

Improving Luminescent Solar Concentrator Efficiency by Mixing Acriflavine and Eosin Y Organic Dyes

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Abstract: In this study, a method was proposed to construct a Luminescent Solar Concentrator (LSC). Two organic dyes (Acriflavine and Eosin Y) were dissolved in ethanol liquid and mixed with the addition of epoxy resin to fabricate eight panels of LSC with two different panel thickness (0.5, 1 mm) and different dye concentrations (2×10^{-5} , 3×10^{-5} , 6×10^{-5} , 10×10^{-5} mol/L). The efficiency of silicon solar cell was measured before and after the use of LSC. Experiments showed that the best results were in 2×10^{-5} mol/L concentration with thickness 1 mm. Results showed that the efficiency was increased from (8.183-9.922%).

Key words: Luminescent solar concentrator, LSC, acriflavine, eosin Y, organic dyes, efficiency

INTRODUCTION

Sun is one of the most important sources of energy earth. The energy of sun is mainly in two types which are heat and light (Amaroli and Balzani, 2007). Heat is energy in the form of moving particles. As the particles move faster in a substance, the object becomes warmer. Light is energy in the form of waves. These waves travel through space to Earth and we see them as light (Anonymous, 2018a, b). Several studies have been done on developing methods to transfer the energy of sun heat and light to electrical energy (Dhakar, 2016; Anonymous, 2018a, b). The photovoltaic solar cells are used to convert the solar energy to electrical energy. Many researches have been done to improve the conversion efficiency of the solar cells (Li *et al.*, 2013; Anonymous, 2018a, b). Some researches were focused on developing techniques to form a nano sized porous structure on the surface of silicon photovoltaics by simple wet chemical etching process (Lin *et al.*, 2015; Li *et al.*, 2013). Other researches were focused on constructing and using concentrators on the solar cell (Van *et al.*, 2008; Mohamed and Hassan, 2015). These concentrators are plastic or glass panels contain or coated with luminescent materials or dyes that absorb sunlight and emit light at longer wavelengths. The used dyes can be organic dyes or inorganic dyes (Rowan *et al.*, 2008; Reisfeld, 1983). The organic dyes are organic chemicals made from plants, animals or metallic materials. The organic dyes have high fluoridation and it is available widely and inexpensive if compared with inorganic dyes (Truant *et al.*, 1962). In this research, we propose a method to construct Luminescent Solar Concentrator (LSC) panels using two organic dyes (Acriflavine and Eosin Y) were dissolved in ethanol liquid and mixed with the addition of epoxy resin. Different dye concentrations and different LSC panel thicknesses have

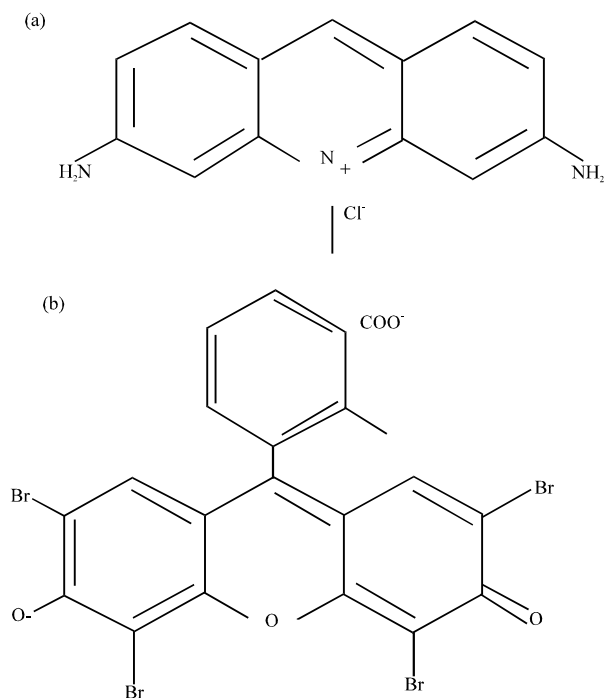


Fig. 1: Chemical structure of acriflavine and eosin Y organic dyes: a) Acriflavine and b) Eosin Y

been used and tested to determine the best concentration and panel thickness which help to increase the conversion efficiency of the solar cell.

