CERTIFICATION OF APPROVAL

STUDY ON IMPROVING THE CONVERSION EFFICIENCIES OF PHOTOVOLTAIC SOLAR PANELS THROUGH THE USE OF WATER FILM

By

Muhd Syafiq bin Suhaimi

9156

A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons) Mechanical Engineering

Approved by,

____

(Dr M Shiraz Aris)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2010

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

MUHD SYAFIQ BIN SUHAIMI

ABSTRACT

Reduction of heat build-up of a solar panel operating under hot temperature is one of the main development researches in solar panel community at the moment. By reducing the operating temperature of a solar panel, the performance output would be increased. The main objective of this study is to establish relevant knowledge on the baseline data of solar panel operating under normal operation and the effect of using water film on a solar panel. Several testing conducted during this study to measure the ability of water as a coolant to cool down the temperature of an operating solar panel. Fabrications for the solar panel testing are made such as water dam installation, and adjustable hinge platform. Several equipments was used namely solarimeter for solar insolation readings, multimeter for manual voltage readings, solar panels, data logger, temperature sensors and other equipments for fabricating purposes. The results obtained show that with water flowing on the panel, open circuit voltage V_{OC} increases. Thus, it can be concluded through this project that performance of solar panel can be increased with the use of water cooling.

ACKNOWLEDGEMENT

First and foremost, the author would like to say Alhamdulillah for able to complete the project and with His guidance, the project was a proud accomplishment for the author. The author would also like to give many thanks to Dr M Shiraz b Aris, the respective project supervisor for his helps and guidance throughout the completion of this project. His keenness to share his knowledge and technical expertise in energy has direct contribution into the success in completing this project within the planned time. His counstructive criticsm and advices are very much appreciated.

The author would also like to express his gratitude to all research officers from Block P weather station, postgraduate student Mr Dimas, and lab technicians of Universiti Teknologi Petronas, for sharing their thoughts and work on solar panel system. Finally, great thanks to author's family and colleagues for their continuous support which kept the author well motivated.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Year by year, more researches are being carried out throughout the world to find or improve other renewable energy sources as an alternative of what we are using now. Analysts estimate that global decline of oil production will start in the year 2030 or later [1]. Consequently oil will run out soon after that. It is imperative that alternative energies are being researched and continuously improved for future use.

Solar panels are an array of photovoltaic cells. These cells make use of renewable energy from the sun, and are a clean and environmentally sound means of collecting solar energy. The hope for a solar revolution has been floating around for decades. The idea that one day we'll all use free electricity from the sun. This is a seductive 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. If we could collect all of that energy, we could easily power our homes and offices for free. Solar panels have big potential to become a reliable energy resource. Nevertheless, solar panels have had their share of problems. Particularly, overheating when exposed to too much sunlight. When the temperature becomes too hot, solar panels generate a lot less energy compared to when they are cool.

1.2 Problem Statement

1. Most of the time a solar panel works well below peak power, usually on hazy days and when the sun is lower in the sky, early morning, or late afternoon for example. Apart from this factors, output efficiency of a solar panel decreases when the solar panel is hot, due to long exposure of sunlight and heat radiation.
2. Very little is known about the effect of running water on the solar cells to decrease the temperature, therefore this study can lead to better understanding on how water film affects the solar panel in terms of output efficiency.

1.3 Objectives and scope of study

1. To build a test rig for pump and water circulation.
2. To study the performance of solar panel by applying water cooling.

The objective of this Final Year Project is to build a test rig and study the performance of solar panel by applying water cooling. It is known that solar panel efficiency decreases when subject to overheating due to long exposure to the sun [2]. Solar panel efficiency decreases under high temperature because of the heat build-up in the PV cells. Consequently this increases their internal electrical resistance and leads to power output decrease.

CHAPTER 2

LITERATURE REVIEW

Solar Panel

A solar panel is a device that converts the energy of sunlight directly into electricity. It is a large flat rectangle, typically somewhere between the size of a radiator and the size of a door, made up of many individual solar energy collectors called solar cells covered with a protective sheet of glass. The cells, each of which is about the size of an adult's palm, are usually octagonal and coloured bluish black. Just like the cells in a battery, the cells in a solar panel are designed to generate electricity, but where a battery's cells make electricity from chemicals, a solar panel's cells generate power by capturing sunlight instead. They are sometimes called photovoltaic cells because they use energy from sunlight [3].

Solar cells are often electrically connected and encapsulated as a module. Solar panels often have a sheet of glass on the front (sun facing) side, allowing light to pass while protecting the semiconductor wafers from wet (rain, sprinkler, etc.). Solar panels are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak DC voltage and current. The power output of a solar panel is measured in watts or kilowatts. In order to calculate the typical energy needs of the application, a measurement in watt-hours, kilowatt-hours or kilowatt-hours per day is often used.

Solar panels collect solar radiation from the sun and actively convert that energy to electricity. Solar panels are comprised of several individual solar cells. These solar panels function similarly to large semiconductors and utilize a large-area p-n junction diode. When the solar panels are exposed to sunlight, the p-n junction diodes convert the energy from sunlight into usable electrical energy. The energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their orbits.

Electric fields in the solar panels pull these free electrons in a directional current, from which metal contacts in the solar cell can generate electricity.

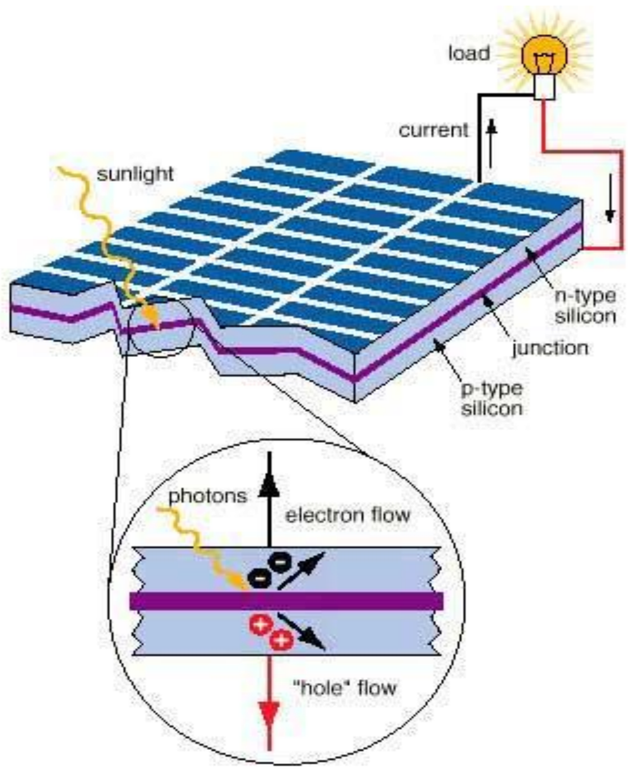


Figure 1: Solar Panel

The more solar cells in a solar panel and the higher the quality of the solar cells, the more total electrical output the solar panel can produce. The conversion of sunlight to usable electrical energy has been dubbed the Photovoltaic Effect.

Types of solar panels [3]

Monocrystalline

Monocrystalline panels use crystalline silicon produced in a large sheet which has been cut to the size of the panel, thus making one large single cell. Metal strips are laid over the entire cell and act as a conductor that captures electrons. Mono panels are slightly more efficient than Polycrystalline panels but do not necessarily cost more than Polycrystalline panels.

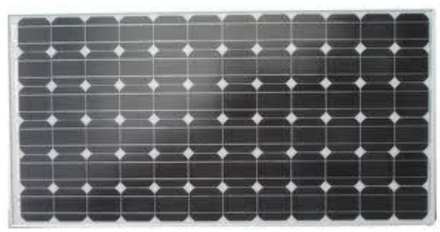


Figure 2: Monocrystalline

Polycrystalline

Polycrystalline panels use a bunch of small cells put together instead of one large cell. Poly panels are slightly less efficient than mono panels. They are also claimed to be cheaper to manufacture.

Figure 3: Polycrystalline

Thin film

Thin film panels are produced very differently from crystalline panels. Instead of molding, drawing or slicing crystalline silicon, the silicon material in these panels have no crystalline structure and can be applied as a film directly on various materials. They are the least efficient type of solar panel currently available. Thin-film technology also uses silicon with high levels of impurities. This can cause a drop in efficiency within a short period of time.

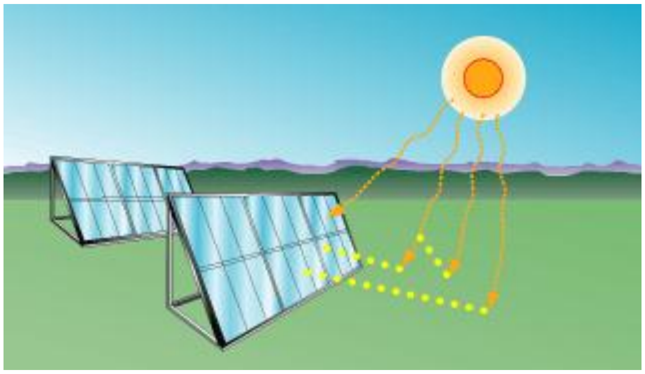
Figure 4: Thin film

DIRECT, DIFFUSE AND GLOBAL SOLAR RADIATION

Solar radiation is a general term for the electromagnetic radiation emitted by the sun. As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapor, aerosols, and clouds. The solar radiation that passes through directly to the earth's surface is called Direct Solar Radiation. The radiation that has been scattered out of the direct beam is called Diffuse Solar Radiation. The direct component of sunlight and the diffuse component of skylight falling together on a horizontal surface make up Global Solar Radiation.

