A Bright Future:

The Use of Organic Waste in Dye-sensitized Cells

in the Creation of Efficient Solar Energy Systems

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Abstract

Solar energy is a rising new alternative to fossil fuel. The most common source of solar energy, silicon-based solar cells, is 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.

Rationale

As the supply of nonrenewable energy sources continues to be depleted, recent societal concerns have begun to revolve around the search for alternative energy sources. Among these, solar energy is becoming an increasingly popular energy source. Solar energy is of great interest because of its clean environmental footprint. Although current solar energy models are functional, more research is needed in order to increase the efficiency and lower production costs of solar cells. Thus, scientists have begun to look more extensively into different approaches to use the sun's energy, and the idea of "artificial photosynthesis" has grabbed the attention of many scientists. Artificial photosynthesis is the process of taking solar energy and converting it into a more ubiquitous energy source, such as electrical energy. 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 Fluorine doped Tin Oxide glass semiconductor that is dipped into a dye to absorb solar energy, which mimics the light absorbing proteins found in natural photosynthesis. Although the approach used in DSSCs suggest a bright future for solar energy conversion technologies because of its 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 and be implemented into society for proper use.

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 to see the change in the efficiency of the cells. Moreover, the efficiency of the cells will be measured every day to observe the degradation of the organic compound over time.

Materials

Materials for the cell:

Scotch tape

Hot plate

Binder clips

Multimeter

Tweezers

Titanium Dioxide paste

Distilled water

Squirt bottle

15 mL of Iodide electrolyte

Wax Candle

2x2.5 cm Fluorine doped Tin Oxide (FTO)

Glass panel

Alligator Clips

Materials for the dye:

Apple peel

Mangosteen peel

Orange peel

Lemon peel

Plastic Bags

Ethanol

Filter paper

Beakers

Procedure

Procedure for preparation of the system

1. Take one piece of the FTO glass, and find the conductive side of the glass (the side with a resistance reading) using the multimeter.
2. Place a strip of scotch tape on the very edge of the glass. It should cover only about ⅛ of the surface area of the glass.
3. Add a couple of drops of the Titanium Dioxide Paste onto the conductive side of the FTO glass. Using the smooth side of the pipette, gently push down on the paste and spread it across to create a thin coating of the paste across the glass.
4. Allow the paste to dry. Once dry, carefully remove the tape from the glass without creating any scratches.
5. Transfer the glass onto a hotplate with the Titanium Dioxide film facing up. Heat the glass on the hotplate for 10 to 20 minutes. After the surface turns brown and then burns off to produce a white sintered titanium oxide coating, turn off the hotplate and allow the glass to slowly cool.
6. Repeat the steps above to create three more pieces of the tin oxide coated FTO glass.
7. To prepare the dyes, remove the peels from the apple, lemon, banana, orange, and mangosteen. Wash the peels with water and place it in a separate containers.
8. Place the container in the Drying Oven and dry it at 75°C for 30 minutes.
9. Take the container out and crush the peels into fine powder using mortar and pestle.
10. Immerse the powder in absolute ethanol at room temperature for 48 hours.
11. Filter the solids out and apply pressure to the powder and squeeze the dyes out.

12. 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. 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. Continue gliding the glass over the flame until a black film of carbon is evident on the glass.
3. Repeat the above two steps to create three more pieces of the graphite coated FTO glass.
4. Using tweezers, carefully remove each glass from the dye. Be careful not to scratch the glass.
5. Hold one of the glasses over a beaker, and use a squirt bottle to rinse off extra dye or solid material within the dye.
6. Set the glass down and gently dab at the glass to wipe off the water. Do not wipe the glass (this will remove the tin oxide layer).
7. Repeat steps 6 and 7 for each of the glass pieces.
8. 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.
9. Slide the graphite glass out so the edge aligns with the beginning of the tin oxide coating.
10. Use binder clips to clip the sides of the glasses that are not offset.
11. Using a pipette, add a small drop of the iodide electrolyte solution to the seam of the glass. A very small at should be sufficient.

