Journal of
Emerging Investigators

The Effect of Various Liquid Mediums on the Transport of Photonic Energy and its Impact on the Quantum Efficiency of Photovoltaic Cells

Syamantak Payra[1] and Susan Long[1]

[1]Westbrook Intermediate School, Friendswood, TX, 77546

Summary

Photons from sunlight with energy slightly higher than that of the band gap of silicon create electric current within a photovoltaic (PV) cell. However, many photons from sunlight have either insufficient or excess energy. This study was conducted to find the effect of different photon transmission mediums on the temperature and voltage output of photovoltaic cells. Two different photovoltaic cells were tested under a 20-watt halogen lamp with 6 transmission mediums: 5% NaCl solution, 5% sugar solution, deionized (DI) water, canola oil, extra virgin olive oil (EVOO), and the control (air). It was hypothesized that the mediums with higher specific heats would result in relatively lower temperature increases, maintain higher voltages and have increased efficiencies compared to the mediums with lower specific heats. The voltage drop for EVOO, canola oil and air were higher than that of the aqueous solutions such as 5% sugar solution, 5% NaCl, or DI water. The results show an estimated increase of 5-6% in the performance of conventional photovoltaic cells by simply placing a layer of aqueous solution above the PV cell.

Received: August 27, 2014; **Accepted:** March 6, 2015; **Published:** May 5, 2015

Introduction

The Sun provides the Earth with a staggering amount of energy. The hope for a "solar revolution" that one day we will all use readily available energy from the sun is an exciting promise, because on a bright, sunny day, the sun's rays give off approximately 1,000 watts of energy per square meter of the planet's surface, a total of 1.2 x 10^{17} watts for the entire Earth (1). If we could collect all of that energy, we could easily power our homes and offices at a much lower cost. A photovoltaic cell (PV cell) or solar cell is a device that converts light (photons) into electricity. Many people recognize that solar energy is the alternative power source of the future, and the global market for photovoltaic cells and modules is forecast to surpass $134 billion by the year 2020 (2). As of now, the efficiency of PV cells has a lot of room to improve. To make solar power the clean alternative energy source of the future, we need to urgently maximize the efficiency of PV cells. Some examples of where breakthroughs in solar technology would be beneficial are rural electrification, water pumping and treatment, healthcare, communications, agriculture, and transportation (3). From electric power plants to households to commercial projects, the results of this study could be used to harness the full potential of one of the world's leading green and sustainable power sources: solar energy.

One of the big limitations of the widespread use of PV cells is their cost-effectiveness. There are three different types of PV cells available in the market today, each with different price ranges and efficiency levels. Making monocrystalline PV cells (cells made of a single silicon crystal) is a painstaking process and expensive, but commercial-grade monocrystalline cells can have an efficiency of higher than 30%. Polycrystalline cells (cells made of many silicon crystals) are less expensive, but have an efficiency of ~15%. Amorphous cells (cells made of scraps of silicon patched together) are the cheapest, but have a low efficiency of ~10% (1, 4).

Dye-sensitized solar cells (DSSCs) use wide band gap semiconductor dyes and electrolytes to increase photon absorption. DSSCs with efficiencies of up to 10.4% have been reported for devices employing nanocrystalline TiO_2 films. Natural dyes from flame tree flowers and pawpaw leaves have also been studied as sensitizers to fabricate dye-sensitized solar cells (5, 6). PV cells absorb a lot of light and heat. The voltage output of a PV cell must be dependent on some factors in addition to the type of PV cell used and the amount of sunlight it receives. A photon only needs to have slightly greater energy than that of the band gap of silicon to be absorbed, but most of the photons that come from sunlight have energies much greater than the band gap of silicon, which causes the excess energy to be turned into heat (**Figure 1**) (7). The efficiency of PV cells decreases as the operating temperature increases. It has been reported that an increase in temperature leads to a decrease in voltage due to the uneven expansion of the different layers of silicon (8, 9, 10). When photons are absorbed by silicon, some electrons will have acquired the energy to jump into the conduction band. The electrons in the conduction band and the holes they left behind in the valence band create an electron-hole pair. The electron motion and the movement of holes in the opposite direction produce the electric current (**Figure 1b**).