Direct solar radiation

Direct solar radiation comes straight from the sun, without reflecting off clouds, dust, the ground, or other objects. The distinction between direct radiation and diffuse radiation is important because flat-plate solar collectors can use both forms of light, whereas concentrator systems can only use direct light.



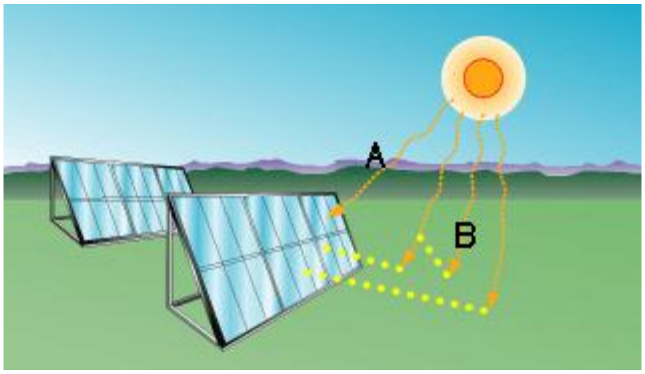
Flat-plate collectors, which typically contain a large number of solar cells mounted on a rigid, flat surface, can make use of both direct sunlight and the diffuse sunlight reflected from clouds, the ground, and nearby objects

Figure 5: Direct radiation

Diffused solar radiation

Diffused solar exposure is the total amount of solar energy falling on a horizontal surface from all parts of the sky apart from the direct sun. The daily diffuse solar exposure is the total diffuse solar energy for a day. The values are usually highest during cloudy conditions, and lowest during clear sky days. The diffuse exposure is always less than or equal to the global exposures for the same period.

Sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust, or other obstructions in the atmosphere or on the ground makes up the diffuse radiation. Unlike direct radiation, diffuse light cannot be focused by the optics of a concentrator photovoltaic system, though it can be used by a flat-plate collector.



Diffuse sunlight (B), reflected from clouds, the ground, and nearby objects, and direct sunlight (A) falling onto flat-plate solar panel

Figure 6: Diffuse radiation

Global solar radiation

Globar radiation is the total direct radiation and diffuse radiation striking a horizontal surface, averaged over a specified period of time.

Global radiation = Direct + Diffused radiation

It is the total amount of solar energy falling on a horizontal surface. The daily global solar exposure is the total solar energy for a day. The values are usually highest in clear sun conditions during the summer, and lowest during raining or very cloudy days.

Effects of water film on solar panel

Other main effects that increase the efficiency of a solar panel when subjected to water cooling is the reduction of light reflection. The light reflection on a commercial solar panel is related to the material used to shield the solar panel active material. In most panels this is glass with a refraction index of n = 1.53. Reflection of the sun's irradiance also typically reduces the electrical yield of PV modules by 8-15%. Anti reflective-coatings are not durable and structured surfaces are expensive, accumulate dust and are difficult to clean. However, water with a refractive index of 1.3, is a viable intermediary between glass (n_{glass}= 1.5) and air (n_{air}=1.0). In addition to help keeping the surface clean, water reduces reflection by 2-3.6%, decreases cell temperatures up to 22^{o}C and the electrical yield can return a surplus of 10.3%; a net gain of 8-9% can be achieved even when accounting for power needed to run the pump [4].

CHAPTER 3

METHODOLOGY

FYP II Flowchart

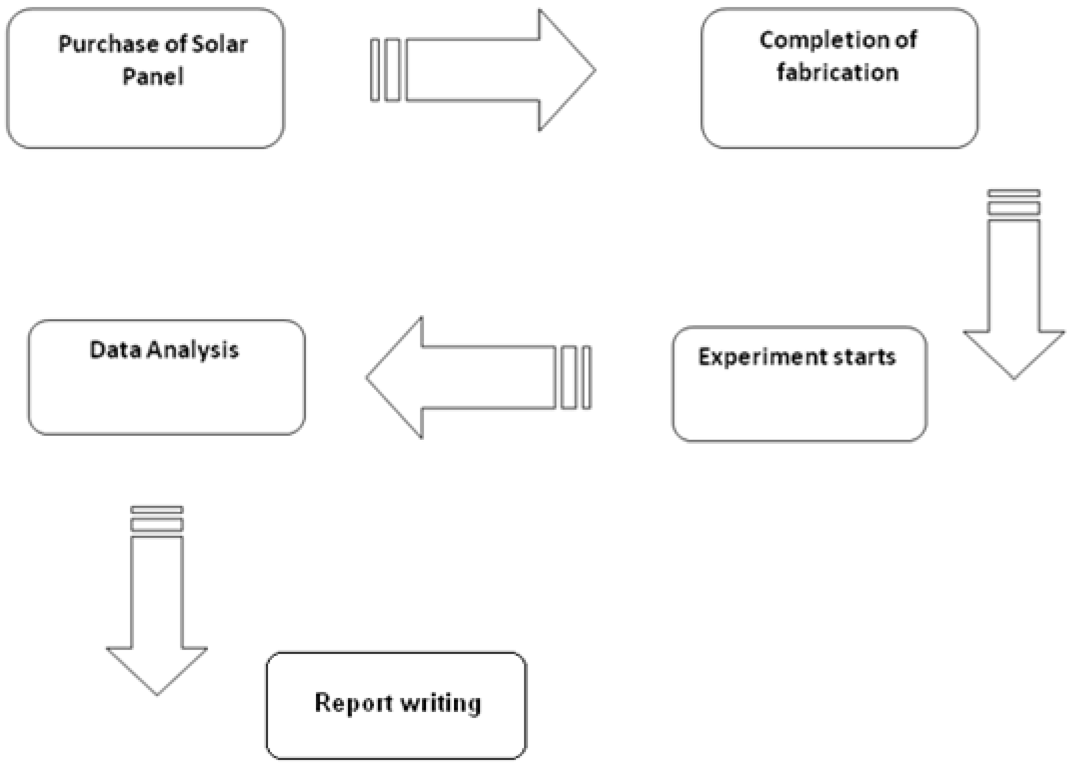


Figure 7: Workflow

Measurement of the PV module

A monocrystalline 50 watts panel was used in the study.

Figure 8: 50 watts monocrystalline

The model is a product from a brand name Photon Energy System Limited. The power output of the module is 50 Watts. Dimension of the module is 610 x 655 x 34mm. The electrical characteristic of the panel is shown in the table below:

Model	PM050
Nominal Power-P_{max} (Watts)	50
Voltage at Maximum Power, V_{mp}(Volts)	17.7
Current at Maximum Power, I_{mp} (Amps)	2.8
Open Circuit Voltage – V_{oc} (Volts)	21.6
Short Circuit Current – I_{sc} (Amps)	3.2
Temperature Coefficient – V_{oc}	-0.074 V/^{o}C

Table 1: Electrical characteristic for PM50 solar panel

Monocrystalline solar panel was used since monocrystalline gives the most obviouse and faster voltage drop per increase of temperature, i.e. power derating[5]. Monocrystalline type is the most efficient among all the available types of solar panels.

Measurement methods:

Diagram of the solar panel system

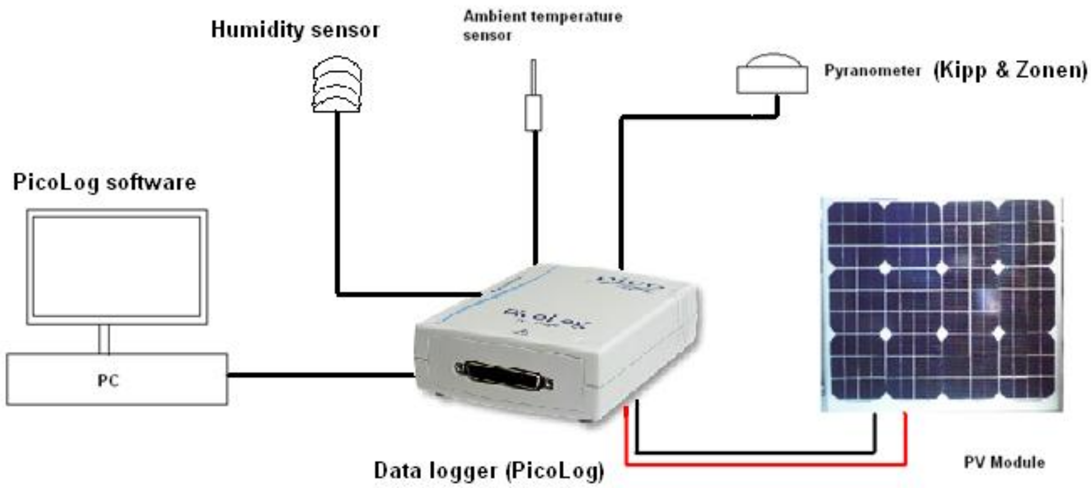


Figure 9:Solar panel diagram

In this experiment, the experiment is done near the end of UTP field, due to the feasibility of doing the experiment using a data logger, which is shared with a postgraduate student. Global solar irradiation on the plane of PV panel is measured every 5 minutes by the LM35 Kipp & Zonen pyranometer. The ambient temperature, which is measured in the shade, is recorded by the ambient temperature sensor every 5 minutes using the Ansolar data logger. Humidity sensor picks up humidity in the air for every 5 minutes (Figure 10). Figure 9 shows the typical measuring diagram for this experiment. The measured signals from temperature sensors, humidity sensors and pyranometer are recorded by the Ansolar Data logger and stores to the PC via the USB communication cable.