MATERIALS AND METHODS

Acriflavine and eosin Y organic dyes: Acriflavine is derived from (acridine family). Figure 1a shows the

Table 1: Properties of acriflavine and eosin Y organic dyes

Properties	Acriflavine (Ladoulis and Gill, 1970)	Eosin (Ulrich <i>et al.</i> , 2008)
Molecular formula	C ₁₄ H ₁₄ ClN ₃	C ₂₀ H ₈ Br ₄ Na ₂ O ₅
Molar mass	260 g.mol ⁻¹	691.9 g.mol ⁻¹
λ _{max} of absorbance	450 nm	518 nm
λ _{max} of fluorescence	458 nm	544 nm
Other names	Acriflavinium chloride	Acid red 87
Form	Powder	Powder

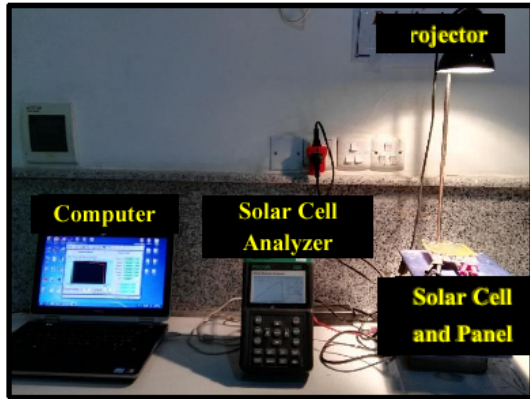


Fig. 2: Setup of the experiment hardware

chemical structure of the acriflavine dye. Table 1 shows the properties of the acriflavine dye. Eosin Y is also known as acid red 87. It is a fluorescent red dye resulting from the action of bromine on fluorescein. Figure 1b shows the chemical structure of the eosin Y dye. Table 1 shows the properties of the eosin Y dye.

LSC panels fabrication: In this study, the steps of constructing the LSC panels are demonstrated as follow: The primary dye concentration of each used dye was calculated using Eq. 1:

$$C = \frac{W \times 1000}{M_w \times V} \quad (1)$$

Equation 1 was taken from (Dhabab, 2013) and rearranged. Where, C is the dye concentration (mol/L). W is the weight of the dye (g) measured using sensitive weighting balance. M_w is the Molecular weight of the dye (g/mol). V is the Volume of the solvent (mL). The volume after dilution for each dye was calculated using Eq. 2:

$$V_2 = \frac{C_1 \times V_1}{C_2} \quad (2)$$

Equation 2 was taken from (Dhabab, 2013) and rearranged. Where V₂ is the volume after dilution. C₂ is the new concentration calculated from Eq. 1. V₁ is the volume before dilution. C₁ is the main required concentration. Four

concentrations were used in this research which are (2×10⁻⁵, 3×10⁻⁵, 6×10⁻⁵, 10×10⁻⁵ mol/L). The absorbance and fluorescence were measured for the acriflavine and eosin Y dyes using UV-Visible spectrometer and spectrophotometer, respectively. These measurements were obtained also for the mixing of the two dyes. The volume after dilution (V₂) were taken from the acriflavine and eosin Y dyes and mixed with epoxy resin and hardener. The ratio of resin and hardener was (2:1).

The obtained mixture was placed in the panel casting mold of dimensions (10×10 cm²) to fit the used solar cell dimensions and left for 48 h at room temperature.

Experiment: Figure 2 shows the setup of the system hardware. The distance between the solar cell and the light source (projector) was adjusted and fixed. The solar cell analyzer was used to measure the voltage, current, fill factor and solar cell efficiency. These measurements can be obtained from a computer connected to the solar cell analyzer. Also, a current-voltage curve can be obtained.