PV cells, used in this experiment, are essentially

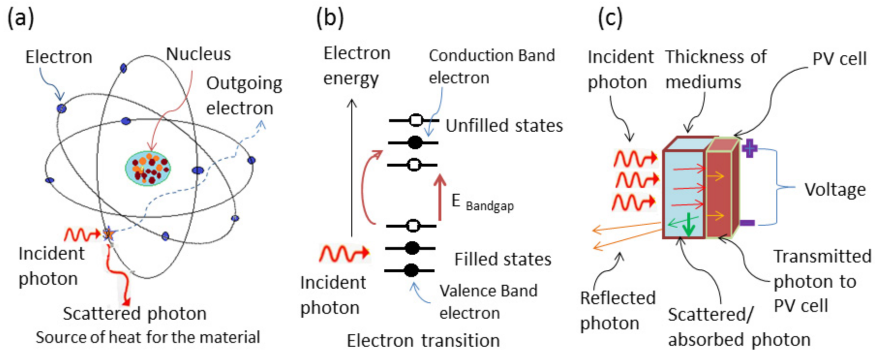

Figure 1. Schematic representation of the absorption of photons by materials a) incoming photon, scattered photon and the outgoing electron, b) photon energy absorption and electron transition, c) effect of intervening material in removing higher energy photons (7).

pieces of silicon with each side coated with either boron or phosphorus. The efficiency of PV cells is defined as the percentage of photons that hit the semiconductor and are converted into electricity:

$$\text{Quantum Efficiency (QE)} = \frac{\left(\frac{\text{Electrons}}{\text{second}}\right)}{\left(\frac{\text{Photons}}{\text{second}}\right)} = \frac{\left(\frac{\text{Current}}{\text{Charge of 1 electron}}\right)}{\left(\frac{\text{Total power of photons}}{\text{Average energy of 1 photon}}\right)}$$

This study was conducted to find the effect of liquid photon transmission mediums on the voltage output and temperature of photovoltaic cells. An objective of this study was to increase the efficiency of the PV cells using readily available and inexpensive materials such as common household items (water, sugar, salt and cooking oils). Specific heat is the amount of heat per unit mass that is required to raise the temperature by one degree Celsius (°C). It was hypothesized that liquid mediums with higher specific heats would minimize the temperature increase of the PV cells and allow them to maintain higher voltage, thus improving their performance. Six different mediums were used, including a control. Considering lower temperature and higher voltage to be indicators of higher performance, it was found that the more efficient mediums were aqueous (ionic and nonionic) rather than the organic mediums, which had lower specific heats compared to the aqueous mediums. This research shows which photon transmission mediums can be used to increase the efficiency of photovoltaic cells.

Results

In this study, two different photovoltaic cells (monocrystalline **PV Cell I** and polycrystalline **PV Cell II**) were tested under a 20-watt halogen lamp during 1800 seconds of exposure to a white light with six different transmission mediums (including control). All liquid mediums and their physical properties such as specific heat, density, and refractive index are listed in **Table 1**. To hold mediums on top of the PV cell, a boundary was made and the PV cell was connected to a Pasco Xplorer GLX™ Datalogger with Pasco voltage and temperature probes. A schematic diagram for the experimental setup is provided in **Figure 2**.

The effect of different mediums on the voltage of monocrystalline **PV Cell I** was plotted in **Figure 3a**. All lines in the graph represent the combined mean voltage across the two trials for 0 to 1800 seconds. It was also observed that the voltage dropped rapidly at the beginning of the experiments. The combined mean voltage of the two trials is listed in **Table 2a**. The combined mean voltage changes Δ (-V) were as follows: extra virgin olive oil (EVOO) (1.023V), air (0.955V), canola oil (0.950V), 5% NaCl solution (0.577V), 5% sugar solution (0.559V), and deionized (DI) water (0.506). The trend of Δ (-V) is shown in the bar graph **Figure 3b**.

The effect of different mediums on the temperature of

Medium	Specific Heat J/g*°C[a]	Density g/mL[b]	Refractive Index	Group	Hypothesis: Δ (+T, °C), Δ (-V)	Observation: Δ (+T, °C), Δ (-V)
Air	~1.00	~0.001	~1.003	Group 1	Higher temp Δ (+T) Lower voltage Δ (-V)	Higher temp Δ (+T) Lower voltage Δ (-V)
Canola Oil	~1.09	~0.914	~1.467			
EV Olive Oil	~1.97	~0.918	~1.465			
5% NaCl	~3.93	~1.036	~1.339	Group 2	Lower temp Δ (+T) Higher voltage Δ (-V)	Lower temp Δ (+T) Higher voltage Δ (-V)
5% Sugar	~4.05	~1.015	~1.342			
DI Water	~4.19	~0.997	~1.333			

Table 1. Physical properties of various liquid mediums used for this study. [a] = literature value of specific heat in J/g*°C (at ~25°C), [b] = literature value of density in g/mL (at ~25°C).