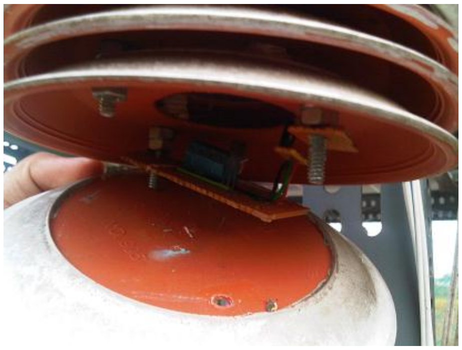


Figure 10:ambient temperature and humidity sensor

Figure 11: LM35 Kipp & Zonen pyranometer

Cooling system by flowing water on the PV panel

Cooling by utilizing a flowing film of water on the panel should theoretically allow operation at lower temperatures. Due to the quick flow of the water there should be only a minimal increase in water temperature

Figure 12: Colletor tank

Water is filled into the front tank. This tank also acts as a collector for the water that flows down from the PV panel. A submersible pump (refer figure 11) is placed in the tank to pump water into the top tank.

Figure 13: Top tank

Figure 14: Submersible pump

Pump is powered by an external power source from the site. Approximately, 15 litres (l) of water/min were pumped by submersible pump into the top tank. Twelve nozzles located along the front of the top tank generated a flow of water into the collecting dam.

Figure 15: Dam

When water is filled, the overflowing water in the dam will overflow and spread over the cell's surface at a thickness of about 2mm.

Figure 16: Collector tank

The water then flows back into the collector tank. The pump will continuously pump the water and circulation of the water from the collector tank to the top tank occurs.

Figure 17: Creation of water film from overflowing the dam

Figure 18:Solar panel rig design

Water is replenished daily in the tank because of evaporation. The measurement takes place from 8am to 5pm starting from 30th October.

Figure 19: Solar panel testing

Two solar panels were used. One with the water film and one without the water film. This is for the comparison of PV panel performance with and without water film. The incidence angle of both panels were made sure to match exactly, which was inclined 10cm.

Parameters for the measurement

Voltage at Open Circuit (VOC)

This is the voltage that is read with a voltmeter or multimeter when the module is not connected to any load.

This voltage is typically used when testing modules fresh out of the box, and used later when doing temperature corrected VOC calculations in system design. We can reference the chart below to find typical VOC values for different types of crystalline PV modules[6].

Nominal Voltage	VOC - typical	VMP - typical	# of cells in series
12	21	17	36
18	30	24	48
18	33	26	54
18	36	29	60
24	42	35	72

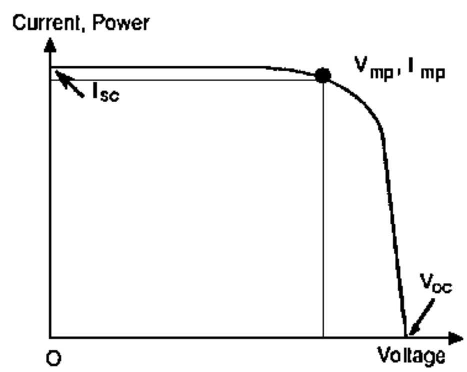


Figure 20: Isc VS Voc graph

V_{MP} = Voltage at max power

I_{MP} = Current at max power

V_{MP} ,I_{MP}, and I_{SC} was not able to be measured since necessary equipments (charge controller for I_{MP}) and load was not available. Without these parameters, the output efficiency of the solar panel was unable to be measured.

There are four important parameters in calculating the quality of the PV module. This includes the max voltage, $V_{MP,}$ maximum current , $I_{MP,}$ short circuit current, I_{SC}, and open circuit voltage, V_{OC}.

The maximum power, fill factor, energy conversion efficiency and module conversion efficiency measures how well a solar panel works and are governed by the equation below:

$P_{max} = V_{mp} \times I_{mp}$

Fill factor, $FF = (V_{mp} \times I_{mp}) / (V_{oc} \times I_{sc})$

Power output efficiency, $\pi = FF \times (V_{ave} \times I_{ave}) / (A \times G)$

Performance ratio = $(P_{mea\,/}\, P_{max}) / (G/1000)$

where A= area of solar; G = solar irradiance

Only V_{oc} was measured since the data logger used then was only able to measure V_{oc}. Measuring parameter I_{sc} would need a charge controller installed. Although the data logger can measure V_{mp} and I_{mp}, a divider block is needed. The data logger can only measure one solar panel at a time. A divider block allows the data logger to measure and log both solar panel (one with cooling water and one without the cooling) simultaneously for comparison purpose.

Solar cells are characterized by a maximum Open Circuit Voltage (Voc) at zero output current and a Short Circuit Current (Isc) at zero output voltage, since power can be computed via the equation: P = I * V. V_{oc} is an important parameter since it is needed for the calculation of fill factor, FF, which is then used for calculating the power output efficiency.

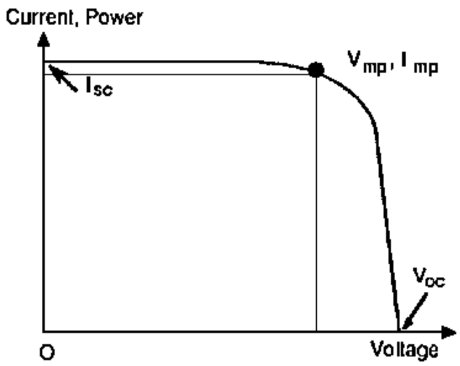


Figure 21: Isc VS Voc graph [7].

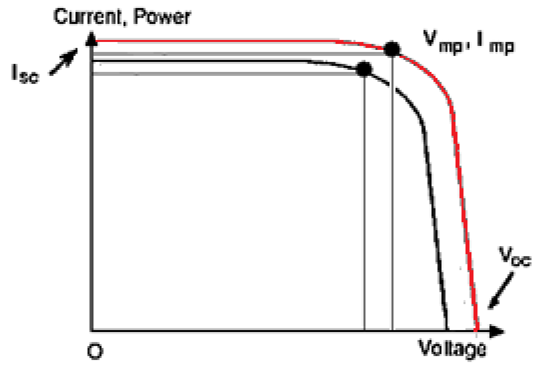


Figure 22: Increase of Vmp and Imp when Voc increases [7].

Based on the graph above, increase of V_{OC} or I_{SC} will cause increment of the V_{mp} and I_{mp}.This dictates that V_{oc} could represent performance increase, albeit not the actual power output[7].

CHAPTER 4

RESULTS & DISCUSSION

Experiment with flowing water film on solar panel

Time,(Hours)	T_{AIR}, (°C)	Humidity,(%)	V_{OC}, (V)	Irradiation, (W/m^2)
800	24.6	93.8	17.71	40.2
900	25.9	90.2	18.87	192.8
1000	27.4	83.2	19.17	257
1100	30.2	72.2	19.98	465.9
1200	31.1	64.1	20.26	682.792
1300	31.3	63.6	19.71	522.1
1400	32.5	60.9	19.29	385.6
1500	30.3	70.2	19.4	216.8
1600	31.8	61.6	19.65	273.1
1700	31.9	57.6	19.98	457.9

Table 2: 30 October data

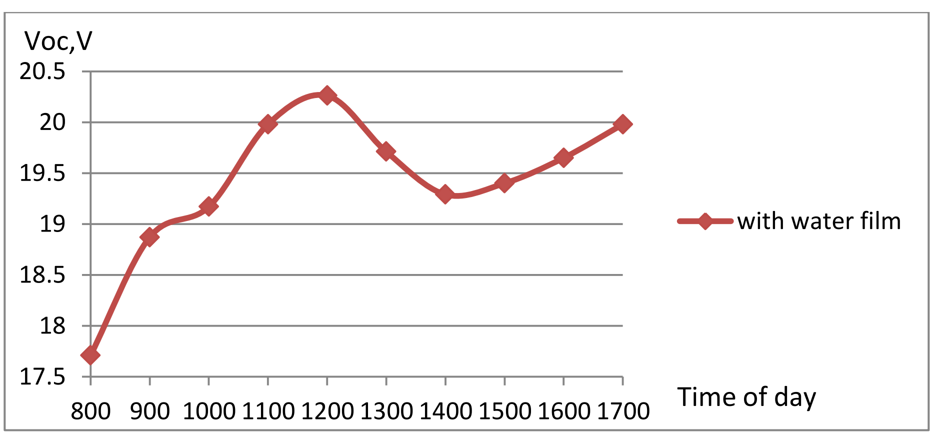


Figure 23: Solar panel with water film on 30 October 2010

Above is the graph for solar panel with water film on 30th December. Irradiation peaks at 12 noon with open circuit voltage of 20.26 V. The voltage starts to decline until 3pm where it starts to increase again after that. There was a sudden rain between 2-3pm.

This can be seen by the increase of relative humidity in the air which is 70.2%, which in turns increase water vapor in air and reduces ambient temperature. Although the rain was short and momentary, it should have reduced the solar panel's surface temperature. Operating temperature is reduced thus increasing open circuit voltage.

