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Photo-thermo electric effect in Zn/orange dye aqueous solution/carbon cell

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Abstract

In this study, we have investigated the effect of heating by filament lamp on the electric properties of a Zn/orange dye aqueous solution/carbon cell. A solution of 5 wt.% orange dye ($C_{17}H_{17}N_5O_2$) in distilled water is used as an electrolyte in the cell. Zinc and carbon rods serve as electrodes. Organic glass box with a height, width and thickness of 35, 30 and 14 mm, respectively was used as a voltameter. The effect of heating by light on the open-circuit voltage and short-circuit currents were studied. As the intensity of light was increased up to 380 Wm^{-2}, the cell's temperature increased from 36 ^oC to 60 ^oC. It was found that the open-circuit voltage of the cell was approximately constant with the increase of temperature, whereas short-circuit current and accordingly output power of the cell increased by 1.6 times. The Zn/orange dye aqueous solution/carbon cell potentially can be considered as a small converter of light energy into electric power.

Keywords: Aqueous solution; conversion of light energy; electric power; electrochemical cell; orange dye; photo-thermo electric.

1. Introduction

It is known that the utilization of solar energy, which is environment-friendly, is very important for the sustainable development (Twidell & Weir 1986; Markvart, 2000). Actually, the energy is a vital factor for the industrial and socio-economic development of a country. The annual efficiency of solar thermal power stations (STPS) is around of 15% and of Dish-Stirling system is 20% and actually is larger than a PV system. On the other hand, the thermal power stations and systems have movable parts that make them less reliable in comparison with PV system. In this concern, investigation of the effect of heating on the properties of some power sources excluding movable parts, for example, as electrochemical cells may have in principle practical importance as one of the means of the conversion of solar energy into electric power through electrochemical processes.

During past years, a number of electrochemical cells based on organic materials and in particular, orange dye (OD), which is a p-type organic semiconductor and is a potential candidate for using in electronic devices, were fabricated and investigated (Karimov *et al.,* 2006, Saleem *et al.,* 2007). In an earlier study (Karimov *et al.,* 2002), we reported a poly-N-epoxipropylcarbazole/OD heterojunction that was deposited from aqueous solution under high gravity conditions by centrifugation. This two layer structure exhibited rectification behavior. Actually, orange dye has excellent solubility in water and good absorption in visible region. It is also stable in normal conditions and harmless. Therefore, it would be useful to use this material in electrochemical devices that could be used for storage and the conversion of energy and as sensors in instrumentation as well. An investigation of the electrochemical properties of a Zn/orange dye aqueous solution/carbon cell was done (Karimov *et al.,* 2006) and the discharge voltage–current, charge voltage/current–time and discharge voltage/current–time studies are made. It is found that the cell is rechargeable. The electrical conductivity of OD aqueous solution was investigated (Karimov *et al.,* 2008). Aluminum electrodes were used in the conductance cell. It was found that the electrical conductivity of the OD solution increased with temperature, frequency and the applied voltage. Conductivity–concentration relationship showed a maximum conductivity at 5 wt.%. Flexible organic photo-thermogalvanic cell based on OD for low power applications was investigated (Ahmad *et al*., 2015). Photoelectric properties of n-InP/Orange dye/ ITO cell were studied (Saleem *et al.,* 2016). Thermo photo-electrochemical effect in n-InP/aqueous solution of orange dye/C cell was observed (Ali *et al*., 2015). In most of these studies with OD, at least one electrode was semiconductor. It would be interesting from research point of view and important from practical point as well to fabricate electrochemical cells with two conductive or metallic electrodes, for example Zn and carbon; whereas OD aqueous solution could be used as an electrolyte. This kind of cells practically could convert any kind of thermal energy, including solar energy, into electric energy. On the other hand, usually metals and conductors are cheaper than semiconductors, which make this approach more attractive in fabrication of electrochemical cells. Moreover, properties of metals are not much dependent upon impurities concentrations. Therefore, in continuation of our efforts for the study of the orange dye aqueous solution based electrochemical cells, in this paper, photo-thermo electric effect is investigation in Zn/orange dye aqueous solution/carbon cell.

