitizer in DSSCs.

The present narrative review paper reveals the potency of textile-dye extract as a sensitizer in DSSCs. Most of the data used in this review paper are from the paper by Abdou et al. (2013), with others from that by García-González et al. (2020). The absorbance of textile dyes and the performance of a DSSC using a textile dye reveal the potency of textile-dye extract as a sensitizer in DSSCs.

## 2. Experimental

The article was written by showing the secondary data obtained from journal databases such as *Science Direct* and google scholar. Research and review articles used in this article relate to DSSC fabrication processes, textile dye characteristics, DSSC performance parameters.

## 3. Results and Discussion

### 3.1. DSSC fabrication

Azo textile dye could be extracted by column chromatography (Umbuzeiro et al., 2017). Then, absorption spectra of textile dye could be obtained by using UV-vis spectrophotometer (Abdou, Hafez, Bakir, & Abdel-Mottaleb, 2013). For DSSC

fabrication, TiO<sub>2</sub> was coated into the conductive glass using doctor blade method (Abdou et al., 2013; Golshan, Osfour, Azin, & Jalali, 2020; Hemalatha et al., 2012; Seyednoruziyan et al., 2021; Suyitno, Saputra, Supriyanto, & Arifin, 2015). Annealing process of the conductive glass coated semiconductor oxide fabrication could be done at about 500°C (Omar, Ali, & Abd Rahim, 2020) or 450°C for 2 h (Chang & Lo, 2010). There are also other studies with the heat treatment carried out at 450°C (Hemalatha et al., 2012; Suyitno et al., 2015) Dye-loading step of the textile dye was done by immersing method (Abdou et al., 2013), immersing method for 24 h (Seyednoruziyan et al., 2021). For the counter-electrode fabrication, catalyst solution was coated into the conductive glass by spin-coating method (Yildiz et al., 2019). Catalyst material could be platinum (Pt) (Chang & Lo, 2010; Seyednoruziyan et al., 2021). Assembly of photoanode and counter electrode in the form of sandwich structure was done using surlyn (Santos, 2013; Seyednoruziyan et al., 2021) then electrolyte solution such as the mixture of LiI 0.1 M and I<sub>2</sub> 0.05 M solutions could be injected into the gap of both electrodes (Seyednoruziyan et al., 2021). Current-voltage characterization of the DSSC cell was done by using AM1.5 solar simulator (El-REFI, 2013).

### 3.2. Chromatography Column

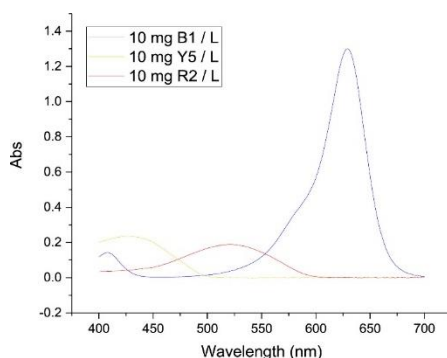
**Table 1.** Initial and final purity values of dispersive azo dyes (Umbuzeiro et al., 2017).

| No. | Dye                            | Initial purity [% area] | Final purity [% area] |
|-----|--------------------------------|-------------------------|-----------------------|
| 1   | <i>C.I. Disperse Violet 93</i> | 68.6                    | 97.3                  |
| 2   | <i>C.I. Disperse Blue 291</i>  | 94.6                    | 99.1                  |
| 3   | <i>C.I. Disperse Blue 373</i>  | 88.9                    | 97.3                  |