Time,(Hours)	$T_{AIR,}$ (^oC)	Humidity,(%)	$V_{OC,}$ (V)	Irradiation, (W/m^2)
800	24.6	93.8	17.19	40.2
900	25.9	90.2	18.12	192.8
1000	27.4	83.2	18.77	257
1100	30.2	72.2	19.25	465.9
1200	31.1	64.1	19.81	682.792
1300	31.3	63.6	19.08	522.1
1400	32.5	60.9	18.92	385.6
1500	30.3	70.2	18.82	216.8
1600	31.8	61.6	18.91	273.1
1700	31.9	57.6	19.71	457.9

Table 3: 30 October data

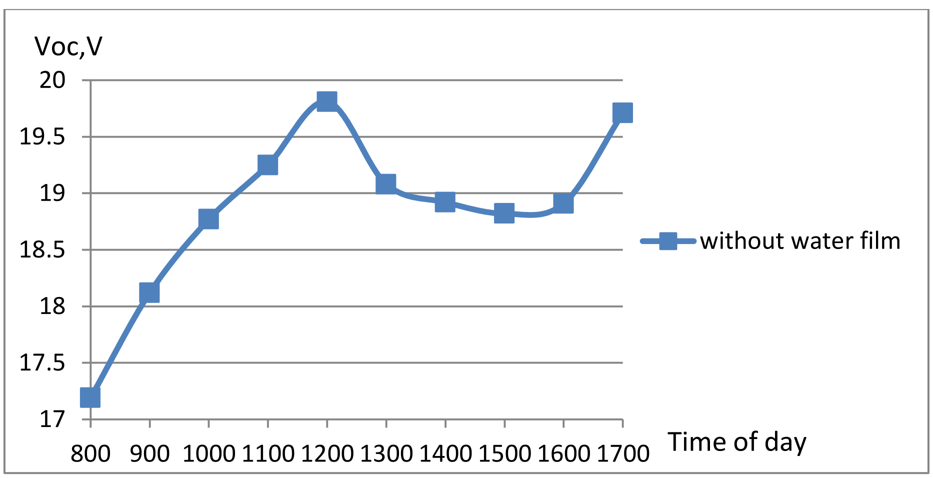


Figure 24: Solar panel without water film on 30 October 2010

Above is the graph for solar panel without the water film. Maximum open circuit voltage was 19.81V. The voltage starts to decline until 4pm where it starts to increase again. There was a sudden but short rain between 2-3pm. This can be seen by the increase of relative humidity in the air which is 70.2, which in turns increase water vapor in air and reduces ambient temperature and solar panel’s surface temperature. The reduced surface temperature because of the rain and high irradiation caused the increase in voltage at 4pm.

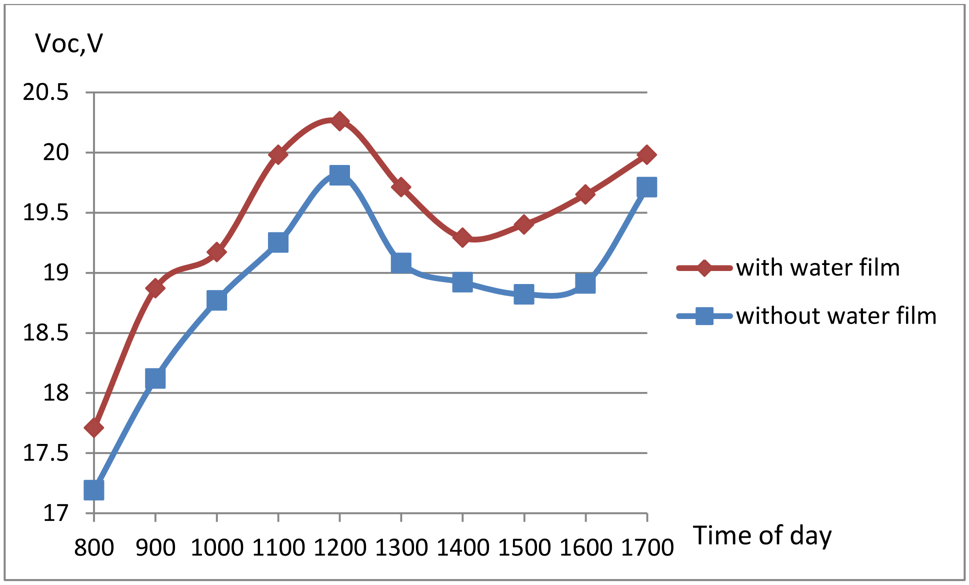


Figure 25: Comparison graph on 30 October 2010

The above graph shows the comparison between solar panels with and without the water film on 30th October under the same conditions. The highest difference is at 4pm with 0.74V (19.65-18.91V) with 3.9% increase. The smallest difference in terms of voltage output is at 5pm, which is 0.27V (19.98-19.71V) or 1.4% increase in voltage. The average output increase for that day is 2.8%

Time, Hours	T_{AIR}, °C	Humidity, %	Irradiation W/m^2	V_{OC}, V	V_{OC}, V	Voc difference(V)	%	Voc/Irradiation	Voc/Irradiation
800	24.6	93.8	40.2	17.71	17.19	0.52	3	0.44	0.43
900	25.9	90.2	192.8	18.87	18.12	0.75	4.1	0.10	0.09
1000	27.4	83.2	257	19.17	18.77	0.4	2.1	0.07	0.07
1100	30.2	72.2	465.9	19.98	19.25	0.73	3.8	0.04	0.04
1200	31.1	64.1	682.792	20.26	19.81	0.45	2.3	0.03	0.03
1300	31.3	63.6	522.1	19.71	19.08	0.63	3.3	0.04	0.04
1400	32.5	60.9	385.6	19.29	18.92	0.37	2	0.05	0.05
1500	30.3	70.2	216.8	19.4	18.82	0.58	3.1	0.09	0.09
1600	31.8	61.6	273.1	19.65	18.91	0.74	3.9	0.07	0.07
1700	31.9	57.6	457.9	19.98	19.71	0.27	1.4	0.04	0.04
							Average	0.098	0.095

Table 4: Comparison table for 30 October data

Time,(Hours)	T_{AIR}, (°C)	Humidity,(%)	V_{OC}, (V)	Irradiation, (W/m^2)
800	26.1	89.5	17.2	32.1
900	26.9	83.6	19	184.8
1000	29.7	66.1	19.7	377.5
1100	32.1	60.5	19.9	626.6
1200	35.1	48.4	20.2	779.2
1300	33.4	51.1	19.96	514.1
1400	33.1	52.5	19.95	610.5
1500	33.1	55.9	19.86	490
1600	32.2	57.5	19.31	289.2
1700	31.8	61.6	19.07	208.9

Table 5: 1 November data

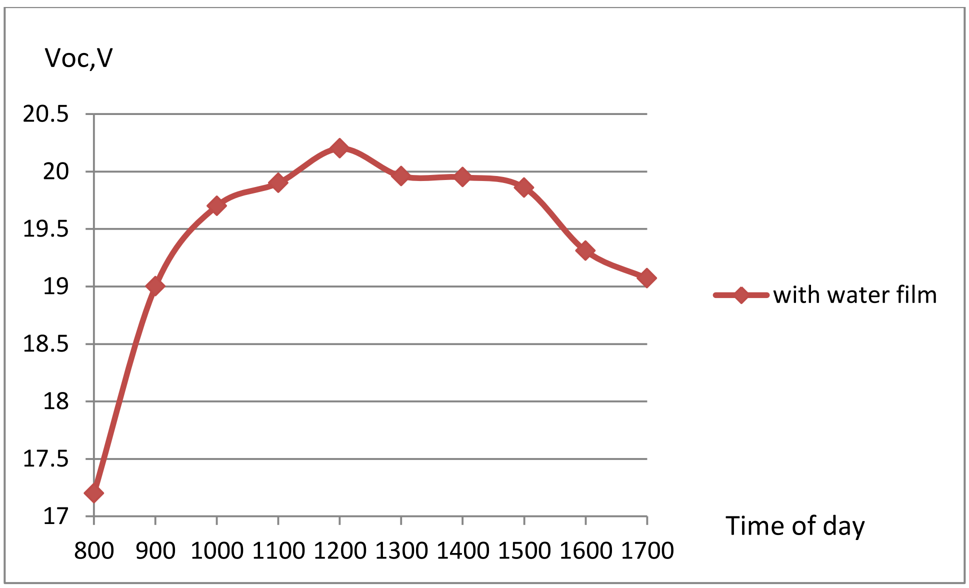


Figure 26: Solar panel with water film on 1 November

Above graph is for the solar panel with water film on 1st November 2010. Voltage is highest at 12 noon with 20.2V. Voltage decreases over time.

Time,(Hours)	$T_{AIR,}$ (^oC)	Humidity,(%)	$V_{OC,}$ (V)	Irradiation, (W/m^2)
800	26.1	89.5	16.7	32.1
900	26.9	83.6	18.54	184.8
1000	29.7	66.1	19.19	377.5
1100	32.1	60.5	19.32	626.6
1200	35.1	48.4	19.66	779.2
1300	33.4	51.1	19.41	514.1
1400	33.1	52.5	19.02	610.5
1500	33.1	55.9	18.91	490
1600	32.2	57.5	18.17	289.2
1700	31.8	61.6	18.07	208.9

Table 6: 1 November data

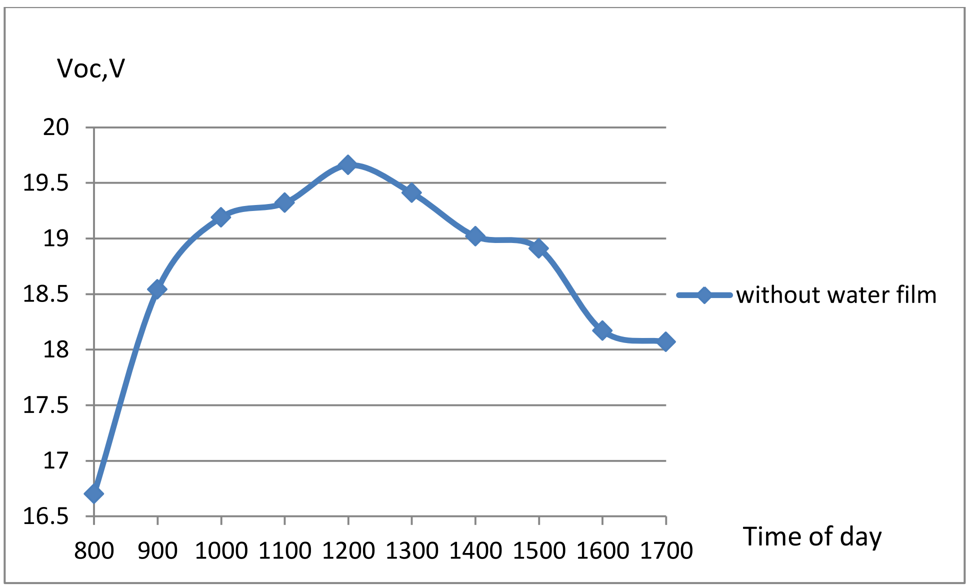


Figure 27: Solar panel without water film on 1 November

Above graph is for the solar panel without water film on 1st November 2010. Voltage is highest at 12 noon with 19.66. Voltage decreases over time due to increase of operating temperature.