2. Experimental

High purity, commercially produced organic semiconductor orange dye (OD), $C_{17}H_{17}N_5O_2$ with a molecular weight of 323 g and a density of 0.9 gcm^{-3} was used for preparation of the electrolyte for a Zn/orange dye aqueous solution/carbon electrochemical cell. Figure 1 shows molecular structure of OD. A solution of 5 wt.% orange dye in distilled water was used as an electrolyte in the cell. The schematic diagram of the cell is shown in Fig. 2. The sizes of zinc and carbon electrodes were 34 x 17 x 1.5 mm and 34 x 26 x 3 mm, respectively. The cell was assembled in an organic glass box with dimensions 35 x 30 x 14 mm. The separation between the Zn and carbon electrodes was 7 mm and the volume of electrolyte was 5 ml. The open-circuit voltage, short-circuit current, of the cell and intensity of the light were measured by FLUKE 87V multimeter, intensity meter Kyocera JIM-100 and lux meter Amprobe LM-80, respectively. The average temperature of the cell was measured by thermocouple and FLUKE 87V multimeter.

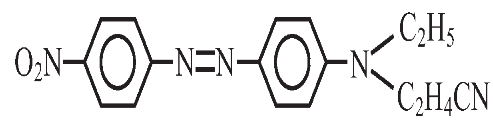

Fig. 1. Molecular structure of orange dye (OD).

For concentration of the light, the compound parabolic concentrator (CPC) was used (Figure 3). The cell was illuminated from the side of carbon electrode.

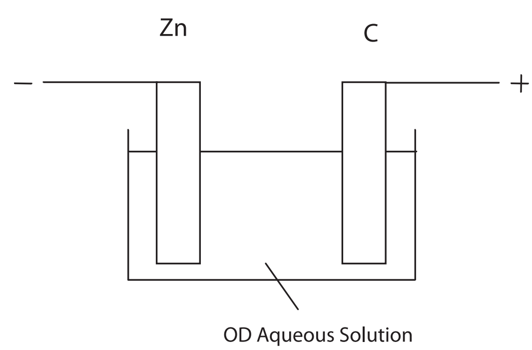

Fig. 2. Schematic diagram of Zn/orange dye aqueous solution/carbon cell.

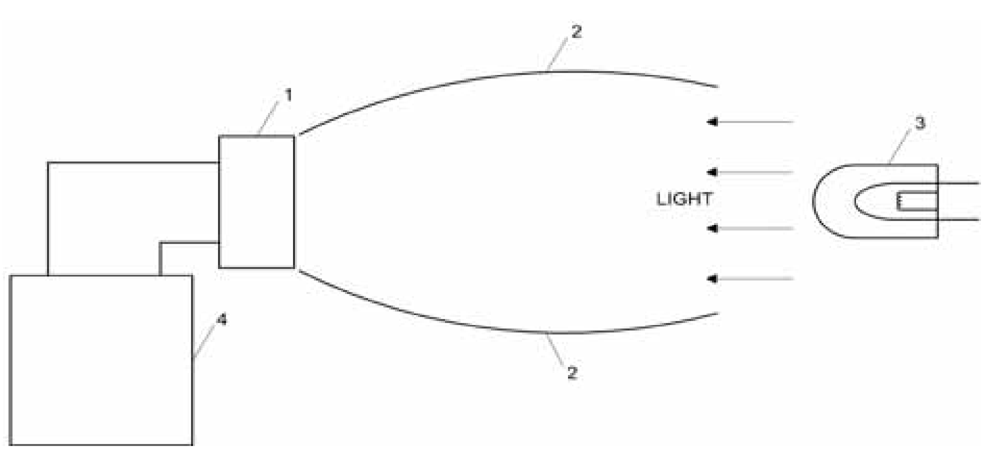

Fig. 3. Schematic diagram of experimental setup: Zn/OD aqueous solution/carbon cell (1), parabolic concentrator (2), light source (3), multimeter (4).

3. Results and discussion

Figure 4 shows temperature–intensity of light relationship for the Zn/orange dye aqueous solution/carbon cell. It is observed from experimental results that the temperature of the cell increases with increase of intensity of light quasi-linearly with a rate of 0.0706 °C/Wm^{-2}. Figure 5 illustrates open-circuit voltage (V_{OC})–intensity of light relationship and Figure 6 shows short-circuit current (I_{SC})–intensity of light relationship for the Zn/orange dye aqueous solution/carbon cell. It is seen that practically the open-circuit voltage remains constant with the increase of the intensity of light. As the intensity of the light was increased up to 380 Wm^{-2}, the short-circuit current and accordingly the output power (P_o) of the cell increased 1.6 times.

