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Bitter Leaf (*Vernonia amygdalin*) for Dye Sensitized Solar Cell

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ABSTRACT

Dye sensitized solar cells, are one of the most promising devices for solar energy conversion into electricity, due to their reduced production cost and low environmental impact especially those sensitized by natural Dyes. This study used bitter leaf extract as the natural dyes for a dye sensitized solar cell (DSSC). The Soxhlet ethanol extraction method was used to extract the dye from the bitter leaf. The energy conversion efficiency and fill factor of this solar cells sensitized by bitter leaf extract is 0.69 and 0.81%. A phytochemical screening was performed for flavonoids and anthraquinones test. The extract obtained indicates the presence of flavonoids and less anthraquinones. We notice that the pH of extract solution has a significant effect on the performance of DSSCs. The efficiency was found to increase with decreasing pH and reached a maximum at the optimum pH 1.0. This might be due the absorption of more light by photoanode made from the bitter leaf extract at pH 1.0 and there is better DSSC stability as pH decreases. The results show a possible conversion of visible light into electricity using locally source conducting glass (mirror).

Key words: Dye sensitized solar cell, natural dyes, bitter leaf, Soxhlet extractor

INTRODUCTION

In order to combat global warming, depleting natural gas and actualizing the energy demands, there is a need to find alternative source of energy. The alternative to fossil fuels and nuclear power is the Renewable energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat, biomass, biofuels, Some alternatives source of energy such as water or wind are limited to areas with windy environments or flowing rivers (Gratzel, 2004).

Among a variety of renewable energy sources in progress is the solar cell. This means harvesting energy directly from sunlight using photovoltaics. The solar cells that have recorded the highest photon to current conversion efficiency are the first generation devices based on single silicon crystal (Belfar and Mostefaoui, 2011). The problem with this solar cell is their high cost production and installation. Various researchers (Konan *et al*., 2007; Bhatti *et al*., 2002) have work on Second generation devices consisting of semiconductor thin film, in order to reduce the high cost of production and improve the efficiency of first generation solar cells, although the efficiency challenges has not being removed. The third generation solar cells are the dye sensitized solar cells, heterojunction cells and organic cells. This are similar to plants that use photosynthesis to absorb energy from sunlight (Zainudin *et al*., 2011; Efurumibe *et al*., 2012), DSSCs use dyes or 'sensitisers' to convert sunlight into electricity. Electricity is created when the dye is 'energised' by solar radiation, which then 'flows' from the dye to the metal oxide surface. Predicted consumer uptake of dye-sensitized solar cell will assist in decreasing our reliance on electricity generation derived from fossil fuels, thereby decreasing greenhouse gas emissions. They are inexpensive (Amao and Komori, 2004; Hao *et al.*, 2006; Polo and Iha, 2006). In this paper, DSSCs were prepared using natural dyes extracted from Bitter leaf (*Vernonia amygdalin*a). Bitter leaf is derived from the leaves of a small ever-green shrub found all over Africa called Vernonia, belonging to the family Asteraceae. There are over a thousand species of this crop. Vernonia amygdaline is commonly found in West Africa and *Vernonia galamensis* in East Africa. True to its name, this leaf is bitter to taste, but surprisingly delicious in meals (Farombi and Owoeye, 2011). Other names with which this plant is known includes: Orugbo (amongst the Itsekiri and Urobo tribes in Nigeria), Onugbo (Ibos), Ewuro (Yoruba), Mojunso (East Africa-especially Tanzania). The leaf can be eaten fresh like spinach in soup or dried too. These leaves have great nutritional, herbal and medicinal value (Idu and Onyibe, 2007). It contains very high amount of zinc, important in many enzyme function and keeping the skin fresh. They also contain saponins and tannins (glycosides), as well as alkaloids. At least 13 other new compounds or vital ingredients have been found in these leaves, after a 40 years study and have the following benefits: Ant-malaria, Anti-bacteria, Anti-parasites, Anti-cancer. It is also effective in preventing indigestion, scurvy, sciatica and rheumatism (Cherepy *et al.*, 1997; Bakowska *et al.*, 2003). The phytochemical screening was performed for flavonoids and anthraquinones test, this is necessary because curative properties in healthcare. Some phytochemicals used in preventive medicine include: flavonoids, saponins, anthraquinones and alkaloids (Oloyede *et al.*, 2011). We have studied the photo-responses of bitter leaf as sensitizers for DSCs, efficiency of the solar cells as related to dye structures and the pH of the dye solution on the DSSC efficiency and stability were also determined.

