Investigating the prospect of micro-energy generation in S.Anisatum Dye-sensitized solar cells (DSCs)

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Abstract. Energy is a requirement for daily existence and a necessity for driving all technology. Thus, indices for generating energy will always be a valid reason for research. It therefore stands to reason that; numerous experimental effort has been devoted to the quest of energy generation. This quest has witnessed a lot of progression, newer innovations being an improvement over older editions. Recent energy studies have shifted its focus from dominant monocrystalline silicon solar cells to organic material sources. This is in the wake of the high expenses incurred in installation of any silicon solar technology. Although the economy of scale applies to increased use of silicon panels, it does not delete the looming future threat of disposal of expired silicon solar panels. This brings to fore, a need for an energy substitute that possesses the salient attributes of monocrystalline silicon solar cells without the limitations. Amongst all the alternatives, the low cost and environmentally benign dye-sensitized solar cells (DSCs) has remained prominent. Other desirable characteristics of dye-sensitized solar cells is all-year availability of raw materials, capacity to perform under low diffuse light conditions, ability to withstand extreme conditions contrary to their silicon counterparts are sterling qualities which necessitate detailed enquiry into dye-sensitized solar technology. In spite of these excellent properties, wide adoption of DSCs is limited by its poor output efficiency relative to monocrystalline silicon solar cells. The significance of this research is thus to investigate optical spectral responses of S.Anisatum dye-sensitized solar cells with an objective to analyze its photovoltaic output and prospect for micro-energy production. Preliminary phytochemical analysis portends S.Anisatum dye as rich in phenols. UV/VIS spectroscopy reveals a porphyrin characteristic absorbance. This research corroborates previous studies such as photovoltaic output of B.spectabilis DSCs to different electrolytes. The spectral responses revealed 0.065 mA, 140 mV, 5.32 X 10^-6 W and 0.86 % respectively as I_sc, V_oc, P_max and η highest output value. Although this result is comparatively low to monocrystalline silicon panels, it conforms with existing standard porphyrin efficiency. This study provides impetus for further studies of S.Anisatum DSCs co-sensitization with other dyes and finds application in modelling of material of synthetic origin.

1. Introduction

Numerical data proves that, energy liberated by the sun in one hour is adequate for meeting global energy needs in a year [1]. These energy needs cut across developed, developing and under developed economies. Despite this startling revelation, many areas especially in the developing and under developed regions of the world are plunged in perpetual darkness due to irregular power supply [2].
The ratio of these nations bear a direct function to provinces where gross domestic production (GDP) and income per capita is low. Thus, the average household is unable to install monocrystalline solar panels to augment the electricity from the [3]. A large number of indigenes resort to the use of fossil fuel powered generators due to availability and comparative cheaper cost. The effect of this choice is monumental to human and environmental health [4]. Consequent on this, research focus is on clean energy sources with vast potential of meeting the teeming energy needs characteristic of developing countries. Initial energy quest witnessed the use of solar energy for space and domestic water heating. This gradually improved to the use of concentrators. The incipient technology was discouraged by the enormous heat generated by such systems and the discomfort to residents [5]. Congruently, research effort on photovoltaic technology evolved from first generation cells which silicon panels represent, to second generation thin films. Dye-sensitized solar cells signify third generation solar cells and provide the fulcrum on which the fourth generation solar cells are developed [6]. Numerous scientific efforts have delved into different components of DSC technology. Foremost among this, is the dye photosensitizer which serves a fundamental role in determining the output efficiency of a DSC. There are several choices of dyes that have been used as sensitizer for DSCs. However, Ruthenium dyes of which the black dye consist, recorded the highest efficiency. This was due to the strong chelation between the semiconductor interface and the functional groups such as phosphonate or carboxylate group. The only challenge was ruthenium was very scarce which made it very expensive [7]. This development brought about the search for ruthenium alternatives, this led to organic dyes. Amidst the organic dye family, porphyrin dyes have shown outstanding output efficiency. This is attributable to their ability to absorb optimum radiant energy in the electromagnetic spectrum. Understandably, their output usually surpasses that of metal-free organic dyes due to the latter’s comparatively narrow absorption wavelength and impeding dye agglutination [8]. Even though, keen research focus is on perovskite solar cells due to their high efficiency output, the lingering challenge of their rapid oxidation may be solved from DSC perspective [9, 10]. Thus, this research seeks to explore tunable optical properties of DSCs which could be incorporated in future energy devices [11].