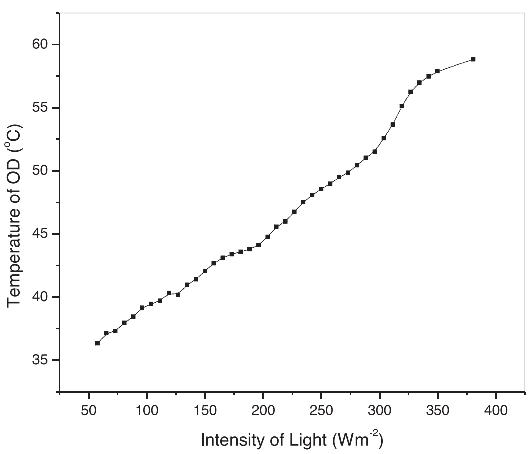

Fig. 4. Temperature–intensity of light relationship for the Zn/OD aqueous solution/carbon cell.

The increase of short-circuit current with increase of the temperature of OD solution can be explained actually by increase of its conductivity (σ) or concentration of ions and their mobility. Concentration of ions in the solution depends on concentration of OD molecules and dissociation of the molecules in the solution. Conductivity of the electrolytes can be calculated by the following expression (Krasnov, 1982):

$$\sigma = 10^{-3}\alpha c F(v_c + v_a) \tag{1}$$

where F is constant, α is dissociation constant, c is concentration of the solution (in mol/dm^3), v_c and v_a are velocities of the cations and anions, respectively. The conductivity–temperature relationship is described by the formula (Krasnov, 1982):

$$\sigma_2 = \sigma_1[1 + A(T_2 - T_1)] \tag{2}$$

where σ_1 and σ_2 are conductivity values at temperature T_1 and T_2 respectively, A is temperature conductance coefficient. The temperature dependence of the electrical conductivity of OD aqueous solution was investigated experimentally (Karimov *et al.,* 2008) and it was shown that conductivity increases with increase of temperature as presented by Equation 2.

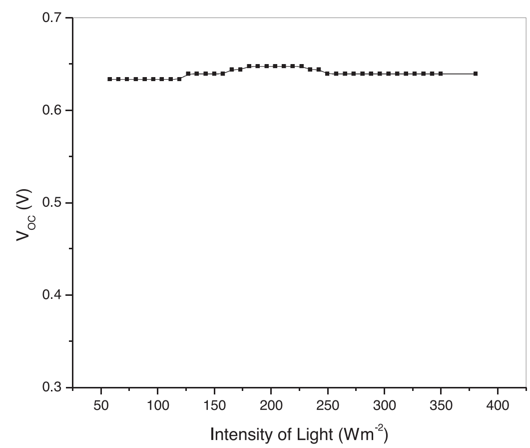

Fig. 5. Open-circuit voltage (V_{OC})–intensity of light relationship for the Zn/OD aqueous solution/carbon cell.

Taking into account that at intensity of the light of 380 Wm^{-2}, the increase in short-circuit current ΔI_{SC} = 0.07 mA at V_{OC} = 0.645 V, the increase of the output electric power (ΔP_o) due to illumination by light can be determined as (Markvart, 2000):

$$\Delta P_o = \Delta I_{SC} \times V_{OC} \times FF \tag{3}$$

where FF is fill factor that was determined to be equal to 0.5 from *I-V* characteristics of the cell presented in (Karimov *et al.*, 2006).

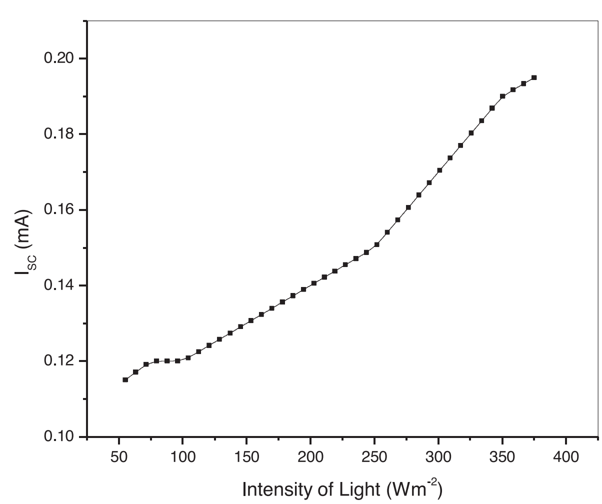

Fig. 6. Short-circuit current (I_{Sc})–intensity of light relationship for the Zn/OD aqueous solution/carbon cell.