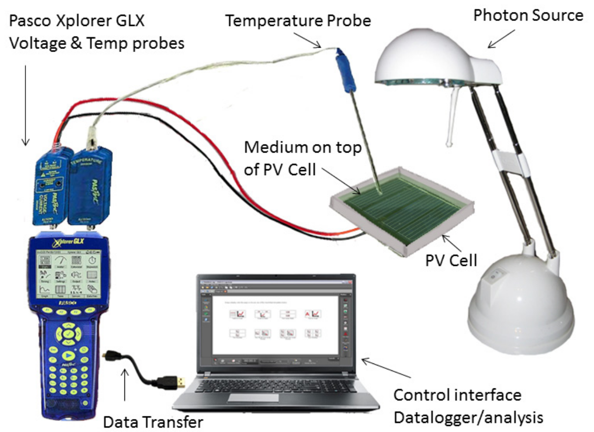

Figure 2. Schematic diagram of the experimental setup used during photon transmission experiments. The voltage and temperature of the photovoltaic cell were measured. Photon source (lamp) was placed 5 cm above the PV cell and the depth of the fluid was 0.28 cm. **PV Cell I** was monocrystalline (6 cm × 4 cm). **PV Cell II** was polycrystalline (12 cm × 5 cm).

PV Cell I was plotted in **Figure 3c**. These lines represent the combined mean temperature across the two trials for 0 to1800 seconds. As observed with the voltage change, the temperature increase was rapid at the beginning of the experiment but over time either plateaued (for aqueous mediums) or increased with a gentle slope (organic medium). The line for the control (air) lies in between those for the aqueous and organic mediums. For **PV Cell I** the combined mean temperature increase Δ (+T) values were as follows: EVOO (22.274°C), canola oil (20.129°C), air (16.538°C), 5% NaCl solution (14.753°C), 5% sugar solution (14.444°C), and DI water (13.784°C) (**Table 2b**). The trend of Δ (+T) is plotted in **Figure 3d**.

Similar to **PV Cell I**, experiments were performed with **PV Cell II**. The effect of different mediums on the voltage of **PV Cell II** was plotted in **Figure 4a**. These lines in the graph represent the combined mean voltage across the two trials for **PV Cell II** from 0 to 1800 seconds. The combined mean voltage changes Δ (-V) for two trials with each of the mediums were as follows: EVOO (0.334V), canola oil (0.332V), air (0.312V), 5% sugar solution (0.171V), DI water (0.167V), and 5% NaCl solution (0.166V) (**Table 3a**). The trend of Δ (-V) is shown in the bar graph, **Figure 4b**.

The effect of different mediums on the temperature of **PV Cell II** was plotted in **Figure 4c**. All lines in this graph represent the combined mean temperature across the two trials for **PV Cell II** from 0 to 1800 seconds. It was observed that the line for the control condition lies in between those for the aqueous and organic mediums. For **PV Cell II** the combined mean temperature change Δ (+T) for the two trials were as follows: EVOO (20.602°C), canola oil (18.453°C), air (14.901°C), DI water (11.505°C), 5% sugar solution (10.957°C), and for 5% NaCl solution (10.240°C) in **Table 3b**. The trend of Δ (+T) is plotted in **Figure 4d**.

We observed that the voltage drop was rapid at the beginning of the experiments, but over time it plateaued for aqueous mediums and decreased with a steeper slope for organic mediums and air. To evaluate the impact of a longer testing time, we had conducted a trial run with 5% NaCl solution and canola oil for 3600 seconds respectively. It was observed that for the 5% NaCl solution there was no significant decrease in voltage from 1800 to 3600 seconds whereas for canola oil a voltage decrease was observed. This indicates that the aqueous solutions were more capable of maintaining the higher voltage of the PV cells. The voltage decrease Δ (-V) trend of **PV Cell I** was found to be $\Delta V_{EVOO} > \Delta V_{air} > \Delta V_{canola\ oil} > \Delta V_{5\%\ NaCl\ solution} > \Delta V_{5\%\ sugar\ solution} > \Delta V_{DI\ water}$ (**Figure 3b**). For **PV Cell II**, the trend was $\Delta V_{EVOO} > \Delta V_{canola\ oil} > \Delta V_{air} > \Delta V_{5\%\ sugar\ solution} > \Delta V_{DI\ water} > \Delta V_{5\%\ NaCl\ solution}$ (**Figure 4b**). The increase in temperature Δ (+T) of **PV Cell I** was observed to be $\Delta T_{EVOO} > \Delta T_{canola\ oil} > \Delta T_{air} > \Delta T_{5\%\ NaCl\ solution} > \Delta T_{5\%\ sugar\ solution} > \Delta T_{DI\ water}$ (**Figure 3d**). Likewise, the increase in temperature Δ (+T) for **PV Cell II** was $\Delta T_{EVOO} > \Delta T_{canola\ oil} > \Delta T_{air} > \Delta T_{DI\ water} > \Delta T_{5\%\ sugar\ solution} > \Delta T_{5\%\ NaCl\ solution}$ (**Figure 4d**).