12. Do this process for each different dye-coated glass.

Procedure for testing the system

1. Take an alligator clip and attach it to one of the overhanging pieces of glass. Take the other side of the clip and attach it to the multimeter probe. Take a second alligator clip and attach it to the other piece of the overhanging glass and the other multimeter probe.
2. Place the cells under the sun lamp.
3. Switch the multimeter setting to DCV to measure the voltage of each cell.
4. After recording observations regarding voltage for each of the systems, switch the setting to DCA to measure the current. Record observations for the current.
5. Test the glass every day to collect more data regarding the dye efficiency over time.
6. Repeat this process outdoors in natural sunlight.
7. Using the data, multiply the current by the voltage to calculate the power of the system.
8. Compare results.

Data

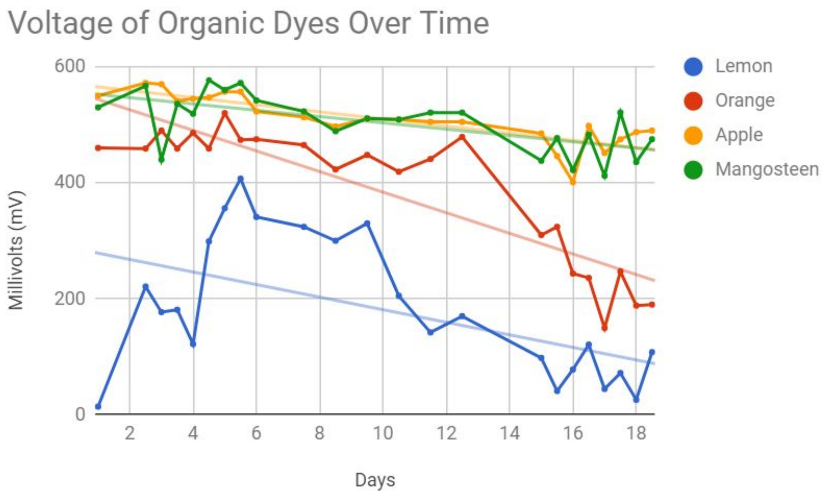