MATERIAL AND METHODS

Preparation of natural dye sensitizers: In this study, fresh bitter leaves were collected from a farmland in Badagry, at Badagry local government area of Lagos State. Leaves of the plant were air dried for weeks at room temperature in the laboratory, until they became invariant in weight; laboratory ceramic made pestle and mortal are then used to crush each dry specimen into tiny bits. Twenty five gram of the crushed sample were weighed (using OHAUS Electronic weighing balance model brain weight B1500 made in USA) and pour into 250 mL ethanol. The Soxhlet extraction method was use for the extraction and the time taken was about 6 h. After extraction the Solid residues were filtered to remove any residual parts and then evaporated by using hot water bath to increase the concentration of dye to the solvent. The obtained solution was directly used as dye solution for the preparation of photovoltaic devices. Elucidation of the exact structures was not done since the aim of the study was to use them as available in the leaves without any isolation. Then, the phytochemical screening of the plant was done and the effect of pH of dye solution was studied by adjusting pH of 4.25 using 0.1 M HCl solution to three different pHs (1.0, 2.0 and 3.0).

Preparation and construction of the cell: The TiO_2 solution was prepared by the incremental addition of 20 mL of nitric acid solution to 12 g of TiO_2 powder in a crucible. The powder was stirred at each 1 mL drop of the nitric acid until an even paste was achieved (Polo and Iha, 2006). For the electrode a glass slide with conductive surface is required. A plane mirror 2×2 cm was used with its outer coating removed leaving a sliver (Ag) layer which is conducting. A window is created in the silver conducting film left to allow incident light photon to enter and interact with the dye titanium interface. The volt-ohm meter was used to check which side of the glass is conductive.

The titanium paste is poured on the conducting surface of the slide glass. A glass rod is allowed to slide over the titanium dioxide suspension in order to spread evenly and smoothly (Amao and Komori, 2004). It was annealed and sintered in an oven at 450°C for 30 min. The TiO_2-coated conductive glass is allowed to cool to room temperature. After cooling the TiO_2 film is stained with a dye solution and allowed to dry.

A second glass slide 2×2 cm with a conducting surface (again plane mirror was used with its outer most coating removed).The conducting side is prepared by carbon coating. The carbon coated slide (counter-electrode) is placed face down on top of the dry stained, titanium dioxide coated side of the other slide (electrode) in such a way that the two slides offset so that all of the TiO_2 is covered by the counter electrode.

Two binder clips are used to gently hold the plates together at the edges. The DSCs were constructed by introducing the redox electrolyte containing a mixture of 0.5 M potassium iodide and 0.05 M iodine. The liquid was drawn into the space between the electrodes by capillary action.

Measurements: The absorption spectra of dye solutions and dyes adsorbed on TiO_2 surface were recorded using a VIS Spectrophotometer (Spectrum lab 23A GHM Great Medical England). Solar energy conversion efficiency (the photocurrent voltage (I-V) curve) was measured by using digital multimeters under illumination of sunlight.

Based on I-V curve, the fill factor (FF) is defined as:

$$FF = (I_{max} \text{ x } V_{max})/(I_{sc} \text{ x } V_{oc}), \quad (1)$$

where, I_{max} and V_{max} are the photocurrent and photovoltage for maximum power output (P_{max}), I_{sc} and V_{oc} are the short-circuit photocurrent and open-circuit photovoltage, respectively. The overall energy conversion efficiency (η) is defined as:

$$\eta = (I_{sc} \text{ x } V_{oc} \text{ x } FF)/P_{in}, \quad (2)$$

where, P_{in} is the power of incident light.