T-tests were conducted by considering two groups of data as listed in **Table 4**. For **PV Cell I**, the two-tailed p-value was equal to 0.0002. For **PV Cell II**, the two-tailed p-value was less than 0.0001. By conventional criteria, this difference in voltage change Δ (-V) between the two groups of data was considered to be statistically significant. Similarly, t-tests performed for temperature change Δ (+T) for both the **PV Cell I** ($p = 0.0351$) and **PV Cell II** ($p = 0.0141$), indicates that the difference between the two groups was statistically significant. A small

a)

PV Cell I	Start time: 0 Second			End time: 1800 Second			Start-End	Performance
	Mean: (V)	SD	SEM	Mean: (V)	SD	SEM	Δ (-V)	improvement
EV Olive Oil	7.615	0.006	0.005	6.592	0.052	0.037	1.023	-0.89%
Air	7.559	0.041	0.029	6.604	0.025	0.018	0.955	0.00%
Canola Oil	7.569	0.071	0.051	6.619	0.050	0.035	0.950	0.07%
5% NaCl	7.626	0.030	0.021	7.049	0.011	0.008	0.577	5.00%
5% Sugar	7.631	0.049	0.035	7.072	0.015	0.006	0.559	5.24%
DI Water	7.568	0.056	0.040	7.061	0.004	0.003	0.506	5.94%

b)

PV Cell I	Start time: 0 Second			End time: 1800 Second			Start-End
	Mean: T(°C)	SD	SEM	Mean: T(°C)	SD	SEM	Δ (+T, °C)
EV Olive Oil	25.572	0.187	0.132	47.846	0.431	0.304	22.274
Canola Oil	26.097	0.249	0.176	46.226	0.157	0.111	20.129
Air	26.000	0.100	0.071	42.538	0.205	0.145	16.538
5% NaCl	25.200	0.177	0.125	39.953	0.789	0.558	14.753
5% Sugar	25.598	0.166	0.117	40.042	0.250	0.177	14.444
DI Water	26.465	1.783	1.261	40.249	1.427	1.009	13.784

Table 2. a) GLX Voltage trend data for **PV Cell I**. Start voltage and end voltage was the combined mean value (1 sec, 11 data points) of two trials. SD: standard deviation between the two trials. SEM: standard error of the mean for two trials (SD/√N; N = 2). PV cell performance = ($\Delta V_{air} - \Delta V_{any\ medium}$) / starting voltage of PV cell with air (7.559V). b) GLX Temperature trend data for **PV Cell I**. Start temperature and end temperature was the combined mean value (1 sec, 3 data points) of two trials.

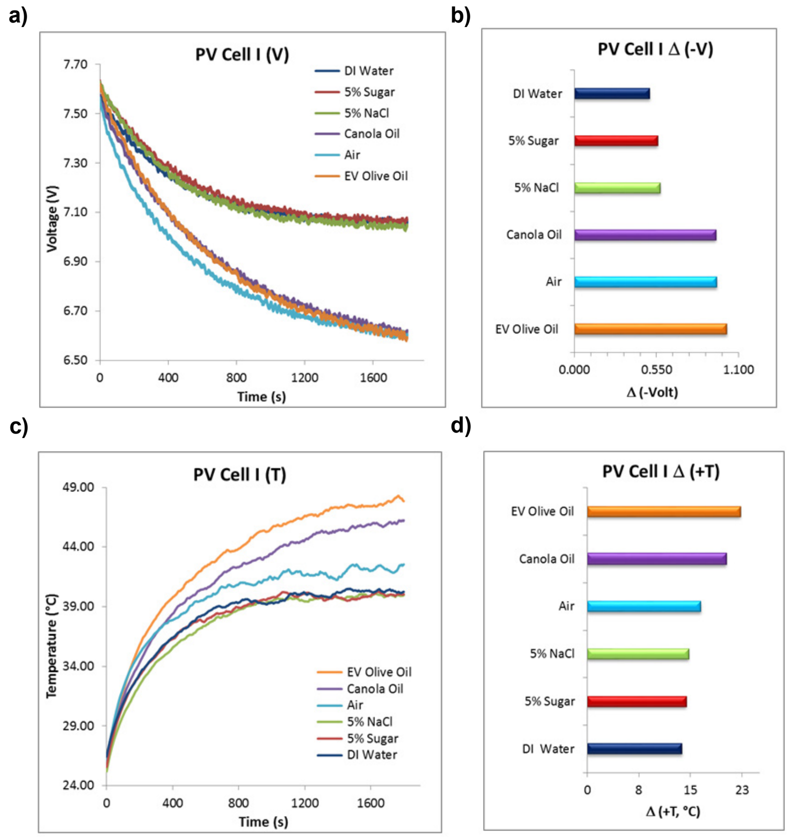

Figure 3. The effect of different photon transmission mediums a) on the voltage of **PV Cell I**, b) bar graphs for the change in voltage, Δ (-V), c) on the temperature of **PV Cell I**, and d) bar graphs for the change in temperature, Δ (+T).

p-value means the observed difference would happen rarely due to random sampling.

