A Bright Future:

the use of organic waste in dye-sensitized cells in the creation of efficient solar energy systems

Introduction

With the recent search for more effective alternative energy sources, solar energy is becoming an increasingly popular due to its clean environmental footprint. However, more research is needed into solar energy in order to increase the efficiency and lower production costs of solar cells. Thus, the idea of "artificial photosynthesis", the process of converting solar energy into a more ubiquitous energy source, has grabbed the attention of many scientists. This process is the basis behind a solar energy system that scientists have developed: the dye-sensitized solar cell (DSSC). The DSSC consists of a Tin Oxide glass semiconductor that is dipped into a dye to absorb solar energy, and it mimics the light absorbing proteins found in natural photosynthesis. Although the approach used in DSSCs suggests a bright future for solar energy conversion technologies because of their simple device construction and inexpensive materials that can easily be fine-tuned to increase their light-absorbing properties, more research is needed for this system to surpass the efficiency of current solar cells.

Hypothesis

Can the efficiency of dye-sensitized solar cells be maximized through the use of different organic dyes?

The goal of this experiment is to test the effectiveness of dyes extracted from organic waste compounds and see if they can have a positive effect upon the efficiency of the dye-sensitized solar cell system. Furthermore, the efficiency of the dye-sensitized cells will be compared in a controlled environment versus natural outdoor environment, and the efficiency of the cells will be measured every day to observe the degradation of the organic compound over time.

Materials

- -2x2.5 cm Fluorine doped Tin Oxide Glass panel
- -Titanium Dioxide paste
- -Wax Candle
- -Distilled Water
- -Scotch Tape
- -Fruit peel (apple, orange, mangosteen, lemon)
- -Bags
- -Beakers
- -Filter paper
- -Multimeter
- -Tweezers
- -15 mL of iodide electrolyte
- -Squirt Bottle
- -Hotplate
- -Binder clips
- -Ethanol
- -Cardboard Box
- -Sun Lamp

Procedure

Procedure for preparation of the system

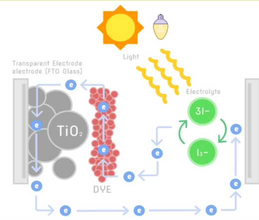
1. Place a strip of scotch tape on the very edge of the glass.
2. Add a couple of drops of the Titanium Dioxide Paste onto the conductive side of the FTO glass and spread it across to create a thin coating of the paste across the glass.
3. Transfer the glass onto a hotplate with the Titanium Dioxide film facing up. Heat the glass on the hotplate for 10 to 20 minutes.
4. To prepare the dyes, remove the peels from the apple, lemon, orange, and mangosteen.
5. Place the container in the Drying Oven and dry it at 75°C for 30 minutes.
6. Take the container out and crush the peels into fine powder using mortar and pestle.
7. Immerse the powder in absolute ethanol at room temperature for 48 hours.
8. Filter the solids out and apply pressure to the powder and squeeze the dyes out.
9. Place each of the dyes in a plastic bag. Take the tin oxide coated glass and place one in each of the dyes inside the plastic bag.
10. Immerse the glasses in the dyes completely until the white tin oxide layer changes to the color of the dye.

Procedure for assembly of the system

1. Take another piece of the FTO glass and find its conductive side using the multimeter.
2. Using tweezers, glide the second piece of glass over a burning flame from a wax candle with the conductive side of the glass facing downwards until a black film of carbon is evident on the glass.
3. Using tweezers, carefully remove each glass from the dye.
4. Use a squirt bottle to rinse off extra dye or solid material within the dye.
5. Set the glass down and gently dab at the glass to wipe off the water.
6. Take one of the graphite coated pieces of glass and one of the dyed pieces of glass. Assemble the two pieces of glass so each of the coated sides is touching each other.
7. Slide the graphite glass out so the edge aligns with the beginning of the tin oxide coating.
8. Use binder clips to clip the sides of the glasses that are not offset.
9. Using a pipette, add a small drop of the iodide electrolyte solution to the seam of the glass.
10. Do this process for each different dye-coated glass.

**All graphs, photos, and illustrations are original work created by students for this project.

How do dye-sensitized cells (DSSC) work?