2. Materials and Method

2.1. Preparation of dye extract
Stoichiometric amount of *S.Anisatum* leaves determined by an Adam PGW 453 series electronic balance to be 77.7 g was air dried until it assumed a constant weight. It was milled to a coarse blend and spread out until it assumed room temperature. Then it was soaked in 1600 ml of methanol of commercial variety in thin layer chromatography (TLC) tanks for fourteen days to extract sufficient dye. This resulting solution had a pH of 5 and was separated using sterile filters, the filtrate was collected in bell jars. The filtrate obtained was fed into a rotary evaporator set to a speed of 45 rpm and water bath temperature of 59°C. *S.Anisatum* dye extract got was stored for further use.

2.2. Phytochemical Screening
The following tests were carried out on 1g of *S.Anisatum* dissolved in 100 ml of distilled water (DW) according to standard laboratory procedure described by Abodunrin et al. [13]. 2 ml of distilled water (DW) was added to 2 ml of the dye extract and vigorously shaken for about fifteen minutes. The formation of a layer of persistent layer of bubbles shows the presence of saponin. 2 ml of concentrated HCl was added to 2 ml of the dye extract then; a few drops of Mayer’s reagent were added. A green colour indicates that alkaloid is present. 2 ml of 5% ferric chloride was added in 1 ml of dye extract. A greenish-black precipitate indicates that tannin is present. 5 ml of dilute ammonia solution was added to about 2 ml of
dye extract then, a few drops of concentrated $\text{H}_2\text{SO}_4$ was added. A yellow colour confirms that flavonoid is present. Two to three drops of 5% ferric chloride solution with 2 ml of glacial acetic acid was added to 0.5 ml of dye extract. Concentrated $\text{H}_2\text{SO}_4$ was carefully added as a layer under. The presence of a brown ring at the interface shows the presence of cardiac glycoside. 2 ml of concentrated HCl was added to 2 ml of the dye extract then; a few drops of Mayer’s reagent were added. 2 ml of DW was added to 1 ml of dye extract and followed by a few drops of 10% ferric chloride. A green colouration indicates the presence of phenol. In each case, absence of the associative colour change implies the chromophore is not present [14].

2.3. Micro-spectroscopy of dyes
0.1g of $S.\text{Anisatum}$ was dissolved in 100 ml of methanol to obtain the spectrograph from within the ultraviolet − visible (UV/VIS) region of the electromagnetic spectrum using Thermo-scientific Evolution 60 S series.

2.4. Preparation of the electrodes
A pair of transparent conducting slides of indium doped oxide (ITO) variety of surface resistivity 10 ohm/m² were used on an active area of 3.16 m² for fabricating $S.\text{Anisatum}$ DSCs. The TiO$_2$ photoanode used for this experiment was obtained from chemically pure variety purchased from Sure Chemical Products assay 98 % min. Doctor blade method of application was used to spread on the TiO$_2$ paste to one of the ITO conducting slide which was prepared using standard laboratory methods described in previous literature [9, 15]. The effect of increasing temperature from 350 to 450 °C was observed in the elimination of air spaces in $S.\text{Anisatum}$ thin film during the sintering process. The last step involved the sintering of the air dried photoanode at a temperature of 450 °C to enhance good surface adsorption using Vecstar furnaces. The counter electrode was prepared by coating the TCO with soot in a vacuum-like enclosure. The result obtained was a stress-free epitaxial layer due to the differences between the lattice constant of substrate and the thin film coat. This set-up was allowed to cool before the two electrodes were fastened together with binder clips and sealed with crazy glue. Subsequently, two drops of aqueous electrolyte constituted in ratio 1 g: 100 g distilled water was introduced in-between the two electrodes to improve the mobility of charge transport.