Discussion

The objective of this research was to determine how the voltage output and temperature of a PV cell would be affected by letting the photons pass through various liquid mediums thereby controlling the photonic energy of light hitting the PV cell. It has been reported that when a photon hits a piece of silicon, it can be absorbed only if its energy is higher than the silicon energy band gap, generating an electron-hole pair that creates electric current, and sometimes heat (7-10).

The physical properties of the liquid mediums such as specific heat, density, refractive index, and color, as well as the purity and crystallinity of the PV cells (monocrystalline or polycrystalline), might be key factors in explaining the observed results. The typical specific heat (J/g*°C) values (at ~25°C) of the mediums were as follows: DI Water, 4.19; 5% sugar solution, 4.05; 5% NaCl solution, 3.93; EVOO, 1.97; canola oil, 1.09; air, 1.00 (**Table 1**).

It was hypothesized that the change in voltage and temperature trends would be dependent on the specific heat of the medium, with lower specific heat mediums producing higher temperatures and lower voltages than the mediums with higher specific heat. This is due to the hypothesis that the absorbed photonic energy will increase the temperature of the mediums (of lower specific heat) causing the PV cells to heat up. The band gap energy of semiconductors tends to decrease with the increase in temperature; this is because with the increased thermal energy the atomic vibration and the interatomic spacing increases causing the band gap energy to decrease. Based on the specific heat values (**Table 1**), the transmitted photonic energy that would be reaching the PV cell surface can be expected as: $E_{air} > E_{canola\ oil} > E_{EVOO} > E_{5\%\ NaCl\ solution} > E_{5\%\ sugar\ solution} > E_{DI\ water}$, which can cause the temperature increase Δ (+T) of the medium as $\Delta T_{air} > \Delta T_{canola\ oil} > \Delta T_{EVOO} > \Delta T_{5\%\ NaCl\ solution} > \Delta T_{5\%\ sugar\ solution} > \Delta T_{DI\ water}$. It can also be predicted that the voltage decrease Δ (-V) trend could be: $\Delta V_{air} > \Delta V_{canola\ oil} > \Delta V_{EVOO} > \Delta V_{5\%\ NaCl\ solution} > \Delta V_{5\%\ sugar\ solution} > \Delta V_{DI\ water}$ because research indicates that an increase in temperature corresponds to a decrease in voltage (8, 9, 10). Although the control (air) has the lowest specific heat compared to the other mediums studied, it might also be possible that heat dissipation from the surface of the PV cell causes some loss of heat whereas the organic mediums (EVOO, canola oil) act as a heat storage medium.

If we consider the density of the mediums, the denser a)

PV Cell II	Start time: 0 Second			End time: 1800 Second			Start-End	Performance
	Mean: (V)	SD	SEM	Mean: (V)	SD	SEM	Δ (-V)	improvement
EV Olive Oil	2.882	0.003	0.002	2.548	0.003	0.002	0.334	-0.78%
Canola Oil	2.885	0.011	0.008	2.553	0.009	0.007	0.332	-0.70%
Air	2.858	0.010	0.007	2.546	0.011	0.008	0.312	0.00%
5% Sugar	2.851	0.013	0.009	2.680	0.002	0.001	0.171	4.93%
DI Water	2.851	0.003	0.002	2.684	0.001	0.000	0.167	5.06%
5% NaCl	2.852	0.004	0.003	2.686	0.004	0.003	0.166	5.11%

b)

PV Cell II	Start time: 0 Second			End time: 1800 Second			Start-End
	Mean: T(°C)	SD	SEM	Mean: T(°C)	SD	SEM	Δ (+T, °C)
EV Olive Oil	24.914	0.164	0.116	45.516	0.321	0.227	20.602
Canola Oil	25.404	0.795	0.562	43.857	0.641	0.453	18.453
Air	25.519	0.130	0.092	40.420	1.134	0.802	14.901
DI Water	25.160	0.292	0.207	36.664	1.378	0.974	11.505
5% Sugar	24.508	0.765	0.541	35.465	0.805	0.569	10.957
5% NaCl	24.915	0.536	0.379	35.154	0.526	0.372	10.240

Table 3. a) GLX Voltage trend data for **PV Cell II**. Start voltage and end voltage was the combined mean value (1 sec, 11 data points) of two trials. SD: standard deviation between the two trials. SEM: standard error of the mean for two trials (SD/√N; N = 2). PV cell performance = (ΔV_{air} - $\Delta V_{any\ medium}$) / starting voltage of PV cell with air (2.858V). b) GLX Temperature trend data for **PV Cell II**. Start temperature and end temperature was the combined mean value (1 sec, 3 data points) of two trials.