RESULTS AND DISCUSSION

Figure 1 shows the UV-VIS absorption spectra of bitter leaves (*Vernonia amygdalina*). It was found that the absorption peak of bitter leaves (*Vernonia amygdalina*) extract is about 400 nm. After adsorption, the absorption spectrum of the photoanode is shown in Fig. 2 and it is 400 nm. We notice there is no difference in the absorption peaks, they were found at the same wavelengths for both extract and being adsorbed onto TiO_2 surface. This is due to the structure of bitter leaf extract (Fig. 3) resulting in a stronger steric hindrance for anthocyanin to form bond with oxide surface and prevents the anthocyanin molecules from arraying on the TiO_2 film effectively (Hao *et al*., 2006). Hence, this leads to a deficiency of electron transfer from dye molecules to conducting band of TiO_2. Figure 4 shows the I-V (current-voltage) curve for the

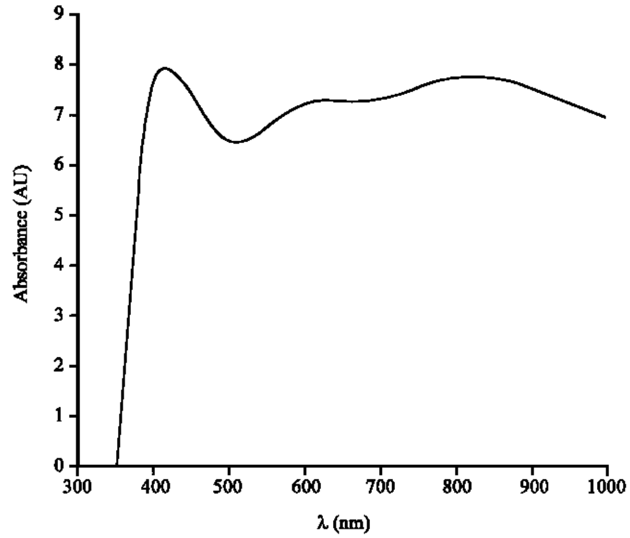

Fig. 1: Light absorption spectra of dye solution of bitter leaves

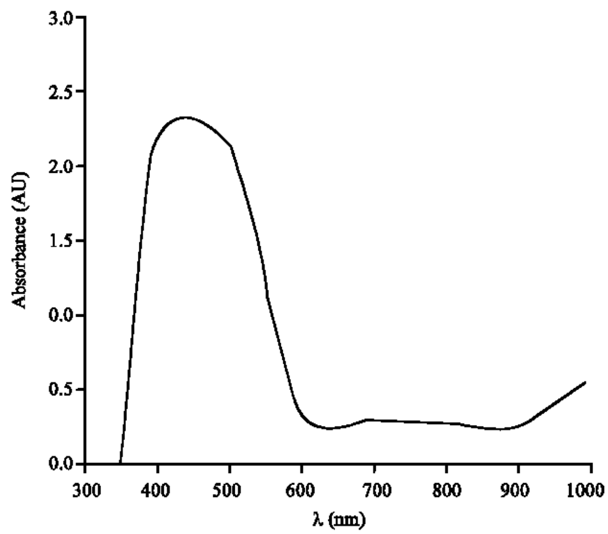

Fig. 2: Light absorption spectra of bitter leaves adsorbed on TiO_2

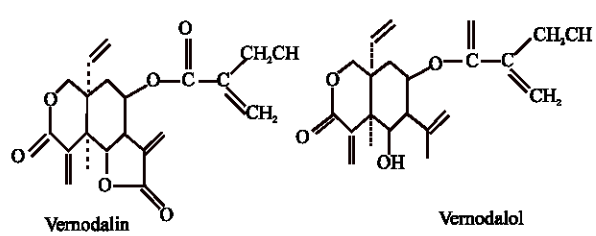

Fig. 3: Some structures of compounds isolated from *Vernonia amygdalina*

sunlight-illuminated bitter leaf extract sensitized cell. Table 1 presents the performance of the DSSCs in terms of short circuit photocurrent (I_{sc}), open-circuit voltage (V_{oc}), Fill Factor (FF) and energy conversion efficiency (η).

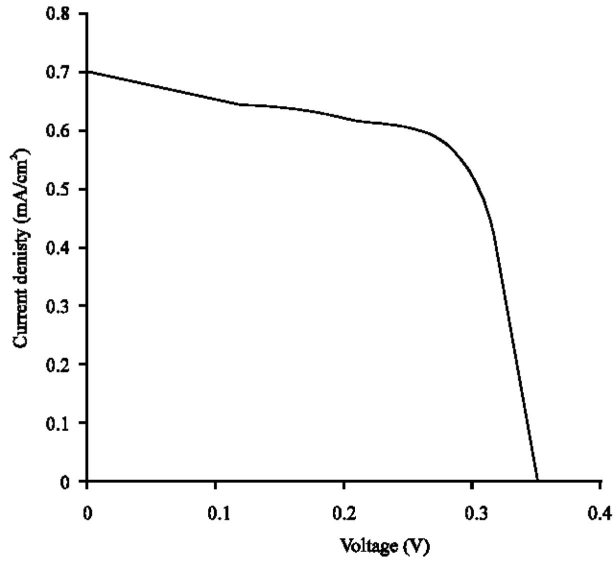

Fig. 4: Current voltage curve for a bitter leaf extract sensitized solar cell

Table 1: Photo electrochemical parameters of the cells sensitized with natural extracts extract sources