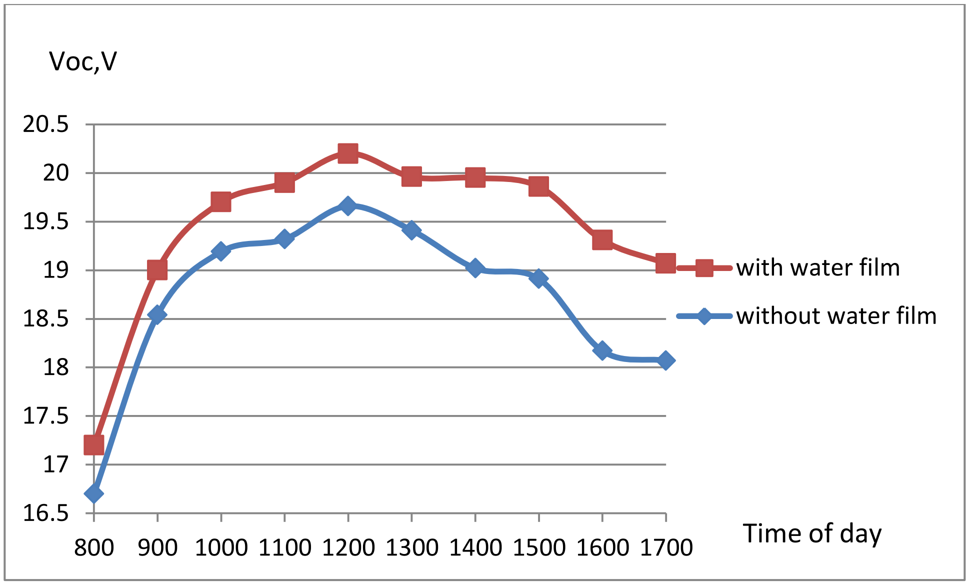


Figure 28: Comparison graph on 1 November

Above graph is for the comparison of open circuit voltage of the solar panels. The highest voltage performance difference is at 4pm, which is 1.14V. The lowest voltage performance difference is 0.46 which is at 9am. The highest performance increase in terms of open circuit voltage for 1st November is 5.9%. The average performance increase is 3.83%.

Time, (Hours)	T_{AIR}, (°C)	Humidity, (%)	Irradiation (W/m^2)	V_{OC}, (V)	V_{OC}, (V)	Voc difference(V)	%	Voc/Irradiation	Voc/Irradiation
800	26.1	89.5	32.1	17.2	16.7	0.5	2.9	0.54	0.52
900	26.9	83.6	184.8	19	18.54	0.46	2.4	0.10	0.10
1000	29.7	66.1	377.5	19.7	19.19	0.51	2.6	0.05	0.05
1100	32.1	60.5	626.6	19.9	19.32	0.58	2.9	0.03	0.03
1200	35.1	48.4	779.2	20.2	19.66	0.54	2.7	0.03	0.03
1300	33.4	51.1	514.1	19.96	19.41	0.55	2.8	0.04	0.04
1400	33.1	52.5	610.5	19.95	19.02	0.93	4.7	0.03	0.03
1500	33.1	55.9	490	19.86	18.91	0.95	4.8	0.04	0.04
1600	32.2	57.5	289.2	19.31	18.17	1.14	5.9	0.07	0.06
1700	31.8	61.6	208.9	19.07	18.07	1	5.2	0.09	0.09
							Average	0.102	0.098

Table 7: Comparison table for 1 November data

Time,(Hours)	$T_{AIR,}$ (°C)	Humidity,(%)	$V_{OC,}$ (V)	Irradiation, (W/m^2)
800	24.8	95.7	17.44	40.2
900	26.2	90.9	19.34	160.6
1000	27.4	82.6	19.2	240.9
1100	27.7	78.1	19.18	257.1
1200	24.6	90.2	19.4	160.7
1300	26.1	82.3	19.75	409.7
1400	26.3	92.1	19.59	232.9
1500	25.6	90.7	19.27	160.7
1600	25.8	91.7	19.02	112.5
1700	26.3	91.5	18.49	72.2

Table 8: 2 November data

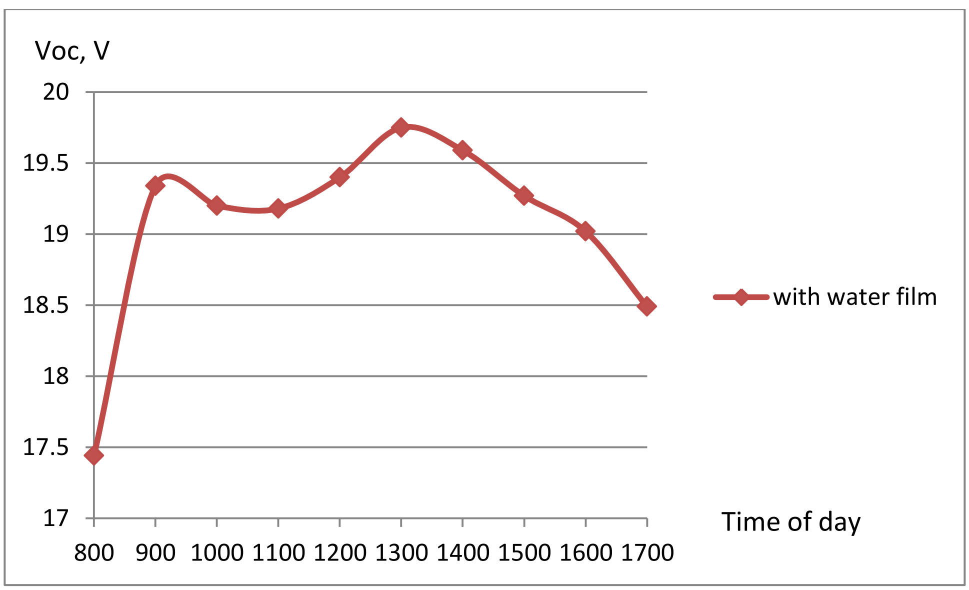


Figure 29: Solar panel with water film on 2 November

The peak open circuit voltage for the above graph is 19.75V at 1pm. Irradiation peaks at 409.7 W/m^2. It was drizzling throughout the day, but occasionally stops and sunny momentarily at 11 till 11.30am.

Time,(Hours)	$T_{AIR,}$ (^{o}C)	Humidity,(%)	$V_{OC,}$ (V)	Irradiation, (W/m^2)
800	24.8	95.7	17.2	40.2
900	26.2	90.9	19.21	160.6
1000	27.4	82.6	18.98	240.9
1100	27.7	78.1	18.91	257.1
1200	24.6	90.2	19.23	160.7
1300	26.1	82.3	19.55	409.7
1400	26.3	92.1	19.14	232.9
1500	25.6	90.7	18.89	160.7
1600	25.8	91.7	18.92	112.5
1700	26.3	91.5	18.21	72.2

Table 9: 2 November data

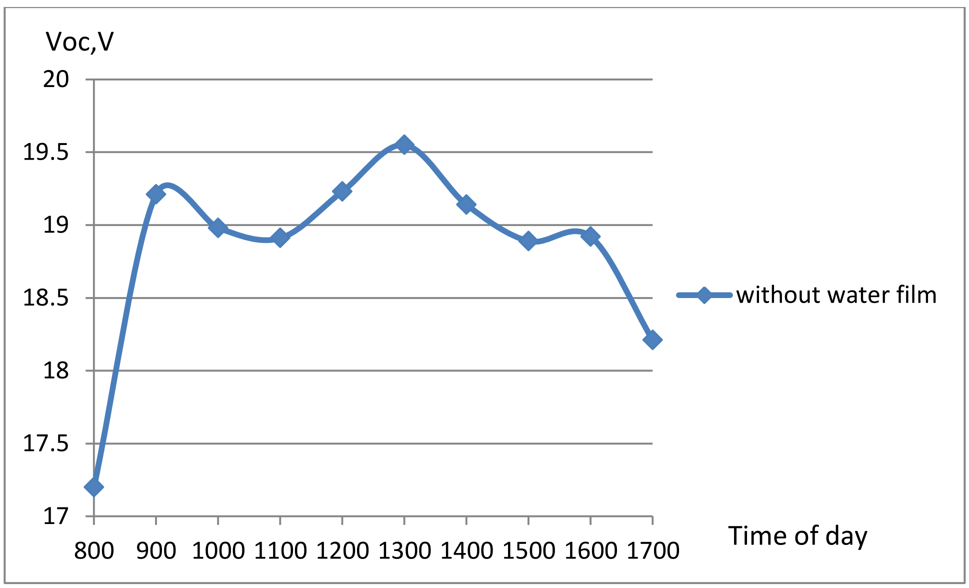


Figure 30: Solar panel without water film

The peak open circuit voltage for the above graph is 19.55V at 1pm. Irradiation peaks at 409.7 W/m^2. The open circuit voltage for the solar panel without the water film is not much different than the one with the water film.