RESULTS AND DISCUSSION

Figure 3 shows the absorbance and fluorescence spectra of four concentrations (2×10⁻⁵, 3×10⁻⁵, 6×10⁻⁵, 10×10⁻⁵ mol/L) of two dyes (acriflavine, eosin Y) mixed with equal proportions. As can be seen, the two mixed dyes (acriflavine and eosin Y) have high absorbance spectrum range (from 464-516 nm). The peak of the absorbance spectrum is 464 nm at the concentration 2×10⁻⁵ while the peak of the absorbance spectrum is 516 nm at the concentration 10×10⁻⁵. The range of the fluorescence spectrum is from 588-561 nm. The peak of the fluorescence spectrum is 588 nm at the concentration 2×10⁻⁵ while the peak of the fluorescence spectrum is 561 nm at the concentration 10×10⁻⁵. Stokes shift (Δλ) has been determined for the four concentrations of the mixed dyes. Stokes shift is the difference between the wavelengths of maximum fluorescence and absorbance (Table 2). MATLAB Software has been used to calculate the area under the curves of absorbance and fluorescence spectra (Fig. 3). These calculations have been used to calculate the quantum efficiency (φ_{fm}) which is the ratio between the area under the Fluorescence spectrum

Table 2: Wavelength of maximum absorbance and fluorescence, Stokes shift, radiated and fluorescence life time and quantum efficiency of four concentrations of two mixed dyes (acriflavine, eosin Y)

Concentration (mol/L)	Wavelength of max absorbance λ_{abs} (nm)	Wavelength of max fluorescence λ_{fl} (nm)	Stokes shift $\Delta \lambda_{max}$ $\lambda_{fl} - \lambda_{abs}$	Radiated life time τ_{fm} (nsec)	Fluorescence life time τ_f (nsec)	Quantum efficiency Φ_{fm} (%)
2×10^{-5}	464	488	24	2.489660	2.457046	98.6921
3×10^{-5}	530	555	25	5.210243	4.977867	95.5409
6×10^{-5}	515	558	43	6.210814	3.494204	56.2604
10×10^{-5}	516	561	45	9.164273	4.732431	51.6452

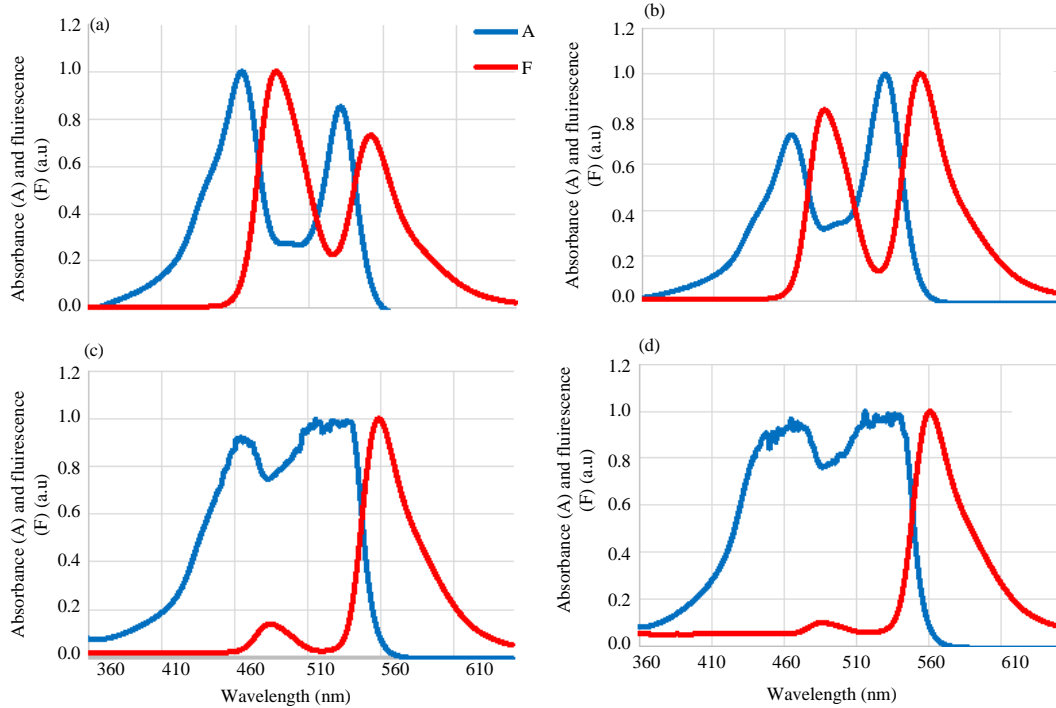


Fig. 3: The absorbance and fluorescence spectra of four concentration of two mixed dyes (acriflavine, eosin Y); a) 2×10^{-5} mol/L; b) 3×10^{-5} ; c) 6×10^{-5} mol/L and d) 10×10^{-5} mol/L