Purification of dyes could be carried out by flash column chromatography (Freeman, Hao, McIntosh, Posey, & Hsu, 1990). Researchwork conducted by Umbuzeiro et al. (2017) was conducted to obtain pure dyes to be tested for their ecotoxicity. The 3 purified dispersive azo dyes are C.I. Disperse Violet 93, C.I. Disperse Blue 291, C.I. Disperse Blue 373 is shown in Table 1. Thin layer chromatography was used to filter the eluents required for maximum column chromatography and to analyze column fractions. The solvents used were hexane and ethyl acetate. Column glass (2.5 cm in diameter and 60 cm long) was used with glass wool on the bottom, followed by 2 cm thick sand, then a 30 cm layer of gel, then a 2 cm of dye coated with silica gel. The target dye is obtained by dissolving 0.5 grams of those dyes in 10 mL ethyl acetate and adding 5 grams of silica gel which is then evaporated. The top part of the purification process was sand with a thickness of 2 cm. A mixture of solvent (2 hexane / 1 ethyl acetate) and air pressure were used for column confining and to test column fractions. In general, 1 L solution was used and 50 mL of the fraction was obtained which is analyzed by TLC to confirm that the dye has been in the purification process which then obtained target dye. These steps were then repeated so that 2 grams of target dye were obtained which would be tested for its ecotoxicity. The purity of the dye was tested by HPLC analysis. The characterization results obtained maximum wavelength for C.I. Disperse Blue 291, C.I. Disband Violet

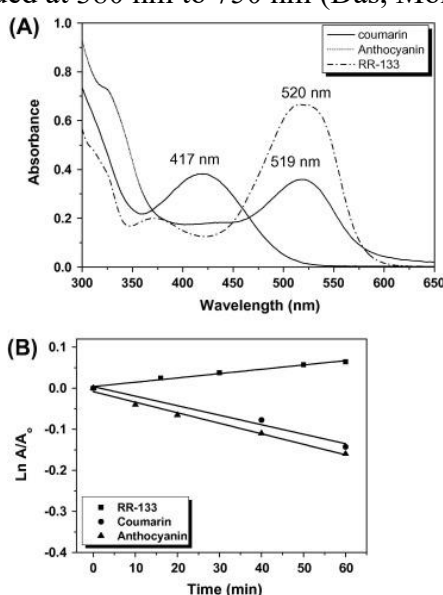
93, C.I. Disperse Blue 373 that have a value of 616 nm, 562 nm, 600 nm, respectively. HPLC analysis of commercial dyes done before and after purification showed increased purity in the using of column chromatography method with the lowest value of 97.3% (Umbuzeiro et al., 2017). These results indicate that it is possible for azo dyes to be further purified using the column chromatography method thus emerge the potential for using the textile dye extract as the sensitizers in DSSCs.

### 3.3. Absorbance and photostability characteristics of textile dyes



**Figure 1.** Absorption spectra of azo dyes (García-González et al., 2020).

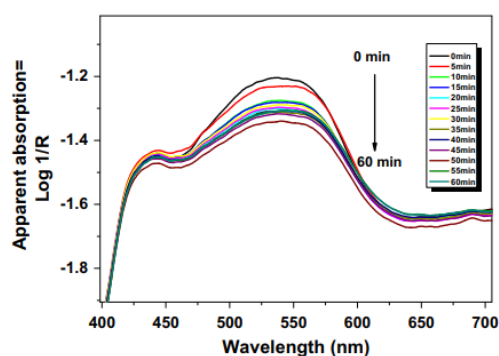
The absorption spectra for azo dyes Yellow 5 (Y5), Blue 1 (B1), and Red 2 (R2) with concentration of 10 mg/L are shown in Figure 1, where the absorbance peaks are 426, 629, and 520 nm, respectively (García-González et al., 2020). These values show that these types of dye have the potential to be used as sensitizers in DSSCs; see also the research by Abdou et al. (2013), which showed that coumarin dye with an absorbance peak of 417 nm can be used as a dye in a DSSC. The absorption spectra for the three azo dyes is in accordance with the maximum wavelength value of dispersive azo dyes in the research of Umbuzeiro et al. (2017) because both are located in the visible range of incident light which is valued at 380 nm to 750 nm (Das, Mondal, & Palai, 2020).