Figure 1: Organic waste dyes were tested over one month period

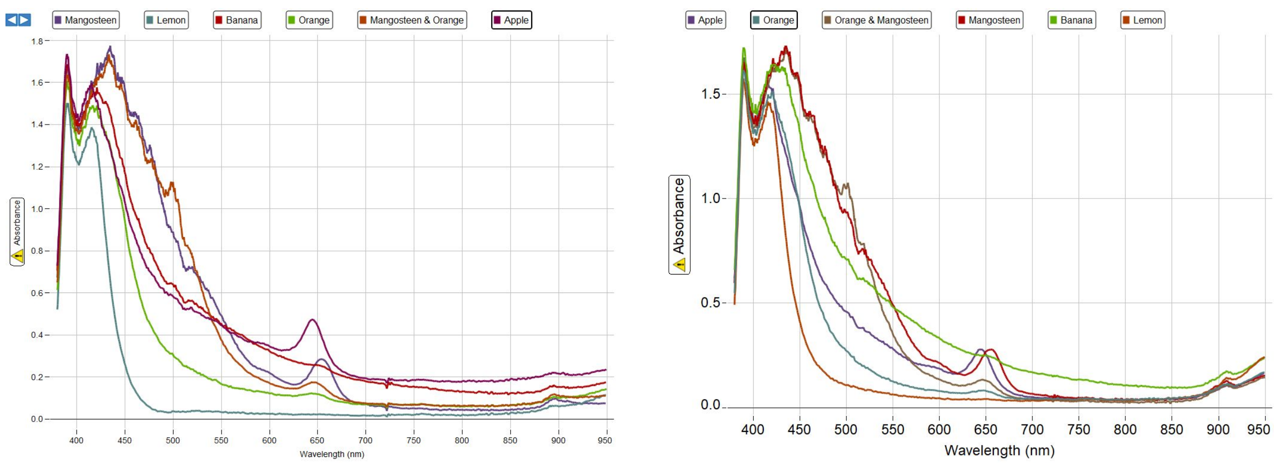

Figure 2, 3: Spectrometry of different organic dyes

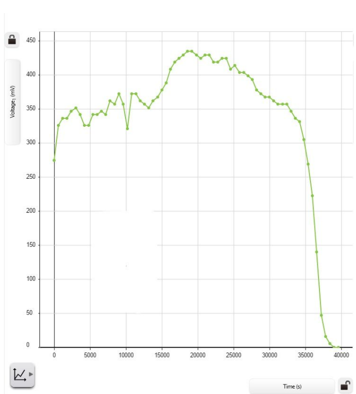

Figure 4: Apple dye

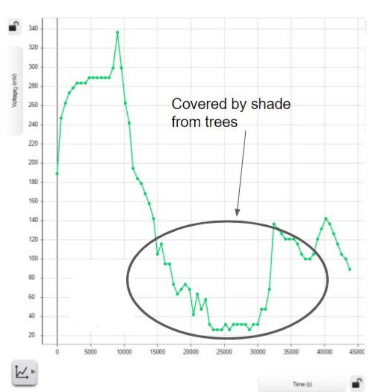

Figure 5: Orange dye

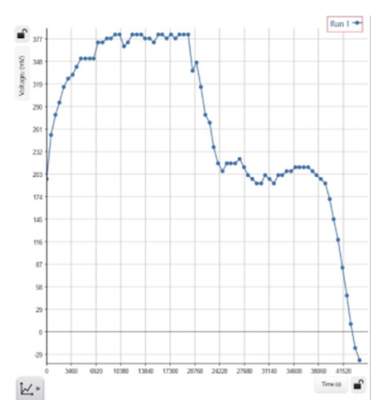

Figure 6: Mangosteen dye

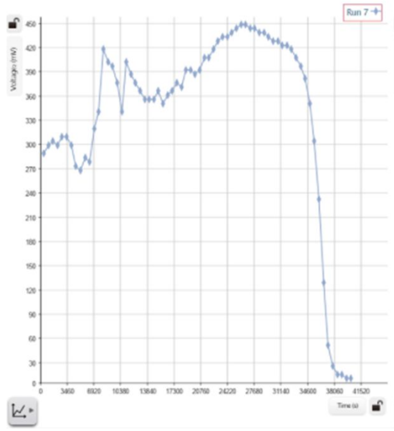

Figure 7: Mangosteen and Apple dye

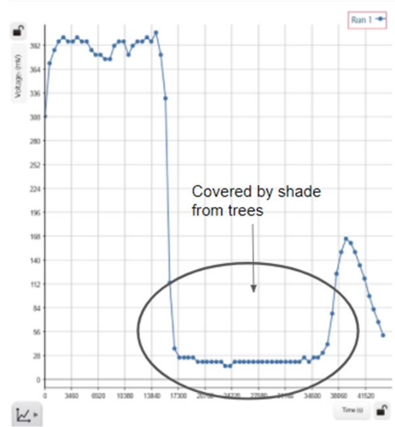

Figure 8: Lemon dye

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

Table 1: Degradation of different organic dyes over time

Conclusion

There were three main goals at the start of this project: first, to test the efficiency of different dyes extracted from organic waste compounds; second, to compare the efficiency of the system in a controlled versus natural environment; third, to measure the degradation of the organic dye over time.