Figure 7 shows power-temperature relationship for the investigated cell. Using Equation (3), it was found that the calculated increase in the output electric power is equal to 0.2×10^{-4} W.

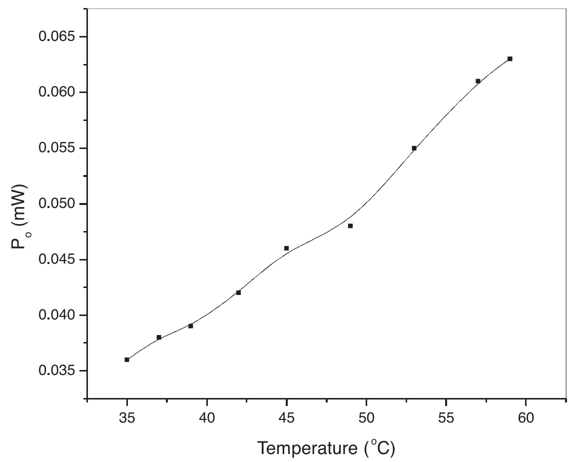

Fig. 7. Output power–temperature relationship for the Zn/OD aqueous solution/carbon cell.

As the area of the receiver (carbon electrode) of the light is 34 x 26 mm^2, the total power (P) of the receiving light will be equal to 0.336 W and accordingly the efficiency (η) is:

$$\eta = (\frac{\Delta P_o}{P}) \times 100\% \quad (4)$$

Calculation showed that $\eta = 0.6\times10^{-2}\%$ only. Further investigations are needed to increase the efficiency of the Zn/orange dye aqueous solution/carbon cell: it can be done by selection of electrodes, solvent and solution of the cell. A value of 0.65 V of V_{OC} as shown in Figure 5, is sufficiently high and H_2O is an environment friendly solvent. The parameters of the solution should be changed in order to increase the conductivity and accordingly decrease the resistance of the solution. We guess, it can be done by adding some water soluble additives which can increase conductivity of the solution. It can be matter of future investigations. If the efficiency of the cell will be increased up to a few percentages, the photo thermoelectric conversion of light energy into electric power can be used in practice.

4. Conclusion

The photo-thermo-electric effect on the electric properties of a Zn/orange dye aqueous solution/carbon cell with concentration of the 5 wt.% of orange dye in distilled water was investigated. It was found that as the intensity of the light was increased up to 380 Wm^{-2}, the cell's temperature increased from 36 °C to 60 °C. It was observed that the open-circuit voltage of the cells was approximately constant with increase of temperature, whereas short-circuit current and accordingly, the output power of the cell increased 1.6 times.

It was found that the efficiency of the conversion of light energy into electric power by the electro chemical cell is equal to $\eta = 0.6\times10^{-2}\%$. Further investigations are needed to optimize the solvent, solution and electrodes of the cell to increase the efficiency. The Zn/orange dye aqueous solution/carbon cell potentially can be considered as a small power converter of light energy into electric power.

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التأثير الكهربائي الضوئي – الحراري في صبغة Zn البرتقالية في الخلية الكربونية.

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خلاصة

في هذه الدراسة نبحث تأثير الحرارة باستخدام مصباح خيطي على الخواص الكهربائية لمحلول مائي لصبغة Zn البرتقالية في الخلية الكربونية. تم استخدام 5% wt صبغة برتقالية ($C_{17}H_{17}N_5O_2$) في محلول مائي معقم كمكون قابل للتحليل الكهربائي في الخلية. الزنك وقضبان الكربون استُخدمت كأقطاب كهربائية. تم استخدام صندوق عضوي زجاجي بارتفاع 35 مم وعرض 30 مم وتخانة 14 مم لقياس التحليل الفلطي. تم دراسة تأثير التسخين بالضوء على فولط تيار الدائرة المفتوحة والدائرة القصيرة. درجة حرارة الخلية ازدادت من 36 C° إلى 60 C° مع زيادة شدة الضوء بمقدار 380 Wm-2. وجدنا أن فولط الدائرة المفتوحة للخلية تقريباً ثابت مع زيادة الحرارة، في المقابل تيار الدائرة القصيرة وبالتالي الطاقة الناتجة للخلية ازداد بمقدار 1.6 ضعف. المحلول المائي لصبغة Zn البرتقالية في الخلية الكربونية له إمكانية الاستخدام كمحول صغير للطاقة الضوئية إلى طاقة كهربائية.