**Figure 2.** (A) Light absorption spectra of dye solutions of anthocyanin, RR-133, and coumarin. (B) Photostability kinetic rate of pure solutions (aqueous) of RR-133,

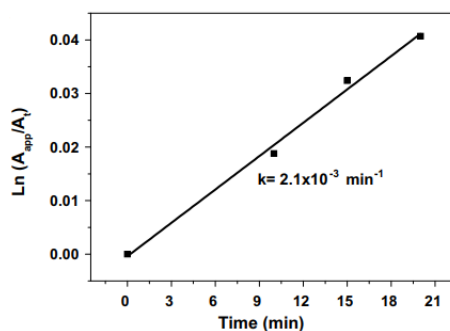
coumarin, and anthocyanin with concentrations of  $4 \times 10^{-5}$  M,  $1 \times 10^{-4}$  M, and 0.5 g/l, respectively (Abdou et al., 2013).

Figure 2(A) shows the absorption spectra of three types of dye sensitizer, namely natural dyes in the form of anthocyanins which are roselle flower extracts (*Hibiscus sabdariffa* L.) and coumarin, and also a synthetic textile dye in the form of RR-133. The absorption peaks of the RR-133, anthocyanin, and coumarin dyes are at 520, 519, and 417 nm, respectively, and that of RR-133 shows that it has a wider absorption spectrum compared to that of the coumarin dye. The three dyes exhibited resistance to UV-vis irradiation photolysis, thereby showing that they have high photostability (Abdou et al., 2013). The absorbance peak of RR-133, which is larger than those of anthocyanin and coumarin, also indicates the potential of textile dyes as dyes where anthocyanins have been widely studied for sensitizer in DSSC. The light absorbance peak of Remazole Red indicates that the textile dye has a wide light absorption range compared to the other two dyes. The peak light absorption value of Remazole Red shows that azo dyes have a light absorption peak in the visible region as well as azo dyes in the previous section. Figure 2(B) shows the photostability kinetic rate of the three dyes under 100-mW/cm<sup>2</sup> UV-vis light irradiation for 1 h. Three types of dye (sensitizer) consisting of Remazole Red, anthocyanin, and 7-methyl coumarin showed resistance to photolysis directly by UV-Vis irradiation as shown in Figure 2(B). This shows the high photostability value of the three types of dye. Azo dyes in both the research of Umbuzeiro et al. (2017) and Garcia-Gonzales et al. (2020) have the potential as DSSC sensitizers when viewed from the wavelength value of the resulting absorption spectra. This value can be compared with the absorption spectrum of 7-methyl-coumarin dye which is 417 nm. 7-methyl coumarin has been used successfully as a dye in DSSC as research by Abdou et al. (2013).



**Figure 3.** The effect of irradiation on the color change diffuse reflectance on TiO<sub>2</sub>/Remazole Red dye photoanode (Abdou et al., 2013).

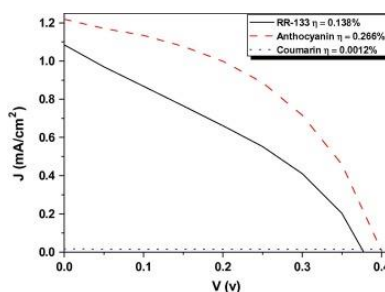
The results of the reflectance diffuse spectroscopy under UV-Vis irradiation are shown in Figure 3. The TiO<sub>2</sub>/ Remazole Red dye apparent absorption has peaks at about 440 nm and 537 nm. These values are still in the visible light spectra. The apparent absorption of TiO<sub>2</sub> / Remazole Red dye at the beginning of the irradiation was higher than that of irradiation after a certain time interval as shown in Figure 3. This could be due to color degradation that occurs after a certain time.



**Figure 4.** Photostability graph of TiO<sub>2</sub>/Remazole Red dye electrode (Abdou et al., 2013).

Figure 4 shows the photostability graph of TiO<sub>2</sub>/Remazole Red dye electrode. The value of the kinetic rate (*k*) of the electrode shows that the dye will have color degradation. The kinetic rate value for the Remazole Red dye is  $2,1 \times 10^{-3} \text{ min}^{-1}$  while the kinetic rate values for anthocyanin and 7-methyl coumarin dyes were  $1,6 \times 10^{-3} \text{ min}^{-1}$  and  $1,9 \times 10^{-3} \text{ min}^{-1}$  (Abdou et al., 2013). This shows that Remazole Red dye has color degradation faster than anthocyanin dye and 7-methyl coumarin. Anthocyanin dye are more stable than Remazole Red and 7-methyl coumarin dyes because of a lower color degradation kinetic rate. The value of the kinetic rate associated with the color degradation can cause a decrease in the apparent absorption value at certain time intervals as shown in Figure 3.