3. Results and Discussion

3.1. Phytochemical Result:The phytochemical screening reveals the presence of several chromophores. However, we would restrict our discussion to two identical phenolic compounds present in $S.\text{Anisatum}$ dye and their effects in DSCs. The impact of two functional groups namely anethole and estragole (methyl chavicol) as shown in Figure 1 will provide the basis for investigation as a result of their application in previous DSCs. The significance of anethole in Figure 1(a) to $S.\text{Anisatum}$ DSCs is that it emulsifies the photoanode support on which it is based through the Ouzo effect. Estragole (methyl chavicol) in Figure 1 (b) is used in perfumes and as a food additive for flavor. Estragole is a volatile terpenoid, which naturally impedes total Na$^+$ current in a concentration-dependent manner. This is observed in a numerical significant drop in slow inactivation time constants. It is noteworthy that, when estragole reacts with potassium hydroxide, it converts to anethole. This in turn would facilitate the redox reaction in the forward direction.
3.2. UV/VIS of S.Anisatum dye extract

The optimal wavelength of absorbance in S.Anisatum is observed to be a porphyrin trend. The significance of this result is that, naturally porphyrins show distinctive spectral emission. They show strong bands within the soret band also known as B-bands between a wavelength range of 380–500 nm. As to their electronic absorption, this is represented by two generic waveforms. The first with molar extinction coefficient value of $10^5$ M$^{-1}$cm$^{-1}$ for shorter wavelengths and $10^4$ M$^{-1}$cm$^{-1}$ at longer wavelengths within 500–750 nm range. Thus, their spectra are made of less forceful, but relatively intense Q bands as shown in Figure 2. In practice, their absorption bands considerably connect with the emission spectrum of insolation reaching the earth, which instigates resourceful conversion of radiation to chemical energy. This in turn assists with the formation of complex compounds and charge transfer owing to their characteristic ring structure which comprises of conjugated double bonds [10]. In addition, this energy is used during reactions with metallic ions, solvent change, and other parameters and all processes involved in obtaining accurate information about aggregation of porphyrins, equilibrium, complexation and general kinematics of redox reactions. In such conversions illustrated by these processes, the favourable emission and energy transfer properties of porphyrin derivatives are indispensable as in the case of chlorophylls, which contain magnesium ion in the core of the macrocycle.
Table 1: Photoelectric Parameters of S.anisatum DSCs

| Electrolyte | $I_{sc}$ (mA) | $V_{oc}$ (mV) | $P_{max}$ (W) | $ff$ | $Ƞ$ (%) |
|-------------|---------------|---------------|---------------|------|---------|
| KI          | 0.0375        | 140           | 5.32          | 0.10 | 0.525   |
| HgCl2       | 0.030         | 85.6          | 2.55          | 0.99 | 0.008   |
| KCl         | 0.0029        | 9.0           | 0.0252        | 0.96 | 7.9E-4  |
| KBr         | 0.065         | 69.2          | 4.2           | 0.93 | 0.86    |

4. Photovoltaic Output
The electrolyte was the variant while S.anisatum dye was constant for four S.anisatum DSCs. The most efficient cell was KBr-S.anisatum DSC, this is due to the comparatively high $I_{sc}$ recorded. The implication of this result is that, effective charge transport occurred as opposed to recombination. The highest $V_{oc}$ was observed with KI- S.anisatum DSC, to the second most efficient cell and highest maximum power output. The best $ff$ was recorded in HgCl2, this contributed to the second best $V_{oc}$. This could be attributable to poor interboundary kinematics between the electrolyte and the dye interface. The least efficient electrolyte was KCl. This is because Cl$^-$ ions required higher energy for their preferential discharge as shown
in Table 1. A pictorial representation of spectral responses from *S.anisatum* DSCs with different electrolytes is shown in Figure 3.

![Comparison of S.Anisatum photovoltaic trend](image)

**Figure 3**: *S.anisatum* DSC photovoltaic performance

5. **Conclusion and Recommendation**

The prospect of the study of *S.anisatum* DSCs presents a distinct possibility of micro-energy generation from environmentally benign source that is also readily available. The redox reaction favored Br\(^{-}\) ions, this is attributable to the less Fermi energy level required to produce the necessary transition from the valence band to conduction band of *S.anisatum* dye. Thus, future inquiry is encouraged in the studies of the wavelength shift of *S.anisatum* dye adsorption band and the absorbance changes as function of pH and temperature.

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References
[1] A reference
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[2] Another reference
[3] More references