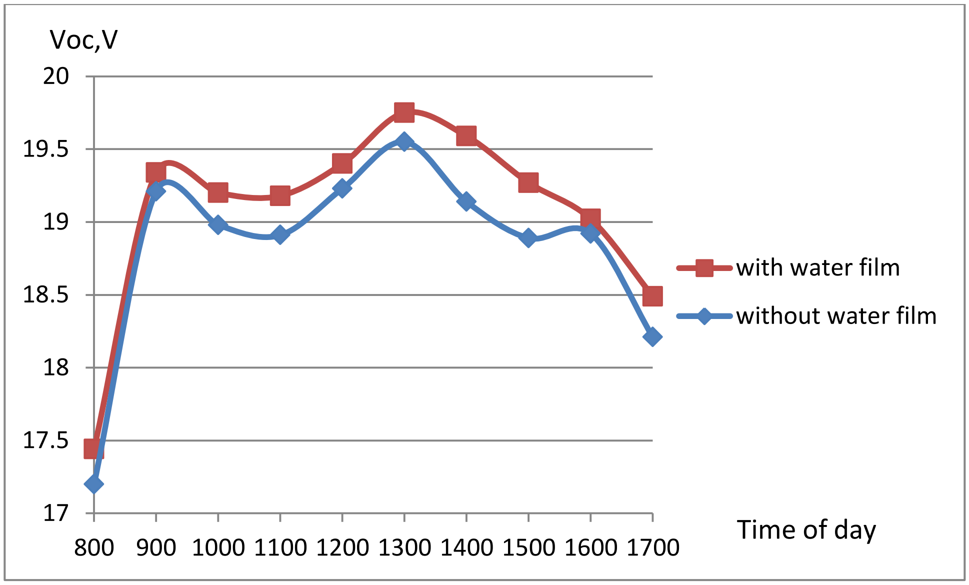


Figure 31: Comparison graph on 2 November

The above graph shows the comparison of PV panel with water film and without water film on a rainy day of 2nd November. The highest open circuit voltage difference is at 2pm with 0.45V@ 2.3% increase. The smallest open circuit voltage difference is at 4pm with 0.1V @ 0.5% increase. The average output performance is 2.17 %. On a rainy day, the performance difference of solar panel with water film and without the water film not very high. This is due to the rain that helps to keep the surface panel cool, much like of the water film.

Time, (Hours)	T_{AIR}, (°C)	Humidity, (%)	Irradiation (W/m^2)	V_{OC}, (V)	V_{OC}, (V)	Voc difference(V)	%	Voc/Irradiation	Voc/Irradiation
800	24.8	95.7	40.2	17.44	17.2	0.24	1.4	0.43	0.43
900	26.2	90.9	160.6	19.34	19.21	0.13	0.7	0.12	0.12
1000	27.4	82.6	240.9	19.2	18.98	0.22	1.1	0.08	0.08
1100	27.7	78.1	257.1	19.18	18.91	0.27	1.4	0.07	0.07
1200	24.6	90.2	160.7	19.4	19.23	0.17	0.9	0.12	0.12
1300	26.1	82.3	409.7	19.75	19.55	0.2	1	0.05	0.05
1400	26.3	92.1	232.9	19.59	19.14	0.45	2.3	0.08	0.08
1500	25.6	90.7	160.7	19.27	18.89	0.38	2	0.12	0.12
1600	25.8	91.7	112.5	19.02	18.92	0.1	0.5	0.17	0.17
1700	26.3	91.5	72.2	18.49	18.21	0.28	1.5	0.26	0.25
							Average	0.151	0.149

Table 10: Comparison table for 2 November data

Time,(Hours)	T_{AIR}, (^oC)	Humidity,(%)	V_{OC}, (V)	Irradiation, (W/m^2)
800	26.1	89.5	16.8	32.132
900	28.7	74.9	17.5	160.7
1000	29.3	67.6	18.1	481.9
1100	32.8	59/8	18.7	465.9
1200	33.8	55.4	19.4	666.7
1300	34.1	51.9	20.16	706.1
1400	34.2	51.8	20.4	866.9
1500	34.9	47.8	19.19	299.5
1600	35.5	45.8	17.83	570.3
1700	33.6	50.9	16.7	144.6

Table 11: 3 November data

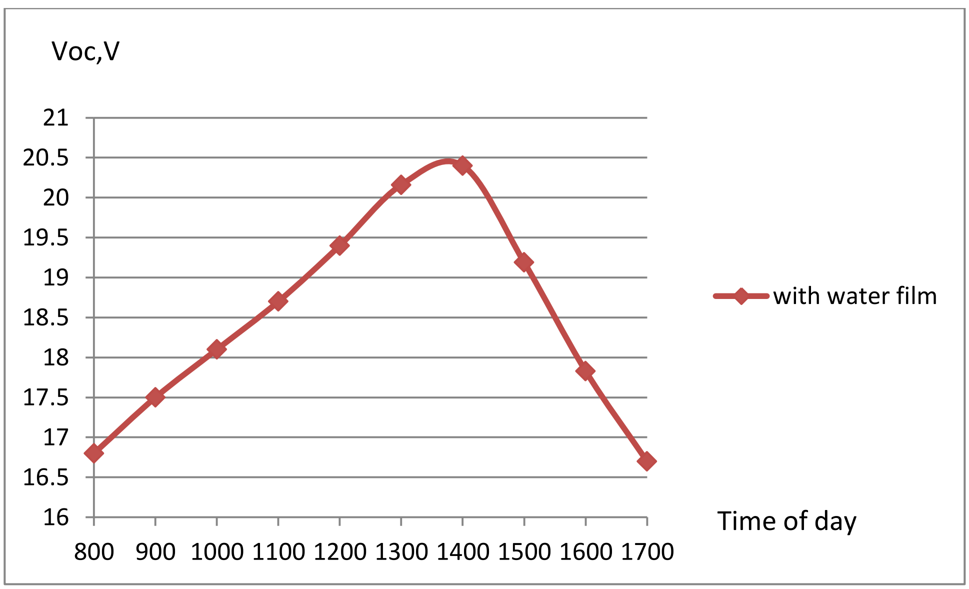


Figure 32: Solar panel without water film on 3 November

The peak open circuit voltage for the above graph is 20.4V at 2pm. Irradiation peaks at 866.9 W/m^2. The open circuit voltage starts to decrease with time after 2pm.

Time,(Hours)	T_{AIR}, (^oC)	Humidity,(%)	V_{OC}, (V)	Irradiation, (W/m^2)
800	26.1	89.5	16.9	32.132
900	28.7	74.9	17.5	160.7
1000	29.3	67.6	17.9	481.9
1100	32.8	59/8	18.2	465.9
1200	33.8	55.4	18.6	666.7
1300	34.1	51.9	18.9	706.1
1400	34.2	51.8	19.2	866.9
1500	34.9	47.8	18	299.5
1600	35.5	45.8	17.4	570.3
1700	33.6	50.9	16.6	144.6

Table 12: 3 November Data

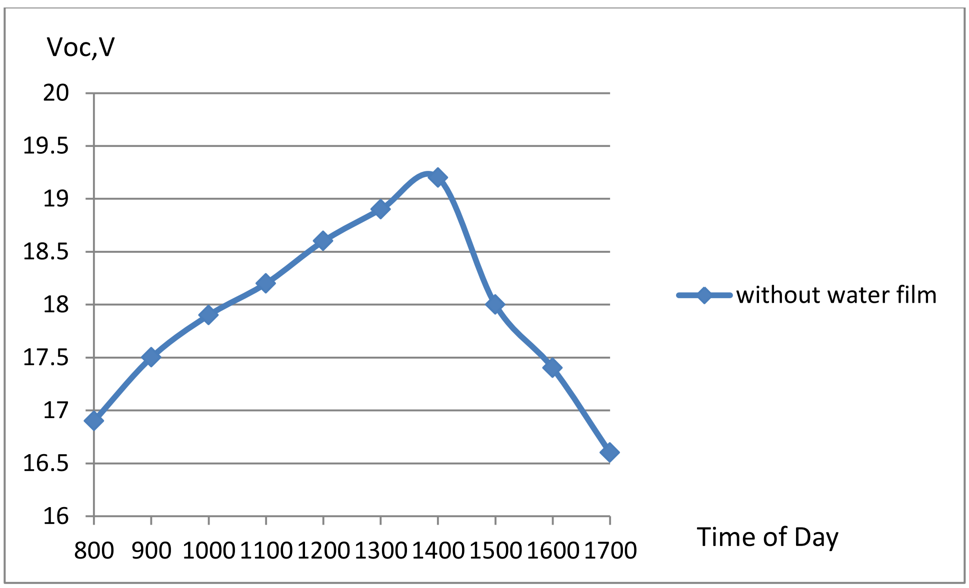


Figure 33: Solar panel without water film on 3 November

The peak open circuit voltage for the above graph is 19.2V at 2pm. Irradiation peaks at 866.9 W/m^2. The open circuit voltage starts to decrease with time after 2pm.