### 3.4. Performance of DSSC using Remazole Red RB-133 textile dye



**Figure 5.** *J*–*V* curves for DSSCs with RR-133, anthocyanin, and coumarin dyes (Abdou et al., 2013)

Figure 5 shows the *J*–*V* curves for DSSCs with RR-133, anthocyanin, and coumarin dyes, and Table 2 lists the performance parameters of the DSSCs.

**Table 2.** DSSC performance parameters (Abdou et al., 2013)

| Dye         | $V_{oc}$<br>[mV] | $J_{sc}$<br>[mA/cm <sup>2</sup> ] | Fill factor <i>FF</i><br>[%] | Efficiency $\eta$<br>[%] <sup>a</sup> |
|-------------|------------------|-----------------------------------|------------------------------|---------------------------------------|
| Anthocyanin | 0.5              | 0.203                             | 0.42                         | 0.27                                  |
| RR-133      | 0.4              | 0.173                             | 0.32                         | 0.14                                  |
| Coumarin    | 0.2              | 0.003                             | 0.38                         | 0.001                                 |

<sup>a</sup>  $\pm 0.02$  for the anthocyanin and RR-133 dyes

Although the current density ( $J_{SC}$ ), open-circuit voltage ( $V_{OC}$ ), fill factor, and conversion efficiency ( $\eta$ ) of the RR-133 dye are lower than those of anthocyanin dyes as indicated in Table 2, the values indicate nevertheless that textile dyes could succeed in DSSC applications. The results in Table 1 also show that anthocyanin dyes have fewer acid protons than do RR-133 and coumarin and/or that using anthocyanin dyes accelerates the recombination of electrons injected with electrolyte (Kisserwan & Ghaddar, 2010). Wongcharee et al. (2007) also studied extracts of natural anthocyanin dyes from roselle (*Hibiscus sabdariffa* L.) and blue pea (*Clitoria ternatea*) flowers as sensitizers in DSSCs. The conversion efficiencies obtained for dye with blue-pea extract, rosella flower, and a mixture of the two were 0.05%, 0.37%, and 0.15%, respectively. The absorption peaks for the blue-pea-extract dye were near 580 and 620 nm, while that for the rosella-extract dye was near 520 nm. Those conversion efficiency value shows the success of the dye used in the DSSC application.

The open-circuit voltage ( $V_{OC}$ ) of DSSC with anthocyanin dye has the highest value compared to Remazole Red and 7-methyl coumarin dyes while the short-circuit current density ( $J_{SC}$ ) value with anthocyanin dye also has the highest value compared to the other two dyes. The current density value is influenced by a good light harvesting ability (Abdou et al., 2013). This shows that anthocyanin dye have better light harvesting than those of Remazole Red and 7-methyl coumarin dyes. When associated with the absorbance characteristics of the material as shown in Figure 2(A), the absorbance peak of anthocyanin and Remazole Red dyes has almost the same value while the absorbance peak of 7-methyl coumarin dye is lower than the two dyes. The peak absorbance value of the dye and the DSSC current density can be related where the higher the absorbance value, the larger the current density value. This is confirmed by the nature of the material which is one of the short-circuit current factors (Al-alwani et al., 2016). The value of the open-circuit voltage ( $V_{OC}$ ) is influenced by the number of acid protons in dye or the recombination rate of electrons injected with electrolytes as mentioned by Kisserwan & Ghaddar (2010). Open circuit voltage with anthocyanin dye were higher than Remazole Red and 7-methyl coumarin dyes.  $V_{OC}$  values of DSSC using anthocyanin, Remazole Red, and 7-methyl coumarin dyes were 0.5 mV, 0.4 mV, and 0.2 mV respectively. Those of values correspond to the factors that affect the open-circuit voltage, namely the number of acid protons and the recombination rate of electrons.

