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Investigation of the optical properties of some dyes from selected plants with the aim of incorporating them in dye-sensitized solar cells

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ABSTRACT

This study focuses on the optical characteristics of some selected dyes meant for use in dye-sensitized solar cells. Out of the eight samples of dyes studied, three were selected for use in three dye-sensitized solar cells. The three dyes that were selected were from *Canarium schweinfurthii* leaf, *Azadirachta indica* leaf and bitter kola leaf. These dyes were selected because of their relatively high absorbance values (0.74, 0.65 and 0.58%, respectively) which they recorded within the visible light wavelength. It was believed that with this relatively high absorbance values, the dyes could harvest greater amount of solar radiation falling on them, when incorporated in dye-sensitized solar cells.

Keywords: Dyes, solar cells, absorbance, reflectance.

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INTRODUCTION

It has been said that the conversion of sunlight to electricity using solar cells represents one of the most promising alternatives to energy production by fossil fuels (Cambell et al., 2007). Among the available renewable energy sources, solar sources appear more promising. The reason for this is that it is readily available. The solar cells that have recorded the highest amount of photon to current conversion efficiency are the ones called the first generation solar cells. They are based on single silicon crystal (Belfar and Mostefaoui, 2001). But the only problem with these types of solar cells is their high cost production and installation. Here we describe a low cost photovoltaic cell, which exhibits a promising prospect in terms of energy-conversion efficiency (Calogero et al., 2010; Grätzel, 2005). The solar cell is based on nano-particulate titanium dioxide film coated with a monolayer of a charge-transfer dye to sensitize the film for light harvesting (Grätzel, 2005). The titanium dioxide film is an optically transparent film and as such the ideal spectral characteristics of the dye helps the solar cell to harvests a high proportion of the incident solar energy flux and afterwards convert the incident photons to electrical current (more than 80%). Light-to-electric energy conversion efficiencies between 1 and 7.9% has been recorded in the past, in simulated solar light and up to 12% recorded in diffuse daylight (Calogero et al., 2010; Dyesol, 2011). Recently, a research team headed by Professors Michael Grätzel and Anders Hagfeldt at the Ecole Polytechnique Fédérale de Lausanne (EPFL) established a new world record conversion efficiency for its Perovskite Solar Cells (PSC) of 21.02% (Dyesol, 2015). This result has already been certified at the laboratories of Newport Corporation in Bozeman, Montana USA. Newport is one of a few institutions in the world that is accredited to issue certifications for such photovoltaic cells. The media release by DYESOL has the comment of Professor Michael Grätzel. He said: “I would like to make particular mention of the very significant contribution of my colleague Professor Anders Hagfeldt and his team in achieving this world record result and I am confident that we will continue to make rapid progress that demonstrates the extraordinary commercialisation potential of this revolutionary solar technology."

Dye-sensitized solar cell has fantastic promises, among which include: large current densities (in most cases greater than 12 mA cm^{-2}), exceptional stability as well as low cost production (Grätzel and Durrant, 2008). These promising characteristics make practical applications of the cell feasible. Again, the increasing public awareness that the earth's oil reserves will run out during this century seems to promote the rapid development of this cell and the like (Grätzel, 2005).

"Natural dyes" used in the fabrication of dye-sensitized solar cells have numerous advantages over rare metal complexes and other organic dyes. The first is that natural dyes have wide availability; second is that it is easy to extract; third is that is can be applied without further purification; forth is that they are environment-friendly; and the fifth is that their use considerably reduce the cost of producing solar cells (Narayan, 2012). Anthocyanins are the major component of natural dye. Although natural dyes have several advantages over other organic dyes and rare metal complexes, the efficiency obtained with their use for now is considerably low (less than 2%). In order for the natural dyes to be used in large scale photon conversion, further studies and researches are needed to improve their efficiency (Fernando and Senadeera, 2008).

In this study, our focus is on the optical characteristics of some selected dyes meant for use in dye-sensitized solar cells. The plants whose extracts (dyes) were selected for study are listed as follows:

1. Touch-and-die (sensitive) leaf known as *Mimoca pudica* (A)
2. English pear known as *Persea americana* (B)
3. Ube Igbo leaf known as *Darrodes edulis* leaf (C)
4. Ube Mgba Leaf known as *Canarium Schweinfurthii* leaf (D)
5. Bitter kola leaf (E)
6. Dogwoyaro (neem) leaf known as *Azadirachta indica* leaf (F)
7. Dogwoyaro (neem) stem known as *Azadirachta indica* stem (G)
8. Bitter leaf known as *Vernonica amygdalena* leaf (H)

The optical properties of these materials were studied using Ultra-violet-visible Infrared spectroscopy via a spectrophotometer (model no: UV-VIS 1138). Some of the dyes show amazing optical characteristics such as high absorbance coefficient at visible light wavelength.