mediums will have more mass (as the volume of the liquid mediums was kept constant, except air) and photons will have more interactions while travelling through these mediums before it reaches the PV cell. **Table 1** indicates that the densities (g/mL) of EVOO (~0.918) and canola oil (~0.914) are very similar to the densities of the aqueous mediums: 5% NaCl solution (~1.036), 5% sugar solution (~1.015) and water (~0.997). Air has the lowest density (~0.001) among all mediums tested. We have conducted further supplementary experiments with a 10% and 15% NaCl solution on **PV Cell I**, and compared the corresponding voltage and temperature change data with that of the 5% NaCl solution, to explore the effect of density, but no significant impact was observed due to this density change. Another factor to consider is the refractive index of the mediums. The refractive index *n* is equal to the velocity *c* of light in empty space, divided by the velocity *v* of light in a substance, or *n* = *c/v*. Incident light at the interface of two mediums is either reflected, absorbed, or transmitted (**Figure 1c**). The refractive indices of organic mediums such as EVOO & canola oil (~1.467) are higher compared to those of aqueous mediums (~1.333 for water) or air (~1.003) (**Table 1**). Due to the higher refractive indices of EVOO/canola oil, the speed of light is slower in the organic mediums causing more photon energy absorption, which could contribute to the temperature increase of the mediums thereby transferring more heat to the PV cells. Since canola oil and EVOO retain heat, the temperature of the photovoltaic cell increases rapidly. The impacts of the color of the liquid mediums on voltage and temperature changes were not investigated in this study.

Irrespective of the medium, all the starting voltages for **PV Cell I** were similar to each other. Such similarity in starting voltages, no matter the medium, was also observed for **PV Cell II**. It can be inferred that the amounts of photonic energy going into the PV cells at the beginning of the experiment were also similar. But due to a lower specific heat capacity of EVOO and canola oil compared to aqueous mediums, the PV cells with the organic mediums experienced greater temperature increases. Although the specific heat capacity of air is the lowest, the fact that EVOO had a higher temperature increase Δ (+T) causing the largest voltage drop Δ (-V), might be attributed to their higher refractive index values compared to air. There were two distinct data groups, 1) aqueous (ionic or 5% NaCl & nonionic or 5% sugar) mediums, and 2) organic hydrocarbon (EVOO, canola oil) mediums. The organic mediums (EVOO, canola oil) generated a higher temperature than the aqueous mediums (DI water, 5% NaCl solution, 5% sugar solution).

Both PV cells showed that the voltage output was highest when the temperature was lowest (which was the starting temp ~25°C). It was observed that the temperature increase of **PV Cell I** was greater than the temperature increase of **PV Cell II**. There could be a number of possible causes. The surface area of **PV Cell I** was less than that of **PV Cell II**. **PV Cell I** was monocrystalline (higher purity), whereas **PV Cell II** was a polycrystalline (lower purity) material. Although unknown, the type of coating materials on the two PV cells could also be a contributing factor since they were obtained from different manufacturers.

At the end of the experiment, the resultant voltages using the aqueous and organic hydrocarbon mediums were compared with that of the control. Overall, the performance of the photovoltaic cells (**PV Cell I** and **PV Cell II**) was increased by 5-6% (an estimated value based on change in voltage Δ (-V) when using aqueous (ionic and nonionic) mediums compared to air (**Table 2a**,

Unpaired T-test	PV Cell I Δ (-V)		PV Cell II Δ (-V)		PV Cell I Δ (+T)		PV Cell II Δ (+T)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Mediums	1.023	0.577	0.334	0.171	22.274	14.753	20.602	11.505
	0.955	0.559	0.332	0.167	20.129	14.444	18.453	10.957
	0.950	0.506	0.312	0.166	16.538	13.784	14.901	10.240
Mean	0.976	0.547	0.326	0.168	19.647	14.327	17.985	10.900
SD	0.041	0.037	0.012	0.003	2.898	0.495	2.879	0.634
SEM	0.024	0.021	0.007	0.002	1.673	0.286	1.662	0.366
N	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Two-tailed p-value	0.0002		0.0001		0.0351		0.0141	

Table 4. Unpaired T-test. Group I (EV olive oil, canola oil, air), Group II (5% NaCl, 5% sugar, DI water). Numerical data of Δ (-V) and Δ (+T) for **PV Cell I** was taken from **Table 2a** and **2b**. Similarly, data for **PV Cell II** was taken from **Table 3a** and **3b**. SD: standard deviation between the mediums. SEM: standard error of the mean for three mediums (SD/√N; N = 3). The p-value is a probability ranging from zero to one; a small number indicates that the observed difference would happen rarely due to random sampling.

