Manuscript type: Primary Research Article

Type of Electrolyte Alters Voltage Output of Dye-Sensitized Solar Cells

Jeremy Dapaah[1*], Sherrie Feng[1*], Kevin Gu[1*], Emily Ye[1*]

[1] Science and Technology Department, Thomas Jefferson High School for Science and Technology, Arlington, VA, USA

[*]Authors for correspondence:
Jeremy Dapaah, email: 2020jdapaah@tjhsst.edu
Sherrie Feng, email: 2020sfeng@tjhsst.edu
Kevin Gu, email: 2020kgu@tjhsst.edu
Emily Ye, email: 2020eye@tjhsst.edu

Short Title: *Various Electrolytes in DSSCs*

Word Count: 1769

ABSTRACT (180 words)

The dye-sensitized solar cell (DSSC) is a recent development in the field of photovoltaics, which converts captured solar energy into an electrical current. As an environmentally friendly and low-budget technology, DSSCs not only combat the negative effects of fossil fuels, but are also easy to manufacture. When sunlight passes through the anode of a DSSC, the photosensitive pigments within the dye absorb the solar energy to 'excite' electrons. The electrons receive enough energy to transport themselves across a layer of TiO_2 nanoparticles and eventually travel to the cathode, generating an electrical current. The electrolyte fills the gaps created by the lost electrons, completing the DSSC circuit. Earlier studies have shown that altering components within the DSSC affects its voltage output. The purpose of our experiment is to demonstrate if changing the type of electrolyte affects the amount of energy generated by the DSSC. After comparing the average voltage produced by three DSSCs containing three different electrolyte solutions, we were able to conclude that changing the electrolyte within a DSSC did have an influence on the DSSC's voltage production.

INTRODUCTION

Consumers around the world are quickly depleting nonrenewable sources at a consumption rate of 82.5 million barrels per day (Al-Alwani, Mohamad, Ludin, Kadhum, & Sopian, 2016), and it is estimated that fossil fuels can only last for about 200 more years (Gong, Sumathy, Qiao, & Zhou, 2017). Fossil fuels also harm the environment and public health, for they intrude on water reservoirs and pollute underground streams. In addition, they can cause neurological damage and cancer (The Union of Concerned Scientists, 2013). In contrast, renewable energy sources provide numerous benefits. One example, solar energy, is practical and adaptable to various applications (Al-Alwani et al., 2016). A study (Lopez, Roberts, Heimiller, Blair, & Poro, 2012) showed that photovoltaics, devices that convert sunlight into electrical energy, have the potential to generate 70 times more than their output today. A subclass of these photovoltaics is the dye-sensitized solar cell (DSSC). First made by Michael Grätzel in the 1980s, the DSSC has gained attention as a photovoltaic due to its low production cost. Researchers have even considered using it as an energy source in developing third-world countries (Parisi, Maranghi, & Basosi, 2014). In addition, DSSCs can utilize both direct and diffuse light, allowing them to function well in low light environments (Gong et al., 2017).

A DSSC contains two glass plates, both with a layer of transparent conducting oxide (TCO), which supplies a charge to a side of each glass plate. Other materials within the DSSC include a source of carbon, an electrolyte solution, titanium dioxide (TiO_2), and a colored dye. When photons from the light source hit the dye, its electrons gain energy and become ‘excited’, which allows them to discharge from the dye molecules. The electrons diffuse through the TiO_2 anode and move out of the cell, generating an electrical current. The movement of electrons exiting through the anode produces energy (Al-Alwani et al., 2016).Throughout the process, the oxidation of the dye molecules results in electron vacancies. To compensate, the electrolyte serves as a mediator by replenishing the lost dye electrons (Pandikumar, 2013).