Extract sources	Isc (mA cm^{-2})	Voc (V)	FF	η (%)
Ethanol	0.07	0.34	0.81	0.69

Table 2: Effect of pH of extract solutions on DSSC efficiency and stability

pH	I_{sc} (mA cm^{-2})	V_{oc} (V)	FF	η (%)
4.25	0.07	0.34	0.81	0.69
3.0	0.06	0.34	0.82	0.71
2.0	0.55	0.36	0.88	0.84
1.0	0.50	0.38	0.89	0.96

The efficiency of cell sensitized by the bitter leaf is very low. This is because of the low interaction between Bitter leaf extract and TiO_2 film and It is believed that the anode (TiO_2) of the standard dye sensitized solar cell (Gratzel and Durrant, 2008) traps some of the electrons passing through it, thereby contributing in the reduction of the efficiency of the dye sensitized solar cell (Tachibana *et al*., 2000; Hollister, 2010). With continuous exposure to direct sunlight noticeable decay was seen in about 5-6 h. Here, the UV in sunlight seems to degrade the pigments. A phytochemical screening was performed for flavonoids and anthraquinones test. The extract obtained indicates the presence of flavonoids and less anthraquinones. Flavonoids protect plants against external pathogens, ultra-violet light or heat. This might be the reason of weak interaction of the dye solution with $TiO_{2.}$

Effect of pH of extract solutions on DSSC's efficiency and stability: Table 2 shows the effect of pH investigation in this study. The original pH of bitter leaf (*Vernonia amygdalin*a) was found to be 4.52. As seen in Table 2, the pH of extract solution has a significant effect on the performance of DSSCs. The efficiency was found to increase with decreasing pH and reached a maximum at the optimum pH 1.0. This might be due to the fact that at pH 1.0, the photoanode

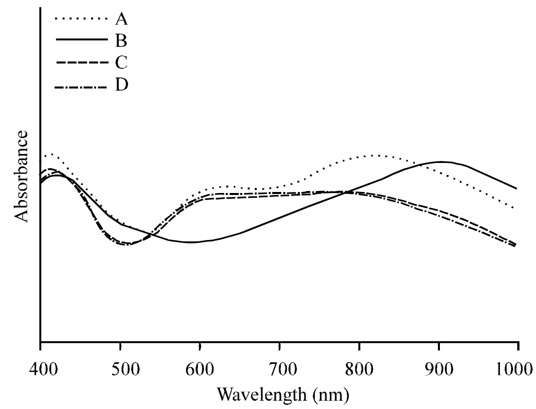

Fig. 5: Light absorption spectra of bitter leaf extract at different pH (A) 4.5 (B) 3.0 (c) 2.0 (D) 1.0

made from the bitter leaf extract can absorb more light; this is indicated by peak intensity as shown in Fig. 5. Also, there is better DSSC stability as pH decreases to 1.0, because anthocyanin existed as flavylium ion, which is stable form of anthocyanin, an increasing pH hydrated this ion to quinonoidal bases. These compounds are labile and can be transformed into the colorless carbinol PseudoBase and chalcone. It was evident that at low pH the formation of flavylium ion form is favorable (Bakowska *et al.*, 2003).

CONCLUSIONS

In conclusion, the Bitter leaf has a lower photosensitized performance this is due to the weak charge transfer between the Bitter leaf dye molecule and the TiO_2 surface which is related to a dye structure. Another reason might be the source of extraction; it is known that water is suitable as an anthocyanin extracting solvent for DSSC application while ethanol gave an adverse effect on the DSSC stability. We noticed from our research that the efficiency and stability of DSSCs can be enhanced by adjusting the pH of the extracts. A phytochemical screening was performed for flavonoids and anthraquinones test. The extract obtained indicates the presence of flavonoids and less anthraquinones; which should explain the lower photosensitivity as the flavonoids are known as antioxidation.

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