When the photons from the sunlight or any light sources hit the dye molecule, the electrons in the **dye molecule** escape and move towards the **titanium dioxide nanoparticles**. When the electrons are transferred, the electrons flow toward the transparent electrode, **Fluorine doped Tin Oxide (FTO) glass**, where they are collected for powering a load. After flowing through the external circuit, the electrons return back to the cell through the **carbon counter electrode**. When the electrons return back into the cell, the electrons flow into the electrolytes, which carry the electrons back to the dye. Through this new way of creating electricity, dye-sensitized cells can expand the range of application where conventional solar cells are unsuitable. DSSC are suitable for low-light applications, eco-friendly, and cheap. With this new focus on the usage of organic waste as a dye, this project hopes to find new and better ways to expand the advantages of dye-sensitized cells.

Results (part 1)

After the dyes were made, the composition of the dyes were analyzed through UV-Vis spectrometer. From two trials using spectrometry, two distinct peaks in absorbance of light were observed. The first peak, around 430nm, was observed in both mangosteen dye and mangosteen/orange mix dye. The molecule that is uniquely present in mangosteen dye is **quercetin-3-O-rutinoside**, also known as **rutin**. Although the apple dye was expected to have high performance because of its rutin content, it did not contain enough rutin for this observation. The second peak, around 650nm, was observed in the mangosteen dye and apple dye. The molecule that is uniquely present in both mangosteen and apple is **Chlorophyll b.** Through the high performance of apple and mangosteen dye, it can be concluded that rutin and chlorophyll had an effect on the performance of the cell.

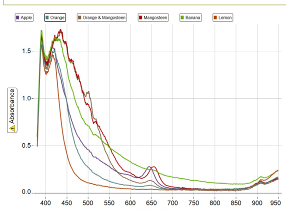


Figure 1. Spectrometry of the dyes (Trial 1)

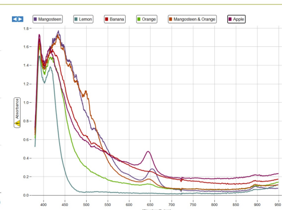


Figure 2. Spectrometry of the dyes (Trial 2)

Compound	Wavelength
Rutin	430nm, 550nm
Chlorophyll	650nm, 450nm
Cyanidin	518nm, 282nm

Results (part 2)

In this experiment, four different dyes and a mix of mangosteen and orange dye were tested outdoors for 12 hours to experiment the stability of the cells in the natural environment. A mangosteen and orange mix dye was created to test how effective the dye would be when all three molecules, rutin, cyanidin, and chlorophyll, are present in the dye.

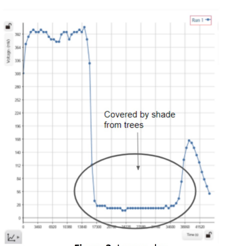


Figure 3. Lemon dye
11/22 7am to 7pm

Figure 4. Mangosteen dye
11/22 7am to 7pm

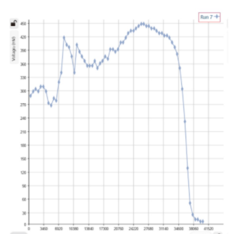


Figure 5. Mangosteen and Orange Mix
11/21 7am to 7pm

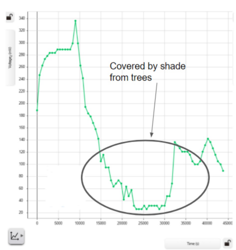


Figure 6. Orange dye
11/23 7am to 7pm

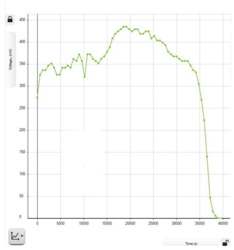
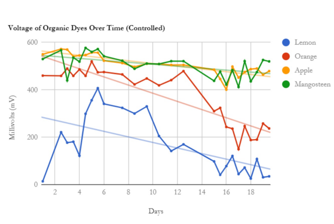


Figure 7. Apple dye
11/23 7am to 7pm

Results (part 3)

In this experiment, four different organic dyes were tested over a month to observe the stability of the cell and the degradation of the dye over time. The voltage of the cell was measured twice a day. Lemon performed the lowest by having inconsistent performance in a controlled environment, whereas mangosteen and apple continued to perform high and showed very little degradation over time.