Altering the electrolyte within a DSSC significantly impacts the cell's dye-desorption rate, which affects its overall efficiency (Heo, Jun, & Park, 2013). Traditionally, DSSCs utilize liquid electrolytes over solid and gel electrolytes, as they allow for the quickest transport of electrons (Wanninayake, Premaratne, Kumara, & Rajapakse, 2016). In an experiment using lithium and sodium electrolytes (Fabregat-Santiago, Bisquert, Garcia-Belmonte, Boschloo, & Hagfeldt, 2004), the DSSC containing the sodium electrolyte produced more voltage, indicating that the ion level within the electrolyte correlates with amount of voltage created by the solar cell. Highly acidic and highly basic substances have large amounts of either H^+ ions or OH^- ions, which are unstable due to the number of electrons they contain. Bases create an imbalance, favoring OH^- ions over H^+ ions, while acids do the opposite. This imbalance allows electrons to flow from a higher to lower concentration, creating an electrical current. Therefore, a stronger base or acid should imply a greater influx of voltage, since the highly basic or acidic electrolyte can supply more electrons and better restock the oxidized dye.

In our experiment, we assigned three liquid electrolytes to be our independent variables. We chose to use iodide as our control, as it is the most commonly used electrolyte. Lemon juice served as our second electrolyte, being a strong acid that could effectively demonstrate a difference in voltage produced due to the pH of a substance. We designated a diluted sodium hydroxide solution (NaOH) as our last electrolyte. It had an extreme pH similar to lemon juice's, but on the alkaline side instead. We hypothesized that the usage of differing electrolytes would cause the DSSCs to produce varied amounts of voltage. Our hypothesis proved to be true, as the

DSSCs with iodide, sodium hydroxide, and lemon juice electrolytes each produced different amounts of voltage.

MATERIALS and METHODS

Assembly of the dye-sensitized solar cell

To begin, we used a multimeter on a surface of the glass slides to detect electrical charge, the presence of which indicates the conductive side. Next, we applied the TiO_2 by spreading two drops onto the conductive side of each glass slide with a stir stick. We then heated the slides for approximately 30 minutes on a hot plate to adhere the TiO_2 onto the glass. Afterwards, we submerged the TiO_2 covered layer in a blackberry dye for a ten minute period. The opposing glass slides required a carbon layer to act as an electrode, which we applied by holding the conductive side of the glass directly above a flame. Next, we added three drops of electrolyte onto the carbon slide, changing the type of electrolyte for each cell. In order to allow for space to attach the Labquest probes, we offset the faces of each cell. The final step was sealing the cells using a binder clip.

Voltage measurements

To record the voltage generated, we wired the cell to a Labquest, connecting one alligator clip to each electrode of the DSSC. The Labquest was set to collect a voltage measurement every minute (shown in Table 1).

Statistical analysis

We chose to conduct a one-way ANOVA test, with a significance level of 0.05.

RESULTS

The voltage produced by the dye sensitized solar cells varied significantly between electrolytes. The DSSC containing lemon juice produced the most voltage on average, while the DSSC containing iodide generated the least average voltage, as seen in Table 1. Lemon juice also showed greater consistency over NaOH, as its variance was five times lower than NaOH's. In Figure 2, the spread of the data between NaOH and lemon juice were similar, with the voltage in both DSSCs decreasing as time went on. While the generated voltage of the iodine DSSC also decreased over time, its descent is more linear than the exponential voltage reductions of the other DSSCs.

We tested the significance of our results using a one-way ANOVA test. The results, as displayed in Table 1, proved that our data are significant at the 0.05 alpha level. Therefore, we are able to reject our null hypothesis, which stated that differing electrolytes would not change the amount of voltage produced by a DSSC.

DISCUSSION

This experiment was conducted in order to test the reliability of different liquid electrolytes in a DSSC and to observe whether a change in electrolyte caused a serious difference in the efficiency of a DSSC. We were able to confirm our hypothesis, which stated that differing electrolytes would cause varying efficiencies of the DSSC.