Due to the ideal optical characteristics of the dye, it is believed that the solar cell that would incorporate this dye would be able to harvests a high proportion of the incident solar energy flux (say about 46%) and be able to convert efficiently the incident photons to electrical current (more than 80%) when adsorbed by the anode and illuminated (Calogero et al., 2010; O'Regan and Grätzel, 1991).

Brief description of some of the plants

Some of the plants, particularly those that recorded high absorbance values, are described briefly in this section. First the Neem tree: this is the tree from where the Neem leafs were gotten from. The tree is also known as Indian lilac. It belongs to the mahogany family Meliaceae. Neem tree is a fast growing tree that can reach a height of 15 to 20 m. It is an evergreen-tree but in severe drought, it may shed most or nearly all of its leaves. The branches are wide and spreading. It can be used for the following (according to Wikipedia, an online encyclopedia):

1. The tender shoots and flower of the neem tree are eaten as a vegetable in India.
2. It can serve a medicinal purpose.
3. It can be used for pest and disease control.

It is a source of lubrication oil. The oil from Neem tree is said to be non-drying and resists degradation better than most vegetable oils.

The next plant on the list is *Canarium schweinfurthii*. This is a tree that is widely distributed across tropical Africa, predominantly across East, Central and West Africa (Keary, 1989). The tree is up to 36.6 m high with slight blunt buttress (Ngbede et al., 2008). A cut on the back of the tree exudes gum which solidifies to a whitish resin. The flowers from the tree are creamy white and a ripe fruit is dark-brown or purplish in complexion. The purplish ripe fruits are common in the forest zone while the dark-brown fruits are common in the savannah region. The fruit pulp contains 30 to 50% oil used as essential oil and known to have analgesic effect (Agbo et al., 1992).

The last plant to be described here is the bitter kola. Bitter kola is a well-known tree that grows in the rain forests of West Africa. The fruit, seeds, nuts and bark of the plant have been used for centuries in folk medicine to treat ailments ranging from coughs to fever. It is often known as *Garcinia kola*. Sources have it that *G. kola* has so much health benefits (Livestrong, 2015; Wikipedia, 2016; Ogbada, 2016).

METHODOLOGY

These materials (the plants leafs and stems) were first obtained from the field and then processed by grinding them (one after the other) in a mortar and the dye/juice from each of them extracted and placed each on a different transparent conducting glass plates. These glasses were exposed to air in the laboratory to enable the dye dry on the glass plates. The glass plates (each of which contains the dye from each of these plants) were

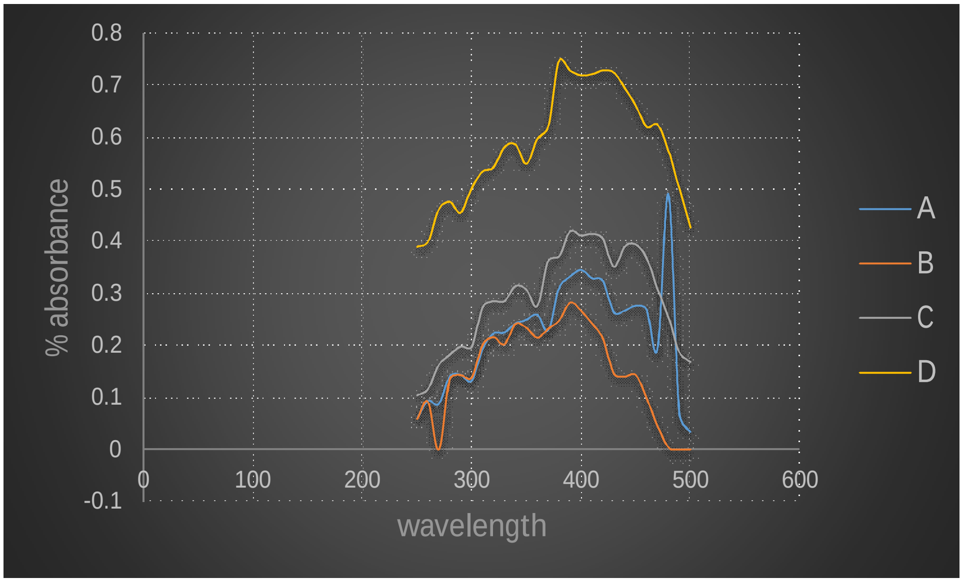

Figure 1. Absorbance against wavelength (in nanometers).