The DSSC conversion efficiency values for anthocyanin dye, Remazole Red dye, and 7-methyl coumarin dye were  $(0.27 \pm 0.02)\%$ ,  $(0.14 \pm 0.02)\%$ , and 0.0012%, respectively (Abdou et al., 2013). DSSC using anthocyanin dye has a higher conversion efficiency value compared to DSSC using Remazole Red dye and 7-methyl coumarin dye. Those of values could be due to better absorption on the  $TiO_2$  surface of anthocyanin dye. The low conversion efficiency on DSSC using 7-methyl coumarin dye could be caused by weak absorption with the  $TiO_2$  surface and a mismatch between the energy of the excited state and the energy of the  $TiO_2$  conduction band gap (Abdou et al., 2013). Good absorption between anthocyanin dye with the  $TiO_2$  surface is due to natural pigments (anthocyanins) that could form bonds with the oxygen site of  $TiO_2$  through the help of carbonyl (C = O) and hydroxyl (O-H) groups (Zhang & Cole, 2015). The short-circuit current generated by

the DSSC could be influenced by the energy difference between the HOMO (Highest Occupied Molecular Orbital) level and the LUMO (Lowest Unoccupied Molecular Orbital) level of dye which is equivalent to the band gap of semiconductors (Al-alwani et al., 2016). The resulting photocurrent can affect the DSSC conversion efficiency.

The performance parameters of DSSC with Remazole Red dye could be compared with DSSC using other types of textile dyes, namely vat dye and hot reactive dye which are included in the anthraquinone group as studied by Yadav et al. (2020). TiO<sub>2</sub> with rutile phase was used as photoanode in that study while the counter-electrode used was platinum. The electrolytes used were 1butyle-3methyle inidazolium iodide (BMIT), 4-tert butyl pyridine, lithium iodide, and iodine while FTO glass was used as a substrate (Yadav, Chaudhary, Negi, & Gupta, 2020).

**Table 3.** DSSC performance parameters (Yadav et al., 2020).

| Dye          | $V_{oc}$ [V] | $J_{sc}$ [mA/cm <sup>2</sup> ] | Fill Factor<br>FF[%] | Efficiency [%] |
|--------------|--------------|--------------------------------|----------------------|----------------|
| hot reactive | 0.5599       | 6.65                           | 32.90                | 1.20           |
| vat          | 0.3870       | 3.76                           | 35.01                | 0.51           |

Hot reactive dye has a wide absorption spectrum that lies between 300 nm to 700 nm. The absorbance peaks of hot reactive dye lie at the wavelengths of 345 nm, 525 nm, and 667 nm. Vat dye has an absorption spectrum ranging from 300 nm to 750 nm. The absorbance peaks of vat dye were at 324 nm and 659 nm lengths. DSSC performance parameters using hot reactive dye and vat dye are shown in Table 3. The current density-voltage (J-V) characteristic in the study of Yadav *et al.* (2020) was done under AM 1.5G irradiation.

The short-circuit current density of DSSC with hot reactive dye is higher than that of DSSC with vat dye due to the good absorption characteristics and better crystallinity of TiO<sub>2</sub>/hot reactive than TiO<sub>2</sub>/vat dye. Good light absorption leads to increased light harvesting while good crystallinity leads to increased charge transport (Yadav et al., 2020). When compared to using Remazole Red dye, hot reactive dye and vat dye have larger open-circuit voltage and short-circuit current values except for vat dye with slightly smaller open-circuit voltage values. DSSC based on hot reactive dye and vat dye showed a higher conversion efficiency value than the anthocyanin dye, Remazole Red-133 dye, and coumarin dye in the study of Abdou et al. (2013). This shows an increase in DSSC performance with textile dyes.