Although we found enough evidence to reject our null hypothesis, there are many aspects of this experiment that need improvement. For example, calibration issues with the Labquest may have skewed the results obtained, as many of our voltage measurements fluctuated from positive to negative. In addition, our constants were not entirely dependable, for the area of the DSSC covered by TiO_2 varied between DSSCs. Due to the weather conditions during the experiment, a consistent source of light was also difficult to maintain. Throughout our experiment, we also noticed that the DSSCs' voltage production corresponded with the extremity of their electrolyte pHs. The DSSCs with lemon juice and sodium hydroxide electrolytes produced far more voltage than the DSSC with an iodide electrolyte. Lemon juice and sodium hydroxide both have extreme pHs, in the acidic and basic directions respectively, whereas iodide's pH is far more moderate. We would like to continue testing the effects of various electrolytes on the voltage produced by DSSCs, factoring in a greater variety in pH and other possible influences.

This research is important as it sheds new light on the field of thin film photovoltaics. Currently the efficiency of dye-sensitized solar cells are quite low, reported at 13% in 2014 (Gong et al., 2017), while larger prototypes are only reaching an efficiency of 5% (Parisi et al., 2014). Conducting studies to further test and determine possible options for even better electrolytes can lead to improving the overall efficiency of DSSCs, thus allowing them to gain recognition as a leading energy source contender in the future.

ACKNOWLEDGEMENTS

This study was heavily supported by Dr. Jennifer James, a former researcher at the National Institutes of Health. She now teaches biology classes at Thomas Jefferson High School for Science and Technology. All the researchers would also like to thank Mrs. Nancy Glover for providing guidance in the creation of this paper, along with Mr. Craig Lewis, who suggested the project idea to build a dye-sensitized solar cell for experimentation and supplied advice on its construction. They teach English 9 and Design and Technology at Thomas Jefferson, respectively.

REFERENCES

Al-Alwani, M. A.M., Mohamad, A. B., Ludin, N. A., Kadhum, A. A. H., & Sopian, K. (2016). Dye-sensitised solar cells: Development, structure, operation principles, electron kinetics, characterisation, synthesis materials and natural photosensitisers. *Renewable and Sustainable Energy Reviews*, *65*, 183-213. http://dx.doi.org/10.1016/j.rser.2016.06.045

Fabregat-Santiago, F., Bisquert, J., Garcia-Belmonte, G., Boschloo, G., & Hagfeldt, A. (2005). Influence of electrolyte in transport and recombination in dye-sensitized solar cells studied by impedance spectroscopy. *Solar Energy Materials & Solar Cells*. http://dx.doi.org/10.1016/j.solmat.2004.07.017

Gong, J., Sumathy, K., Qiao, Q., & Zhou, Z. (2017). Review on dye-sensitized solar cells (DSSCs): Advanced techniques and research trends. *Renewable and Sustainable Energy Reviews*, *68*, 234-246. http://dx.doi.org/10.1016/j.rser.2016.09.097

Heo, N., Jun, Y., & Hyeok Park, J. (2013). Dye molecules in electrolytes: new approach for suppression of dye-desorption in dye-sensitized solar cells. *Scientific Reports*. http://dx.doi.org/10.1038/srep01712

Lopez, A., Roberts, B., Heimiller, D., Blair, N., & Porro, G. (2012, July). *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis* [PDF]. National Renewable Energy Laboratory.

Pandikumar, A. (2013). *Potential development in dye-sensitized solar cells for renewable energy: Special topic volume with invited peer reviewed papers only.* Retrieved October 19, 2016, from http://site.ebrary.com/lib/tjhsst/detail.action?docID=10803701

Parisi, M. L., Maranghi, S., & Basosi, R. (2014). The evolution of the dye sensitized solar cells from Grätzel prototype to up-scaled solar applications: A life cycle assessment approach. *Renewable and Sustainable Energy Reviews*, *39*, 124-138. http://dx.doi.org/10.1016/j.rser.2014.07.079

The Union of Concerned Scientists (2013). *Benefits of Renewable Energy Use.* Retrieved October 15, 2016, from http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/public-benefits-of-renewable.html#bf-toc-5

Wanninayake, W., Premaratne, K., Kumara, G., & Rajapakse, R. (2016). Use of lithium iodide and tetrapropylammonium iodide in gel electrolytes for improved performance of quasi-solid-state dye-sensitized solar cells: Recording an efficiency of 6.40%. *Electrochimica Acta*, *191*, 1037-1043. http://dx.doi.org/10.1016/j.electacta.2016.01.108

Table 1.