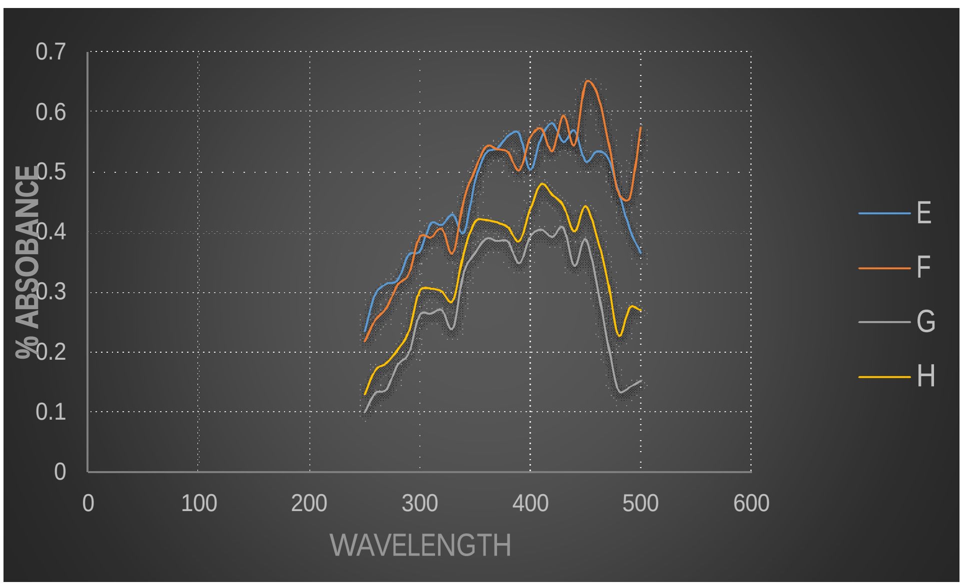

Figure 2. Absorbance against wavelength (in nanometers).

afterwards placed in a spectrophotometer (model no: UV-VIS 1138) for study of the optical properties of the dyes from each of the plants investigated.

RESULTS AND DISCUSSION

The results of the investigation are shown in Figures 1, 2, 3 and 4. Looking at the result of the spectrophotometer, the absorbance of the touch-and-die leaf fluctuated between 0.08 and 0.34%. At the mark 0.18% (at incident wavelength of 480 nm), the absorbance surged to 0.49% and then came down to 0.03% (at incident light wavelength of 500 nm). The absorbance of the dye from C*anarium schweinfurthii* leaf increased relatively between 250 and 380 nm and afterwards fell to 0.42% at 500 nm. It was observed that the dye from *C. schweinfurthii* leaf attained the highest absorbance of 0.74% at a wavelength of 380 nm, followed by the dye from the touch-and-die leaf (0.49% at 480 nm). The absorbance of the dye from *Darrodes edulis* leaf toped that of the touch-and-die leaf up to 480 nm before the sudden rise in the absorbance of the touch-and-die leaf at that wavelength. The highest absorbance value recorded by the dye from

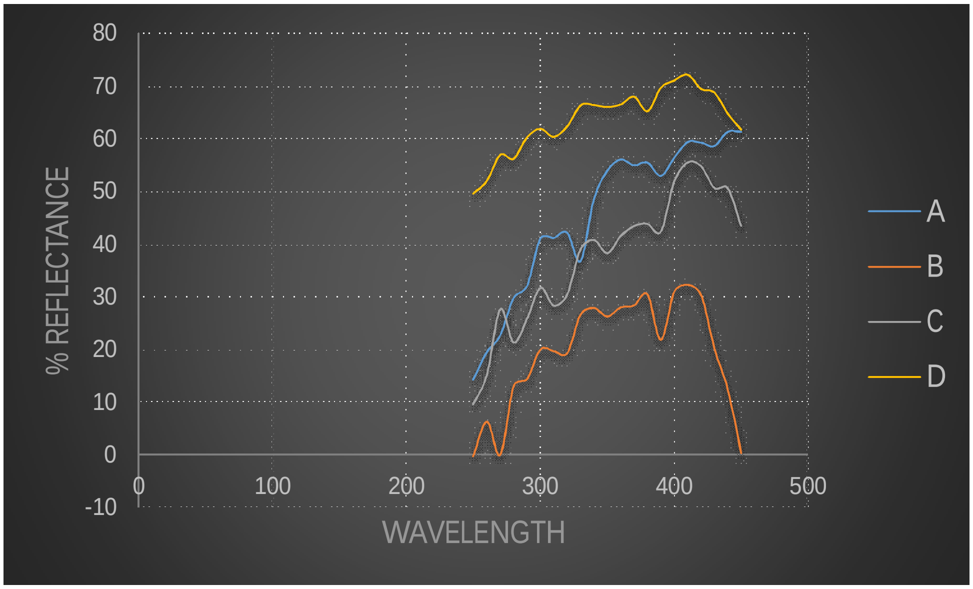

Figure 3. Reflectance against wavelength (in nanometers).