**Table 4.** DSSC performance parameters using some sensitizers.

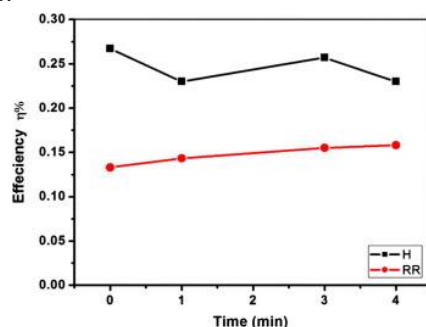
| Dye                                   | $\lambda_{max}$ | $V_{oc}$<br>[V] | $J_{sc}$<br>[mA/cm <sup>2</sup> ] | Fill<br>factor<br>FF [%] | Efficiency<br>$\eta$ [%] | Ref.                       |
|---------------------------------------|-----------------|-----------------|-----------------------------------|--------------------------|--------------------------|----------------------------|
| Anthocyanin<br>compounds<br>(roselle) | 519 nm          | 0.5             | 0.203                             | 0.42                     | 0.27±0.02                | (Abdou<br>et al.,<br>2013) |



| Dye   | $\lambda_{max}$                    | $V_{OC}$<br>[V]   | $J_{SC}$<br>[mA/cm <sup>2</sup> ] | Fill factor<br>FF [%] | Efficiency<br>$\eta$ [%] | Ref.                 |
|---|------------------------------------|-------------------|-----------------------------------|-----------------------|--------------------------|----------------------|
| flower extracts<br>)                                  |                                    |                   |                                   |                       |                          |                      |
| Anthocyanin<br>(barberry<br>fruit extracts)           | 522 nm                             | 0.57<br>4         | 5.47                              | 0,64                  | 2.01                     | (Güzel et al., 2018) |
| Anthocyanin<br>(mulberry<br>fruit extracts)           | 543 nm                             | 0.55<br>5         | 1.89                              | 0.49                  | 0.548                    | (Chang & Lo, 2010)   |
| 7-methyl<br>coumarin                                  | 417 nm                             | 0.2               | 0.003                             | 0.38                  | 0.001±0.0<br>2           | (Abdou et al., 2013) |
| D- $\pi$ -A azo<br>bridge of<br>coumarin<br>thiophene | 401<br>nm,<br>454 nm               | 0.62<br>±0.0<br>1 | 10.28±0,3<br>0                    | 0.687±<br>0.002       | 4.5±0.2                  | (Ayare et al., 2020) |
| Remazole<br>Red RB-133                                | 520 nm                             | 0.4               | 0.173                             | 0.32                  | 0.14                     | (Abdou et al., 2013) |
| Hot reactive  | 345<br>nm,<br>525<br>nm,<br>667 nm | 0.55<br>99        | 6.65                              | 0,329                 | 1.20                     | (Yadav et al., 2020) |
| Vat   | 324<br>nm,<br>659 nm               | 0.38<br>70        | 3.76                              | 0.3501                | 0.51                     | (Yadav et al., 2020) |

Some of sensitizers that have been used in DSSC applications are shown in Table 4. Dye (sensitizer) that has an absorbance peak value of more than 519 nm has the lowest current density value of 0.173 mA/cm<sup>2</sup> and a minimum open circuit voltage value of 0.3870 V. The D- $\pi$ -A azo bridge coumarin thiophene dye has a smaller absorbance peak value ( 401 nm and 454 nm) but shows higher  $I_{SC}$  and  $V_{OC}$  values because they have a Donor- $\pi$ -Azo-Acceptor system, stated as coumarin with azo thiophene dye bridge and with -COOH as acceptors. Hot reactive and vat textile dyes have absorbance peaks in the visible spectra so they have good light absorption. The absorbance peak value affects the current density value because the current density value is influenced by light harvesting ability (Abdou et al., 2013) while the light harvesting ability is related to the absorption of the material (Yadav et al., 2020). Optical properties are one of the factors that affect short-circuit currents (Al-alwani et al., 2016). If the absorbance value is large, dye (sensitizer) will absorb light with a large wavelength value. If the absorbed light has a