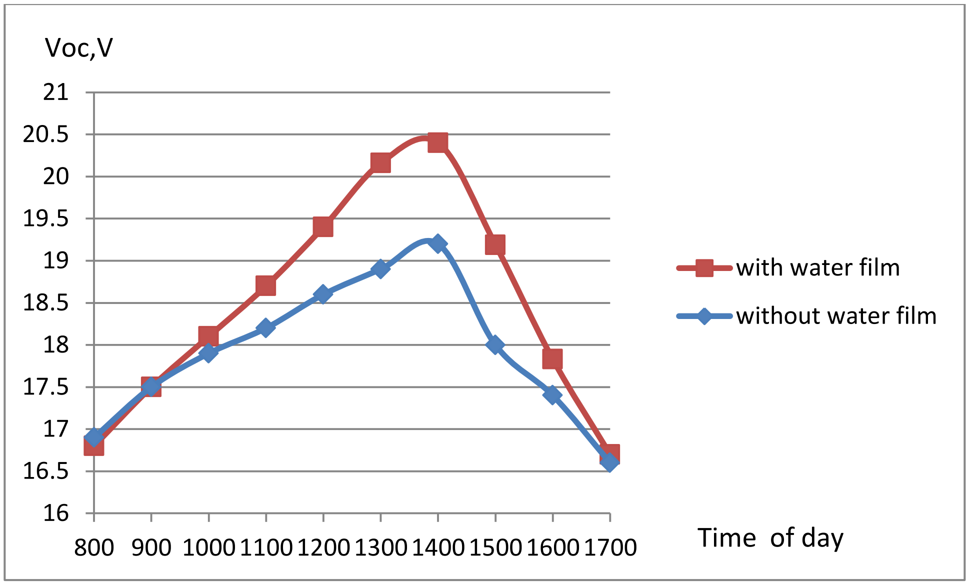


Figure 34: Comparison graph on 3 November

The comparison graph above shows that the highest performance difference in terms of open circuit voltage is 1.26V or 6.3% increase at 1pm. The average performance increase is 4.2%.

Humidity, (%)	Irradiation (W/m^2)	V_{OC}, (V)	V_{OC}, (V)	Voc difference(V)	%	Voc/Irradiation	Voc/Irradiation
89.5	32.1	16.8	16.9	-0.1	-0.6	0.52	0.53
74.9	160.7	17.5	17.5	0	0	0.11	0.11
67.6	481.9	18.1	17.9	0.2	1.1	0.04	0.04
59.8	465.9	18.7	18.2	0.5	2.7	0.04	0.04
55.4	666.7	19.4	18.6	0.8	4.1	0.03	0.03
51.9	706.1	20.16	18.9	1.26	6.3	0.03	0.03
51.8	866.9	20.4	19.2	1.2	5.9	0.02	0.02
47.8	299.5	19.19	18	1.19	6.2	0.06	0.06
45.8	570.3	17.83	17.4	0.43	2.4	0.03	0.03
50.9	144.6	16.7	16.6	0.1	0.6	0.12	0.11
					Average	0.100	0.099

Table 13: Comparison table for 3 November

Time,(Hours)	$T_{AIR,}$ (^oC)	Humidity,(%)	$V_{OC,}$ (V)	Irradiation, (W/m^2)
800	24.6	93.8	16.78	40.2
900	25.9	90.2	17.98	192.8
1000	27.4	83.2	18.88	257
1100	30.2	72.2	19.54	465.9
1200	31.1	64.1	20.03	782.8
1300	31.3	63.6	20.45	988.2
1400	32.5	60.9	19.78	810.3
1500	30.3	70.2	18.82	750.1
1600	31.8	61.6	18.01	465.2
1700	31.9	57.6	17.1	457.9

Table 14: 4 November data

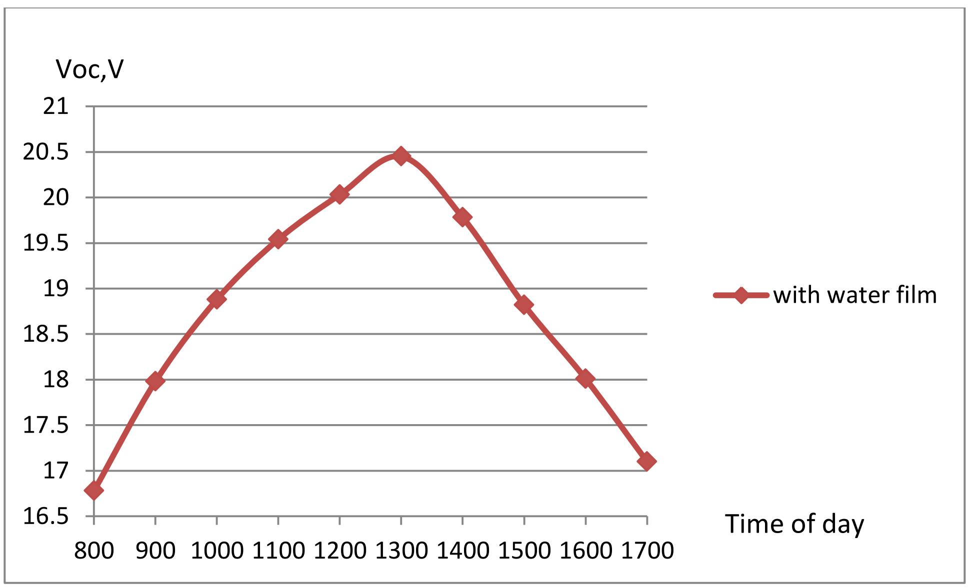


Figure 35:Solar panel with water film on 4 November

The peak open circuit voltage for the above graph is 20.45V at pm. Irradiation peaks at 988.2 W/m^2. Overall it was a sunny day with high average irradiation readings.

Time,(Hours)	T_{AIR}, (°C)	Humidity,(%)	V_{OC}, (V)	Irradiation, (W/m^2)
800	24.6	93.8	16.78	40.2
900	25.9	90.2	17.75	192.8
1000	27.4	83.2	18.42	257
1100	30.2	72.2	18.89	465.9
1200	31.1	64.1	19.25	782.8
1300	31.3	63.6	19.49	988.2
1400	32.5	60.9	18.71	810.3
1500	30.3	70.2	18.13	750.1
1600	31.8	61.6	17.53	465.2
1700	31.9	57.6	16.84	457.9

Table 15: 4 November Data

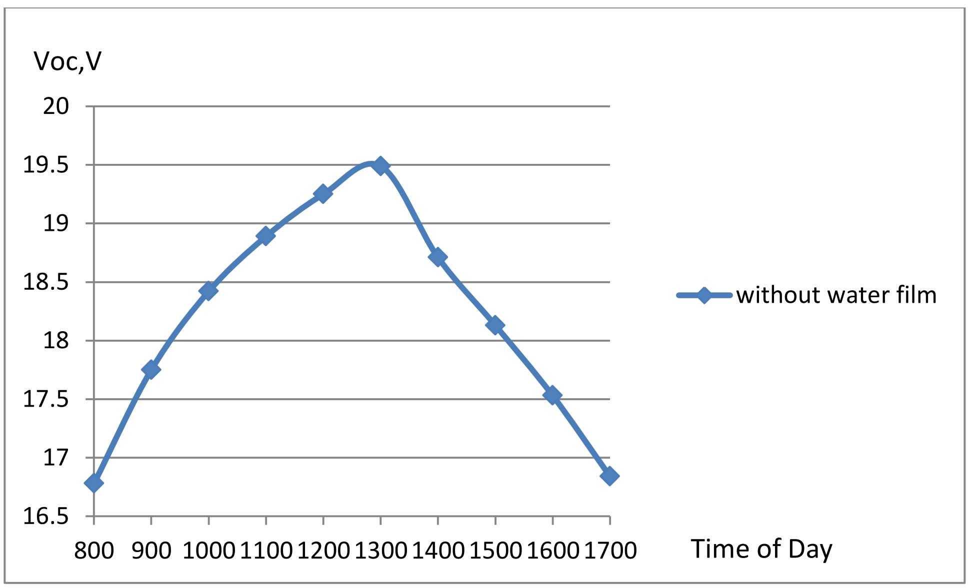


Figure 36: Solar panel with water film on 4 November

The peak open circuit voltage for the above graph is 19.49V at 1pm. Irradiation peaks at 988.2 W/m^2. High average solar irradiation gives high open circuit voltage.

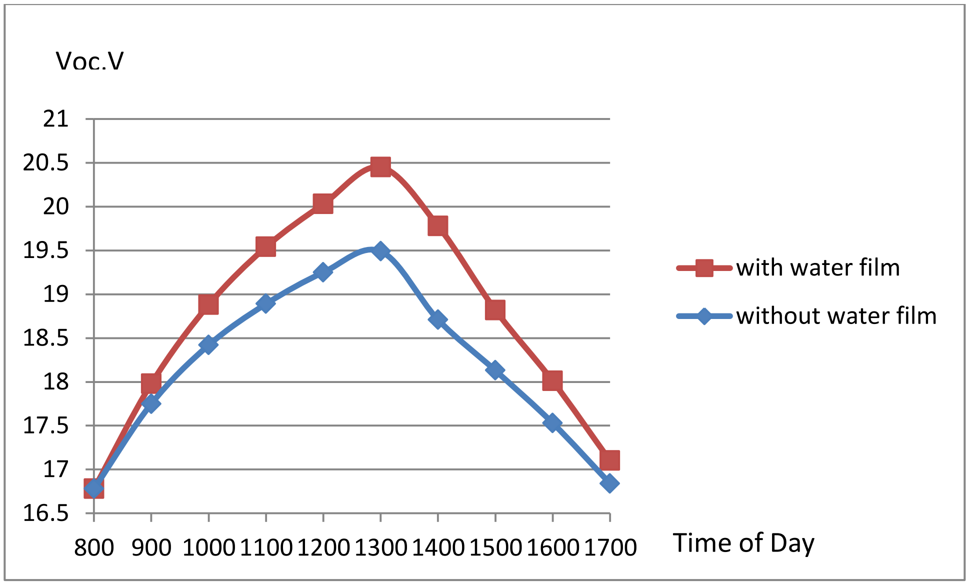


Figure 37: Comparison graph on 4 November

The comparison graph above shows that the highest performance difference in terms of open circuit voltage is 1.07V or 5.4% increase which is at 2pm. The average performance increase is 3.0%.