Dyes	Composition	Slope	Average
Lemon	Low Cyanidin, Chlorophyll, Rutin	-11.1mV/day	164.009 mV
Orange	High Cyanidin Low Chlorophyll, Rutin	-17.2mV/day	365.097 mV
Apple	High Cyanidin, Chlorophyll. Rutin	-6.57mV/day	503.161 mV
Mangosteen	High Chlorophyll, Rutin Low Cyanidin	-5.68mV/day	494.531 mV

Abstract

Solar energy is a rising new alternative to fossil fuel. The most common source of solar energy, silicon-based solar cells, are often overpriced and environmentally harmful. In light of this, dye-sensitized cells are another option to utilize solar energy that promises potential replacement. These cells, which rely on the excitation of dye electrons to produce electricity, are favorable due to their cheap price and effectiveness. The purpose of this project was to find the most effective and sustainable dye that can be found in everyday organic waste that can work as effectively as expensive ruthenium based dyes and platinum electrodes. In this project, two experimentations were performed to identify the most effective and sustainable dye in both controlled and practical environments. In the first experimentation, four different fruit peels were used as dyes: Apple, Mangosteen, Orange, and Lemon. The dyes were tested two times a day for a month. From experimentation, Apple and Mangosteen were proven to have the highest voltage production, with averages of 509.114 mV and 499.972 mV respectively. In the second experimentation, the same four dyes were used, but they were tested outside in the sunlight for 12 hours. No significant degradation was observed throughout this time period, although voltage production did fluctuate with exposure to the sun and the sun's light intensity. Through these experiments, it can be concluded that fruit dye based dye-sensitized cell systems have potential to create efficient, cheap, and environmentally friendly solar energy systems.

Conclusion #1

First, the efficiency of different dyes extracted from organic waste compounds was tested. The four different organic materials all of contained compounds that mimicked the light absorbing protein used in natural photosynthesis. The dyes were selected to test different composition of flavonoids. These flavonoids were selected due to their ability to bond with Titanium Oxide and to sensitize the dyes. Apple most likely had a higher voltage due to rutin and its supplement of anthocyanin content. Orange, which had a content of anthocyanin, had a higher voltage production that lemon, which didn't have any flavonoids. From these results, it was concluded that organic compounds with rutin would result in the highest voltage, and with a supplement of anthocyanin, they would yield the best results. However, these results called up a question if a dye that contained rutin, anthocyanin, and cyanidin would result in the highest results, since apple, which had both rutin and anthocyanin, had the highest voltage production. Thus, we created a mangosteen and orange mix, which would have rutin from the mangosteen as well as anthocyanin and citric acid from the orange. This mix did prove to have a high voltage production as expected.

Conclusion (part 2)

Second, the efficiency of the system in a controlled versus a natural environment was compared. It was observed that the overall averages of the efficiency of the dyes was generally lower in the natural environment. This is due to the fact that the light intensity in the natural environment fluctuates greatly day to day, and in some days with a relatively lower light intensity, the voltage production decreased in all the dyes. Out of the five days tested in the natural environment, three of the days had a light intensity that mirrored the light intensity of the controlled environment. Thus these experiments yielded a similar voltage production as the dyes did in the controlled environment. However, the other two days, the light intensity was significantly less than the light intensity in the controlled environment, resulting in a lower voltage production that would lower the overall average of the dye efficiencies as well. Thus, it was concluded that although the dyes have the ability to function in a natural environment, the efficiency of the dyes is very unstable and inconsistent. However, in places where light intensity is consistent or during the summer, this system has the potential to become an alternative source of energy.

Conclusion (part 3)

Third, the degradation of the dyes over time was measured. Two major observations were made. First, it was observed that Mangosteen and Apple did not have a huge degradation over time, but Lemon and Orange had a significant degradation around day 13. The systems were tested in a natural environment to see if there would a greater degradation when the system was exposed to a natural environment. The results for the testing showed that the systems did not have a degradation in voltage within this time period; rather, the voltage just fluctuated with the light intensity. Additionally, at the end of our research, it was noted that in the orange and lemon systems, the titanium dioxide particles had fallen off the FTO glass. Parts of the titanium dioxide particles fell off of the apple and mangosteen systems as well but too a lesser degree. It was concluded that this was a result of either the dye's or the iodide electrolyte's degradation over time.

Further Research Options

To improve upon this project, research could be done to test the efficiency of these dye-sensitized cells in a natural environment. The bulk of this research was done to test the efficiency in a controlled environment, thus more research is needed to prove the effectiveness of this system in a natural environment. Additionally, more research can be conducted to test the degradation of the iodide electrolyte versus the degradation of the dye when exposed to UV light. With this research, it may be possible to make some modifications to the cell to prevent the degradation of the cell through whatever compound causes the cell to lose efficiency, leading to a more effectively built cell that can function as a new source of solar energy.