Statistics Summary Table for the Effect of the Electrolyte Type on the Voltage Produced by a Dye-Sensitized Solar Cell

	Electrolyte Type		
	Iodide	Sodium Hydroxide	Lemon Juice
Mean Voltage Produced (volts)	0.009	0.068	0.123
Standard Deviation	0.008	0.071	0.041
# of trials	20	20	20
One-way ANOVA			0.05 2.11E-09

**p < .05.
Table 1. Running a one-way ANOVA test proved that these results are statistically significant at a 0.05 level.

Figure 1.

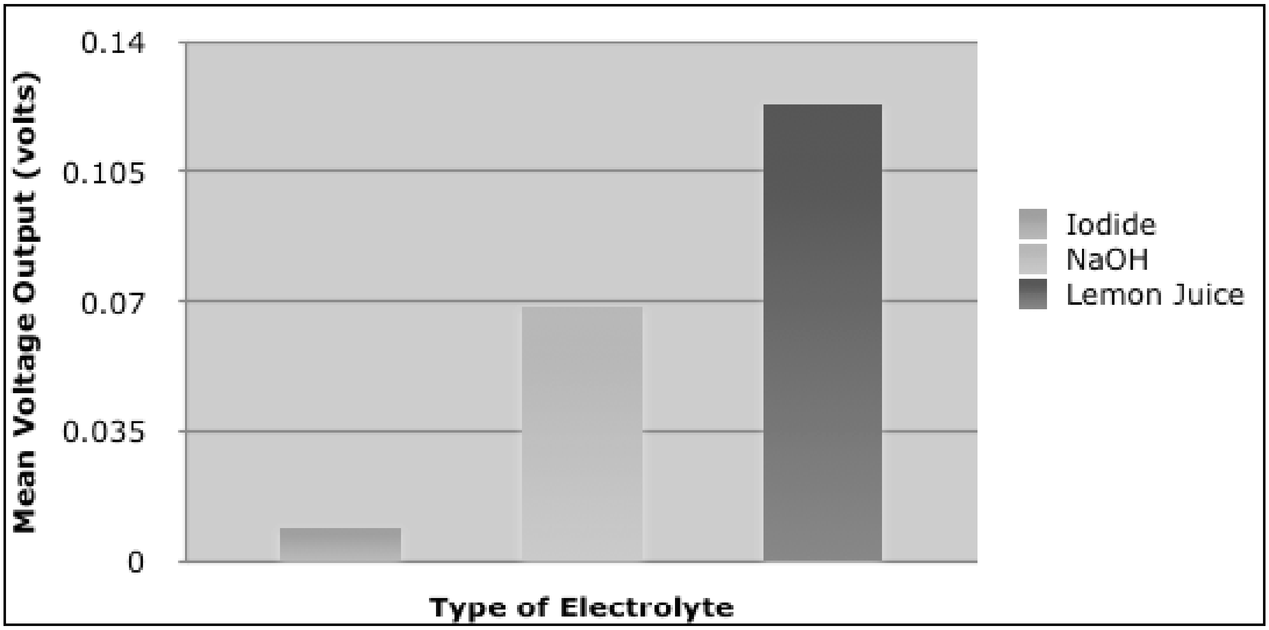

Figure 1. The DSSC with a lemon juice electrolyte produced the most voltage on average, while the DSSC with an iodide electrolyte produced the least voltage on average. This showed that a change in electrolyte does affect the voltage produced by a DSSC.

Figure 2.