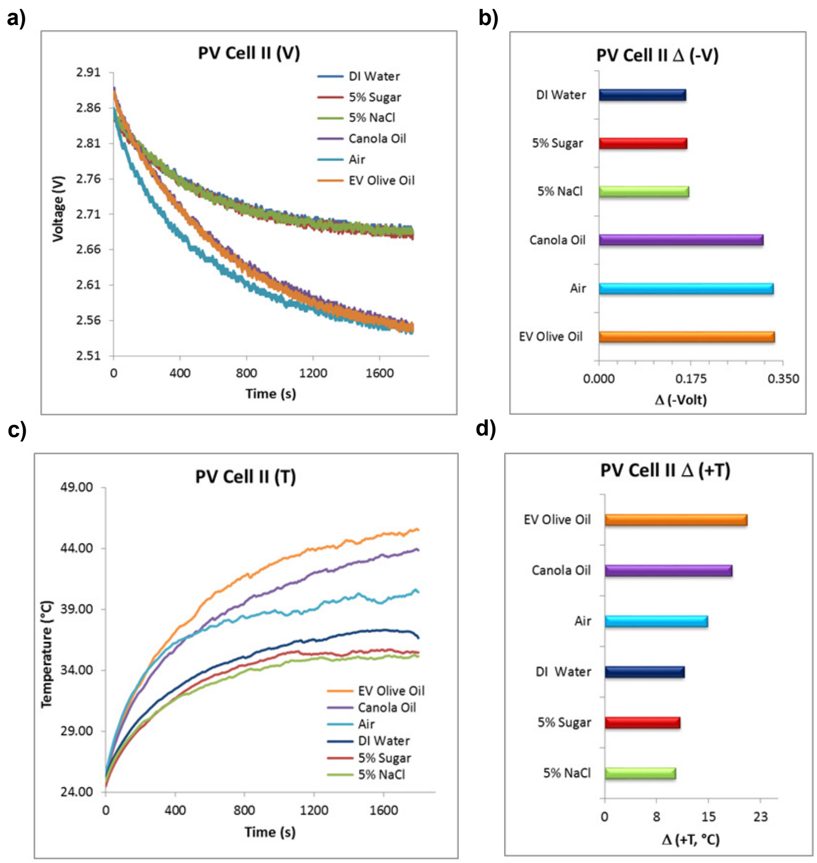

Figure 4. The effect of different photon transmission mediums a) on the voltage of **PV Cell II**, b) bar graphs for change in voltage, Δ (-V), c) on the temperature of **PV Cell II**, and d) bar graphs for change in temperature, Δ (+T).

3a)). However, it is possible that a number of potential factors such as measurement error, or the biased effect of experimental conditions could be impacting the data. A statistical analysis was performed to better understand the data generated during the experiments.

Based on the increase in temperature and decrease in voltage data of the two different photovoltaic cells used in this study, it was found that the more efficient mediums were aqueous (ionic/nonionic) and had higher specific heats and lower refractive indices than the less efficient mediums, which were organic compounds and had lower specific heats and higher refractive indices. This research shows that common household items such as salt, sugar, and water may be used to increase the efficiency of photovoltaic cells. This study was important because although solar energy may have great potential in today's world, it cannot be fully utilized unless we optimize the power output of photovoltaic cells.

Methods

To hold the liquid mediums on top of **PV Cell I** (Elenco; 6 cm × 4 cm), a containment boundary was made using acrylic plastic and latex-silicone caulk and allowed to cure overnight. **PV Cell I** was connected to the Pasco Xplorer GLX^{TM}, model PS-2002. The 20W Ikea halogen lamp was positioned over the PV cell at a distance of 5 centimeters from the PV cell. Pasco voltage and temperature probes were used to connect the PV cell to the GLX Datalogger that recorded voltage changes every 1/10 second and temperature every 1⁄2 second. The voltage (V) and the temperature in degrees Celsius (^{o}C) of **PV Cell I** were recorded for 1800 seconds. To minimize any experimental error, the above process was repeated in two trials (Trial 1 and Trial 2) and the data was recorded using Pasco DataStudio software. In order to ensure that both the trials had a similar starting temperature, the panel was allowed to cool down to room temperature before performing each trial. After the first experiment as control (air), 6 mL DI (deionized) water was added on top of **PV Cell I**. The boundary area on top of the PV cell that holds the liquid was 21.56 cm^2 (5.75 cm × 3.75 cm), and the liquid height was 0.28 cm (6 cm^3 / 21.56 cm^2). Similarly, 6 mL of 5% NaCl solution, 5% sugar solution, EVOO and canola oil were tested for voltage and temperature changes respectively and the corresponding data were recorded using the GLX Datalogger.