curve to the area under the absorbance spectrum curve (Table 1). Radiated life time (τ_{fm}) and fluorescence life time (τ_f) have been determined using the following Eq. 3 and 4:

$$\tau_{fm} = \frac{1}{K_{fm}} \quad (3)$$

$$\tau_f = Q_{fm} \times \tau_{fm} \quad (4)$$

Where K_{fm} is the rate of disappearance which can be calculated using the Einstein coefficient for self-emission equation (Ulrich *et al.*, 2008).

Figure 4 shows the current-voltage curves of the solar cell with the constructed LSC panels of the mixed dyes (acriflavine, eosin Y) with four concentrations with panel thickness 1 and 0.5 mm. Table 3 shows the measurements of maximum current, maximum voltage, fill factor, solar cell efficiency with the use of LSC panels and the change ratio in the efficiency after the use of LSC panels.

Table 3 shows measurements of maximum current different rates depending on the dye concentration and panel (I_{max}), maximum Voltage (V_{max}), Fill Factor (FF), solar cell thickness. the greatest increase in the efficiency of solar cell efficiency (η) with the use of LSC panels and the change is (9.922%) at the dyes concentration (2×10^{-5} mol/L) and ratio in the efficiency (η) after the use of LSC panels panel thickness (1 mm). However, the lowest efficiency of These measurements have been conducted using solar solar cell is (9.080%) at the dyes concentration (10×10^{-5} mol/L) module analyzer instrument which is connected to a and panel thickness (0.5 mm). The efficiency of solar cell is computer. The first row in Table 2 shows the measurement increased at the panel thickness (1 mm) more than that at the of the pure solar cell without using any LSC panel. After the panel thickness (0.5 mm) for the same concentration. The use of different LSC panels, measurements have been reason for this is that the increment in the panel thickness conducted and compared with the first row measurement leads to increase the dye molecules in the LSC

Table 3: Measurements of maximum current (I_{max}), maximum Voltage (V_{max}), Fill Factor (FF), solar cell efficiency (η) with the use of LSC panels and the change ratio in the efficiency ($\eta\Delta$) after the use of LSC panels

Concentration (mol/L)	Thickness (mm)	I_{max} (mA)	V_{max} (V)	FF	η (%)	$\eta\Delta$ (%)
Pure cell	--	59.50	4.126	0.720	8.183	--
2×10^{-5}	1	73.70	4.039	0.790	9.922	21.25
	0.5	69.20	4.247	0.724	9.796	19.17
3×10^{-5}	1	71.10	4.144	0.792	9.821	20.01
	0.5	73.10	4.144	0.792	9.821	20.01
6×10^{-5}	1	66.80	4.199	0.758	9.449	14.24
	0.5	65.70	4.205	0.772	9.208	12.52
10×10^{-5}	1	66.20	4.137	0.830	9.128	11.54
	0.5	66.99	4.072	0.780	9.080	10.96