In order to test the first goal, four different organic materials, all of which contained compounds that mimicked the light absorbing proteins used in natural photosynthesis, were

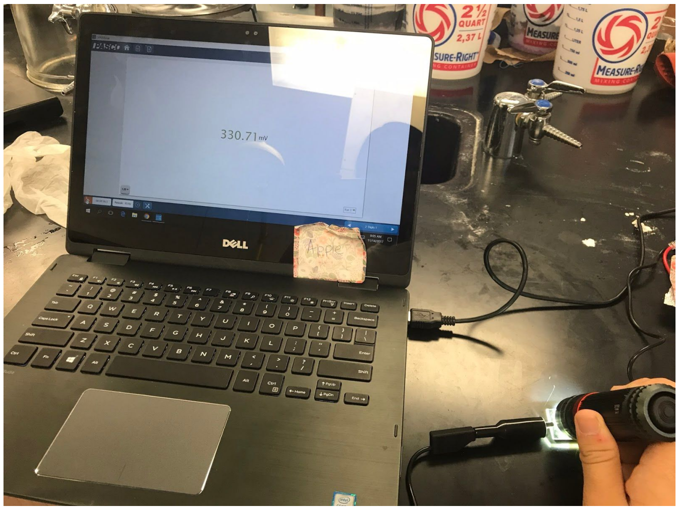

Figure 9: Organic dyes were tested in a controlled environment

tested. The dyes were selected to test different composition of flavonoids. Apple and mangosteen had a high content of rutin. Apple additionally had a high content of anthocyanin. Orange also had anthocyanin, and it also had a high content of cyanidin; on the other hand, lemon had a low content of cyanidin. These flavonoids were selected due to their ability to bond with Titanium Oxide and sensitize the dyes. These systems with these dyes were tested throughout a three week period in a controlled indoor environment that mirrored the energy of the sun. Before experimentation, apple and mangosteen were predicted to have the highest voltage because of their content of rutin. Additionally, the dyes with an anthocyanin content were predicted to result in the second highest voltage production, and dyes with cyanidin would have the lowest voltage production. These hypotheses proved correct, as apple produced an average voltage of 503.161 mV and mangosteen produced an average voltage of 494.531 mV. Apple most likely had a higher voltage due to it also having a supplement of anthocyanin content. Orange, which had a content of anthocyanin and citric acid, had a higher voltage production that lemon, which just had citric acid, but a lower voltage production than the two compounds that contained rutin, anthocyanin, and cyanidin. Orange had an average voltage production 365.097 mV, and lemon had an average voltage production of 164.009 mV. However, lemon had an inconsistent voltage throughout this three week period, jumping from 132 mV to 299 mV within the matter of days. 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.