Following the same procedure, **PV Cell II** (Horizon, 5 cm × 12 cm), was also prepared with a containment boundary to hold the liquid and connected to the GLX

Datalogger on a table top. The 20-watt halogen lamp was positioned over the PV cell at a distance of 5 centimeters and Pasco voltage and temperature probes were used to connect **PV Cell II** to the GLX Datalogger. In order to ensure that both the trials had a similar starting temperature the panel was allowed to cool down to room temperature before performing each trial. After the first experiment as control (with no liquid medium), 16.4 mL DI water was added on top of **PV Cell II**. The boundary area for holding the liquid medium was 57.50 cm^2 (11.5 cm × 5 cm), and the liquid height was 0.28 cm (16.4 cm^3 / 57.5 cm^2). Accordingly, 16.4 mL of 5% NaCl solution, 5% sugar solution, EVOO and canola oil were individually tested for temperature and voltage, and the corresponding data was recorded.

The voltage and temperature outputs of the PV cells were recorded constantly throughout the 1800 second period. Two trials were performed with each medium for each of the PV cells. For each trial, a total of 18,000 data points for voltage and 3,600 data points for temperature were collected. During the experiment, ten data points for voltage were collected every second by the voltage probe. Eleven data points from the first 1 second (0-1 second) and eleven data points from the last 1 second (1799-1800 seconds) of each trial were averaged to find the mean voltage at the start and end of that trial. For every second, two data points for temperature were collected by the temperature probe. Three data points from the first 1 second and three data points from the last 1 second were averaged, respectively, to find the mean start and end temperatures of each trial.

Statistical analysis: T-tests were conducted by considering two groups of data, Group1 (EVOO, canola oil and air) and Group 2 (5% NaCl, 5% sugar solution, and DI water) (**Table 4**). Results from an unpaired t-test for PV cell I voltage change Δ (-V) were as follows: Group 1 (Mean: 0.976, SD: 0.041, SEM: 0.024, N: 3) and Group 2 (Mean: 0.547, SD: 0.037, SEM: 0.021, N: 3). The two-tailed p-value was equal to 0.0002, and the confidence interval (the difference between the mean of Group 1 and Group 2) was 0.399. The 95% confidence interval of this difference was from 0.310 to 0.487. For **PV Cell II**, unpaired t-test results for the voltage change Δ (-V) were: Group 1 (Mean: 0.326, SD: 0.012, SEM: 0.007, N: 3) and Group 2 (Mean: 0.168, SD: 0.003, SEM: 0.002, N: 3). The two-tailed p-value was less than 0.0001, and the confidence interval (difference between the mean of Group 1 and Group 2) was 0.158. The 95% confidence interval of this difference was from 0.138 to 0.178. Similarly, t-tests were performed for temperature change Δ (+T) for both the **PV Cell I** ($p = 0.0351$) and **PV Cell II** ($p = 0.0141$), indicating that the difference between the two groups is statistically significant.

Acknowledgments

The authors are grateful to Clear Creek Independent School District for providing the Pasco GLX Datalogger and probes. This study was presented as a poster and was awarded 1st place in Physics at the ExxonMobil Texas Science and Engineering Fair (EMTSEF) in March 2014 after receiving 1st place at the Science and Engineering Fair of Houston (SEFH) in February 2014 and continued on to qualify as a National Semifinalist in the Broadcom MASTERS competition. It also received an award of excellence from the 'Krishen Foundation for Arts & Sciences'. The authors would like to thank Dr. Sanjukta Ghose & Dr. Pramatha Payra for their support throughout the course of this experiment.

References

1. Crabtree GW, Lewis NS. Physics Today. 2007;60(3):37-41.
2. Martin R. Worldwide Solar PV Market Will Surpass $134 Billion in Annual Revenue by 2020. Navigant Energy Research, Navigant Consulting. 2013.
3. Cruden G. Solar Power. Energy Alternatives San Diego: Lucent Books. 2005. p.25-38.
4. Carlson DE, Wronski CR. Amorphous Silicon Solar Cells. Applied Physics Letter. 1976;28:671-73.
5. Kimpa MI, Momoh M, Isah KU, Yahya HN, Ndamitso MM. 2012 Materials Sciences & Applications. 2012;3(5):281-86.
6. Kaniyoor A, Ramaprabhu S. Thermally exfoliated graphene based counter electrode for low cost dye sensitized solar cells. Journal of Applied Physics. 2011;109(12):124308(1-6).
7. Saleh BEA, Teich MC. Semiconductor photon detectors. Fundamentals of Photonics. 1991. p.644-695.
8. Hughes BN, Ng PSC, Beg O. Computational study of improving the Efficiency of Photovoltaic Panels. UAE World Academy of Science, Engineering & Technology. 2011;73:278-87.
9. Fischer S, Goldschmidt JC, Loper P, Bauer GH, Bruggemann R, Kramer K, Biner D, Hermle M, Glunz SW. Enhancement of silicon solar cell efficiency by upconversion: Optical and electrical characterization Journal of Applied Physics. 2012;108(4):044912 (1-11).
10. Liu G, Ji S, Xu G, Ye C. Interface engineering: Boosting the energy conversion efficiencies for nanostructured solar cells. Pure & Applied Chemistry. 2012;84(12):2653-75.