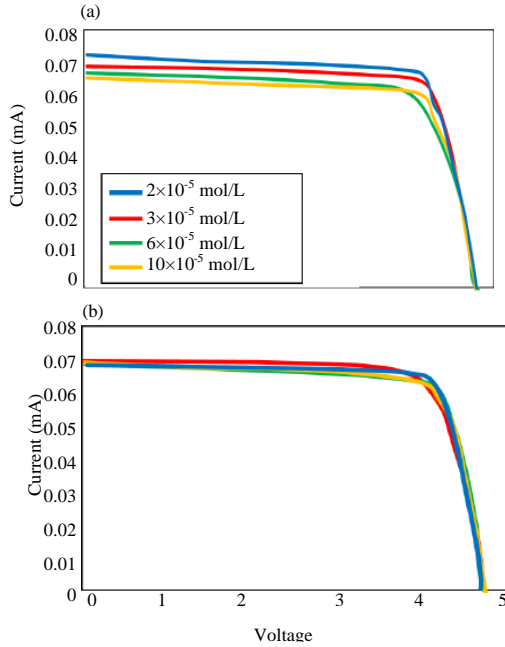


Fig. 4: Current-voltage curves of the solar cell with the constructed LSC panels of the mixed dyes (acri flavine, eosin Y) with four concentration; a) 1 mm panel thickness and b) 0.5 mm panel thickness

panel for limit obtain the increasing ratio (η) in solar cell efficiency as range. Therefore, the fluorescence intensity can be increased shown in the following equation (Daram *et al.*, 2011):

$$\Delta\eta = \frac{\eta(\text{LSC})-\eta(\text{pure})}{\eta(\text{pure})} \times 100\% \quad (5)$$

As can be seen in Table 3 and Fig. 4, the greatest increase in the efficiency of solar cell is (9.922%) at the dyes concentration (2×10^{-5} mol/L) and panel thickness (1 mm). However, the lowest efficiency of solar cell is (9.080%) at the dyes concentration (10×10^{-5} Mol/L) and panel thickness (0.5 mm).

It is important to mention that the efficiency of solar cell is increased at the panel thickness (1mm) more than that at the panel thickness (0.5 mm) for the same concentration. The reason for this is that the increment in

the panel thickness leads to increase the dye molecules in the LSC panel for limit range. Therefore, the fluorescence intensity can be increased as a result.

Another important point is that the solar cell efficiency with the LSC panels of lower dye concentrations is more than that with the use of LSC panels of higher dye concentrations. The reason of this is that at the low concentrations, the number of probable collisions between dye molecules is decreased. However, at the higher concentrations, the likelihood of molecules collisions is increased. Therefore, the increase in the collisions number leads to increasing the heat of LSC panel which affects the fluorescence process accordingly.

CONCLUSION

Different dye concentrations and different LSC panel thicknesses have been used and tested to determine the best concentration and panel thickness which helped to increase the conversion efficiency of the solar cell. From the obtained results, it was found that all the LSC panels of the mixed dyes (Acri flavine and Eosin Y) have increased the conversion efficiency of the solar cell by different rates depending on the dye concentration and panel thickness. The greatest increase in the efficiency of solar cell is (9.922%) at the dyes concentration (2×10^{-5} mol/L) and panel thickness (1 mm). However, the lowest efficiency of solar cell is (9.080%) at the dyes concentration (10×10^{-5} Mol/L) and panel thickness (0.5 mm). The efficiency of solar cell is increased at the panel thickness (1 mm) more than that at the panel thickness (0.5 mm) for the same concentration. The reason for this is that the increment in the panel thickness leads to increase the dye molecules in the LSC panel for limit range. Therefore, the fluorescence intensity can be increased as a result. In addition, the solar cell efficiency with the LSC panels of lower dye concentrations is more than that with the use of LSC panels of higher dye concentrations. The reason of this is that at the low concentrations, the number of probable collisions between dye molecules is decreased. However, at the higher concentrations, the likelihood of molecules collisions is increased. Therefore, the increase in the collisions number leads to increasing the heat of LSC panel which affects the fluorescence process accordingly.

RECOMMENDATIONS

Future research can be done by testing different concentrations and different panel thicknesses to evaluate the best range of dye concentrations and panel thicknesses. part of the proposed algorithm was tested using six data sets. The data sets contain different times and weather conditions. The vehicle counting algorithm is compared with the manual counting which is considered as ground truth. The experiments show a good result as (90.8%) for vehicle counting. To evaluate the proposed vehicle speed measurement algorithm, we used five videos from five datasets available online where these data sets have a ground truth file for the actual speed of each vehicle using very precise inductive loop detector. Experiments shows that the speeds measurements were within the acceptable error interval where the speed measurement was considered acceptable if it is within the [-5, and +5 km/h].

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