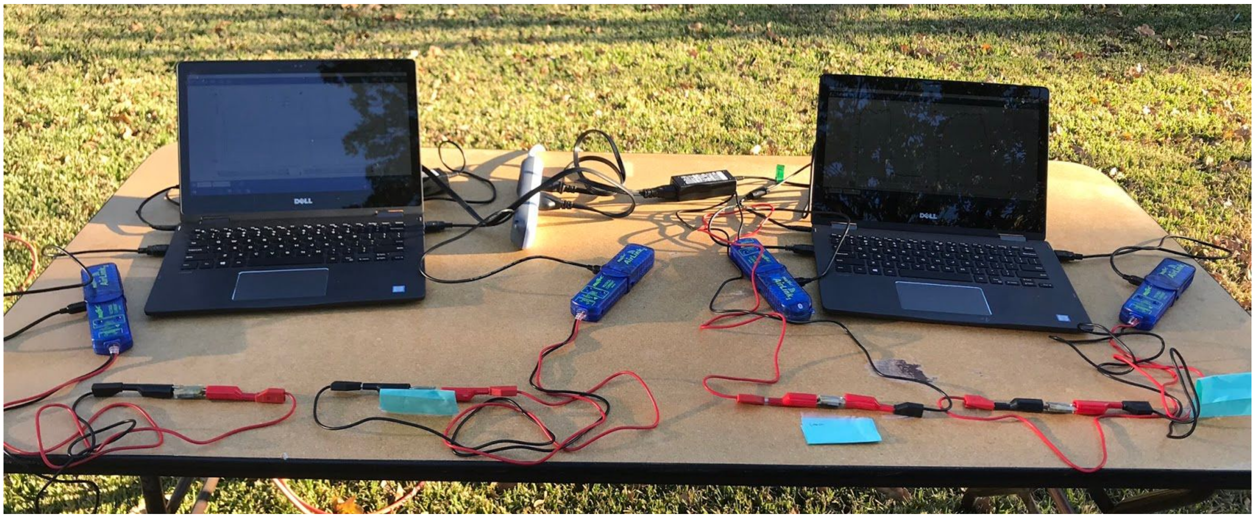

Figure 10: Organic dyes were tested in a natural environment

To test the second goal, the efficiency of natural versus controlled environment, through the course of five days, the dyes were taken outside to test their efficiency in a natural environment. The rankings of the efficiency of each dye was the same in the natural environment as it was in the controlled environment (apple being the highest, lemon being the lowest). However, 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. The controlled environment had a light intensity of about

20,000 lux, which is similar to the light intensity of a natural environment on a average bright day. Out of the five days we tested the dyes in the natural environment, three of the days had a light intensity of about 20,000 lux, thus yielding a similar voltage production as the dyes did in the controlled environment. However, the other two days, the light intensity was significantly less than 20,000 lux, 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.

To test the third goal, two courses of action were undertaken. First, the dyes were measured in the controlled environment over time to see how long it would talk for the voltage production to significantly drop. 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. Mangosteen had a degradation of about 4.12 mV per day, and Apple had a degradation of about 5.79 mV per day. Lemon had a degradation of 11.7 mV per day, and Orange had a degradation of 17.2 mV per day. With more research, it would be possible to test how much more time it would take to observe a significant degradation in Apple and Mangosteen. This testing was done in a controlled environment, so 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. Because the iodide electrolyte and the dye is said to degrade through exposure to UV, we wanted to see if the systems would have a fast degradation within the matter of hours when exposed to real UV in a natural environment. We tested the systems in two trials outside for a 12 hour period and kept a constant measurement going of the voltage. 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. Further research could be done to see how long it would take for the system to degrade in a natural environment. Additionally, at the end of our research, we took a look at our systems and 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. We hypothesized that this was a result of either the dye or the iodide electrolyte degradation over time. Further research can be done to test whether the iodide electrolyte or dye experienced the degradation that caused the titanium dioxide particles to fall off with it.

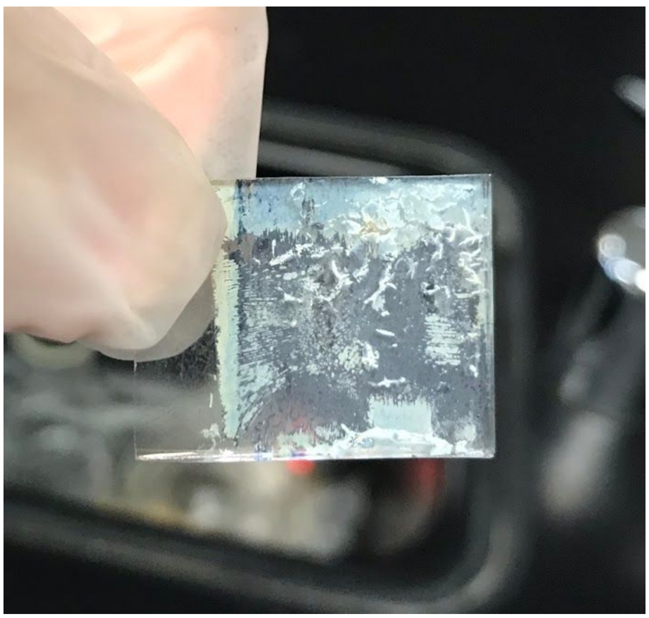

Figure 11: Wearing of Titanium Oxide

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