large wavelength, the photon energy required to excite electrons to the conduction band is not too large (Supriyanto, Kartikasari, Alviati, & Wiranto, 2019). The larger the wavelength value of light absorbed by natural dyes, the smaller the energy absorbed (Syafinar, Gomesh, Irwanto, Fareq, & Irwan, 2015). Natural dye with the ability to absorb light with large wavelengths has a small bandgap energy value. This is in accordance with the equation  $E = hc/\lambda$  where energy is inversely proportional to wavelength (Supriyanto et al., 2019). Textile dyes that have been used as sensitizers have good absorption characteristics. This is important because the peak of sunlight intensity is in the visible light spectrum as shown in the solar standard spectrum graph. The results of this maximum wavelength value indicate that the dye has the ability to absorb the visible light spectrum. Dyes (sensitizers) that can absorb light in the solar spectrum and absorb as much light as possible enable to have high conversion efficiency values of DSSC (Al-Qurashi, Jedidi, & Wazzan, 2021). Easy injection of electrons from the excited state to the conduction band of  $\text{TiO}_2$  and a wide absorption spectrum (visible to near infrared) are criteria for a good DSSC sensitizer which strongly affects DSSC performance (Mahmood, Tahir, Irfan, Al-Sehemi, & Al-Assiri, 2015). Sensitizers anchored to the oxide semiconductor will absorb photons and make electrons excited (Ghann et al., 2017). The weakness of textile dyes as a DSSC dye compared to anthocyanins is the weak bond with the  $\text{TiO}_2$  surface which anthocyanins have hydroxyl and carbonyl groups thus the bond to the  $\text{TiO}_2$  surface is good.



**Figure 6.** DSSC photostability test with two types of dye under irradiation of  $100 \text{ mW/cm}^2$  (Abdou et al., 2013).

Figure 6 shows the conversion efficiency ( $\eta$ ) of a DSSC with RR-133 dye and one with anthocyanin plotted against time. Based on that graph, the performances of DSSCs with RR-133 and anthocyanin dyes are relatively stable (Abdou et al., 2013). The photostability results show the good stability of the dye used as a sensitizer for  $\text{TiO}_2$ -based photoanodes, thereby meaning that it can be used as a sensitizer in DSSC applications. DSSC with Remazole Red dye did not experience a decrease in conversion efficiency for 4 hours of irradiation. DSSC with anthocyanin dye decreased the conversion efficiency slightly for 4 hours of irradiation.

#### 4. Conclusion

DSSCs are potential alternatives to silicon solar cells because of their ease of fabrication, environmental friendliness, and affordable fabrication process. An important part of a DSSC is the sensitizer dye, given its role in absorbing photons and injecting

excitation electrons into the conduction band of the oxide semiconductor. The textile dye RR-133 has been used as a dye in DSSC applications, as in the work of Abdou et al. (2013). Azo textile dye has potential as a sensitizer for DSSC applications. The absorbance test results of one type of textile dye, namely RR-133, showed an absorbance peak at 512 nm. The  $J-V$  characterization of DSSCs based on RR-133 resulted in values for the DSSC performance parameters of open-circuit voltage ( $V_{OC}$ ), short-circuit current density ( $J_{SC}$ ), fill factor, and conversion efficiency ( $\eta$ ) of 0.4 mV, 0.173 mA/cm<sup>2</sup>, 0.32%, and 0.14%, respectively, while those for the anthocyanin-based DSSC were 0.5 mV, 0.203 mA/cm<sup>2</sup>, 0.42%, and 0.27%, respectively. These result were compared to the study of Yadav et al. (2020) by using the hot reactive and vat dyes which belong to anthraquinone group as sensitizers in DSSC. Comparing the DSSC performance parameters between using RR-133 dye or anthocyanin dye shows that dyes derived from textile dyes or textile-dye with advanced purification, such as the use of column chromatography, have opportunities as alternatives to complex Ru dyes and natural dyes. Comparing the DSSC performance to the study of Yadav et al. (2020) shows an increase in DSSC performance with textile dyes.

## References

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