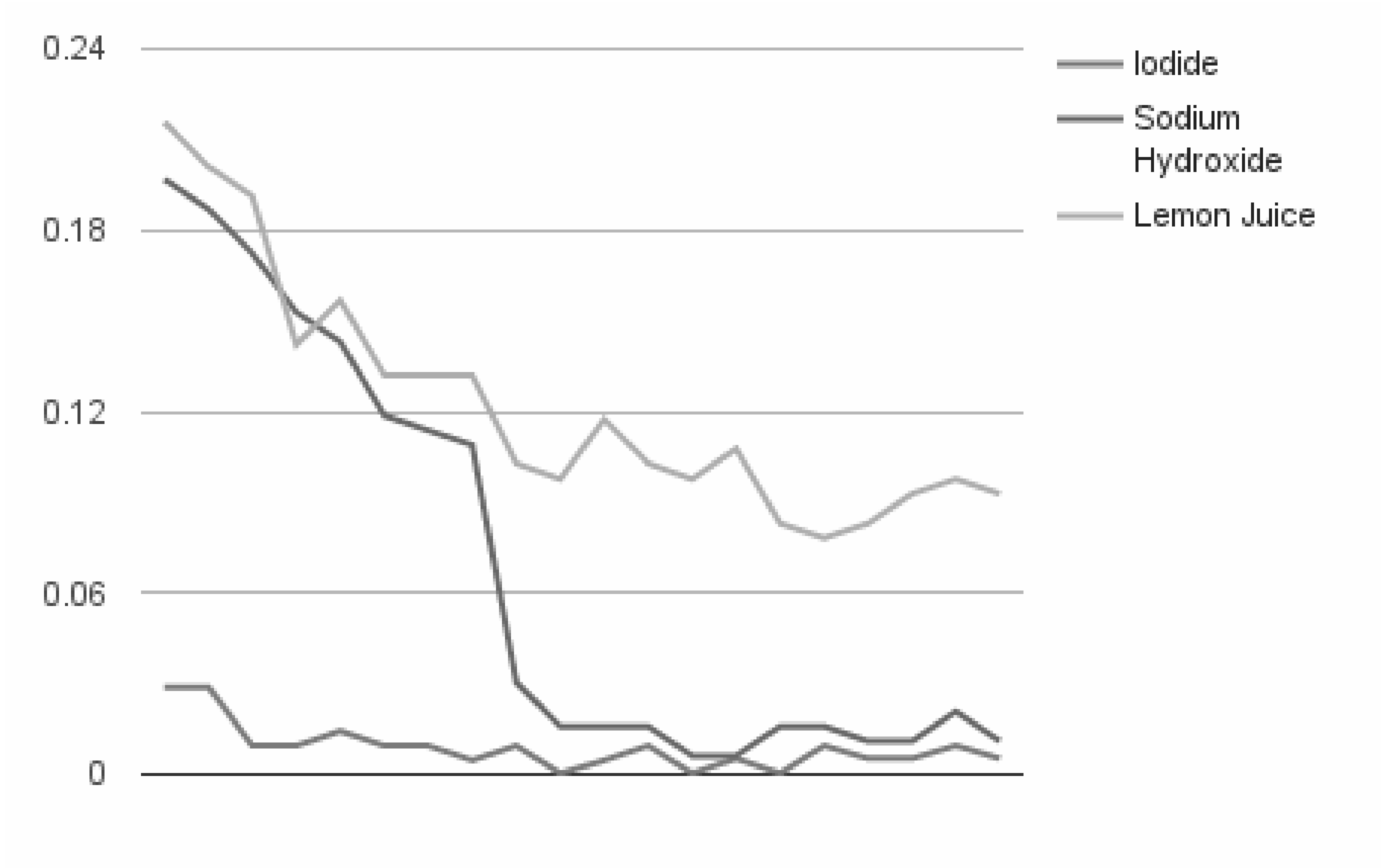

Figure 2. All three of the DSSCs decreased in voltage production over time. Sodium hydroxide and lemon juice both showed large reductions, while iodide's voltage production stayed low throughout the experiment.