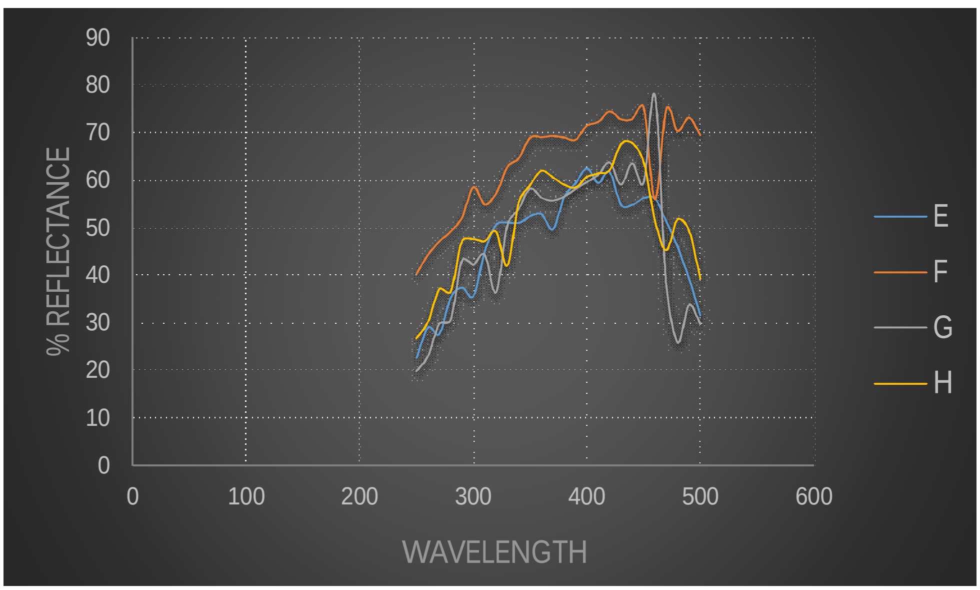

Figure 4. Reflectance against wavelength (in meters).

D. edulis leaf is 0.4% between 400 and 460 nm. The absorbance of the dye from *P. americana* is relatively low. The dye recorded the lowest absorbance of 0.28% at 380 nm in comparison with other dyes in Figure 1. Comparing the absorbance of the dyes from bitter cola leaf, *Azadirachta indica* leaf, *A. indica* stem and *Vernonica amygdalena*, it can be observed that the dye from *A. indica* stem recorded the least absorbance (0.4% between 400 and 430 nm) followed by the dye from *V. amygdalena* leaf (0.48% at 420 nm), followed by the dye from bitter cola leaf (0.58% at 430 nm) and then the dye from *A. indica* leaf (0.65% at 470 nm).

As for the reflectance of the dyes in Figure 3, the dye from *P. americana* leaf gave the least reflectance (31% at 410 nm), followed by the dye from *D. edulis* (55% at 410 nm), followed by the dye from *Mimoca pudica* leaf (that is touch-and-die leaf) and then the dye from *C. schweinfurthii* (71% at 410 nm). Looking at Figure 4, the dye from bitter kola leaf gave reflectance of 61% at 420 nm; followed by the dye from *V. amygdalena* (68% at 430 nm); followed by the dye from *A. indica* leaf (75% between 440 and 460 nm) and lastly the dye from *A.*

indica stem (79% at 470 nm).

CONCLUSION

From Figures 1, 2, 3 and 4 it was obvious that all the dyes showed high fluctuations in their values of absorbance and reflectance within the visible light wavelength range.

The high absorbance values recorded by dyes from *C. schweinfurthii* leaf, *A. indica* leaf and bitter kola leaf are an indication that they could harvest greater amount of solar radiation falling on them (Calogero, 2010). So as a result, the dyes from these mentioned plants were incorporated in the design of three test dye-sensitized solar cells. Again the relatively high reflectance values (71, 75 and 61%, respectively) recorded by these dyes shows that they are good optical materials.

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