$T_{AIR,}$ (°C)	Humidity, (%)	Irradiation (W/m^2)	$V_{OC,}$ (V)	$V_{OC,}$ (V)	Voc difference(V)	%	Voc/Irradiation	Voc/Irradiation
24.6	93.8	40.2	16.78	16.78	0	0	0.42	0.42
25.9	90.2	192.8	17.98	17.75	0.23	1.3	0.09	0.09
27.4	83.2	257	18.88	18.42	0.46	2.4	0.07	0.07
30.2	72.2	465.9	19.54	18.89	0.65	3.3	0.04	0.04
31.1	64.1	682.792	20.03	19.25	0.78	3.9	0.03	0.03
31.3	63.6	522.1	20.45	19.49	0.96	4.7	0.04	0.04
32.5	60.9	385.6	19.78	18.71	1.07	5.4	0.05	0.05
30.3	70.2	216.8	18.82	18.13	0.69	3.7	0.09	0.08
31.8	61.6	273.1	18.01	17.53	0.48	2.7	0.07	0.06
31.9	57.6	457.9	17.1	16.84	0.26	1.5	0.04	0.04
						Average	0.094	0.092

Table 16: Comparison table for 4 November data

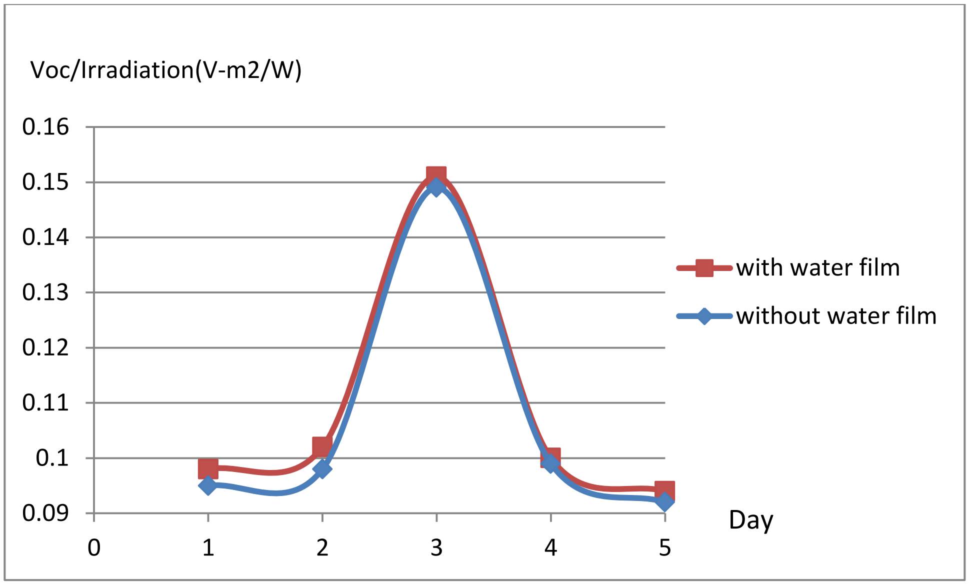


Figure 38: Comparison graph of average V_{OC}/Irradiation for solar panel with and without water film per day.

Based from the results obtained, average V_{OC}/Irradiation per day graph for both solar panels was plotted. From the graph above, the highest difference of average V_{OC}/Irradiation between the solar panels was on Day 2, with difference of 0.004 $Vm^{2/}W$ (0.102-0.098 Vm^2/W) (Refer Table 7) . If referred to the data tables, the average open circuit voltage per irradiation for Day 2 (1^{st} of November) was the highest compared to the other days (Table 10 and Figure 31). The lowest difference of average V_{OC}/Irradiation was on Day 5 (4^{th} of November). From the data for that day, it can be seen that 4^{th} of November data measures the lowest average open circuit voltage per irradiation for both panels, with difference of 0.002 $Vm^{2/}W$ (0.094-0.092 Vm^2/W) (refer Table 16 and Figure 37).

CHAPTER 5

CONCLUSION

The weather condition in Malaysia is suitable to use solar panel. From the previous data gathered, the weather condition here is almost predictable and sunlight availability is more than 10 hours.

This project is critical and practical in analyzing the performance decrease of PV panels that contribute to its efficiency and output rating. Water is a viable and good natural coolant for solar panels. With high specific heat capacity of 4.182 J/gram ^{o} C, it can absorb surface heat of the panel and reduces surface temperature significantly. Output performance increases when operating temperature decreases. From this study, conclusion can be drawn that the highest performance increase in the experiment is 6.3% with highest average open circuit voltage per irradiation difference is 0.004 Vm^2/W. Higher performance increase should be attainable if given the right weather conditions.

There are three recommendations for future work expansion related to increasing solar panel efficiency which can be carry out to further understand the effects of having water film to cool down solar panels. The recommendations are as following:

1. Experiment with bigger power rating solar panels. With this bigger and more obvious difference of performance increase can be obtain.
2. Equip a charge controller to the data logger. This is so current can be measured from the solar panel. With measured current, power output in terms of wattage can be obtained.
3. A divider block is recommended to be installed on the data logger. This will enable both solar panels to be measured by the data logger at the same time.

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APPENDIX I: Pump Sizing

Pump sizing was done to obtain Head pressure necessary to circulate the water in the tank. The author was given an aquarium pump from the lab:

i)SDF-3333

H_{max}=5.2 ft

Flowrate=2000 L/h

Output = 30 Watts

Figure 39: Aquarium pump

Pump will be placed on the rig floor platform as below:

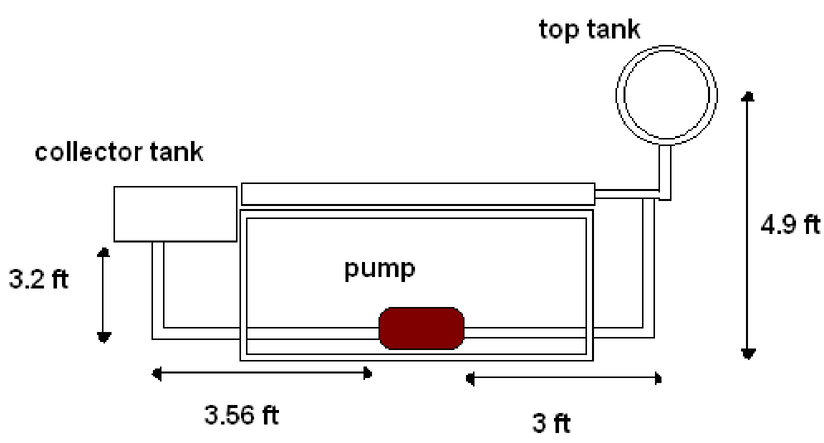

Figure 40: Solar stand pump sizing

To calculate the system head, the author must calculate the total head on both the suction and discharge sides of the pump. In addition to the static head there is a head caused by resistance in the piping, fittings and valves called friction head, and a head caused by any pressure that might be acting on the liquid in the tanks including atmospheric pressure, called surface pressure head.

System head = total discharge head – total suction head

$$H = H_D - H_S$$

Total discharge head, $H_D = H_{SD} + H_{PD} + H_{FD}$

where H_{SD} = discharge static head

H_{PD} =discharge surface pressure head

H_{FD} = discharge friction head

Total suction head, $H_S = H_{SS} + H_{PS} – H_{FS}$

H_{SS}= suction static head

H_{PS}= suction surface pressure head

H_{FS}= suction friction head

Head loss is a common term used to describe two types of pressure loss in a liquid system. The first type is static head loss due to the elevation of part of a piping above its source. The second type is dynamic head loss. It is a loss of flowing pressure in a pipeline or pipe due to friction from the pipe walls or as the liquid flows through elbows, valves and fittings.

Suction head calculation:

H_{SS} = 3.2 feet

The suction tank is open, so the suction surface pressure equals atmospheric pressure :

H_{PS} = 0 feet gauge

The pressure head loss *(*feet H_2O per 100 feet pipe*)* in straight plastic pipes made of materials as PVC, PP, PE, PEH or similar, can be estimated from the table below:

Pressure Friction Head Loss *(ft H_2O/100 ft pipe)*												
Volume Flow		Nominal Pipe Diameter (inches)										
Gallons Per Minute *(GPM)*[1)]	Gallons Per Hour *(GPH)*[2)]	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	6
		Nominal Inside Diameter *(inches)*										
		0.493	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	4.026	6.065
1	60	3.3	1.1	0.3								
2	120	11.8	3.8	1.0	0.3	0.1						
4	240	42.5	13.7	3.5	1.1	0.3	0.1					
5	300	64.2	20.7	5.3	1.6	0.4	0.2					
6	360		29.0	7.4	2.3	0.6	0.3					
8	480		49.5	12.6	3.9	1.0	0.5	0.1				
10	600		74.7	19.0	5.9	1.6	0.7	0.2	0.1			
20	1200			68.6	21.2	5.6	2.6	0.8	0.3	0.1		
30	1800					11.8	5.6	1.7	0.7	0.2		
40	2400					20.1	9.5	2.8	1.2	0.4	0.1	
50	3000						14.4	4.3	1.8	0.6	0.2	
60	3600						20.1	6.0	2.5	0.9	0.2	
70	4200							7.9	3.3	1.2	0.3	
80	4800							10.2	4.3	1.5	0.4	
90	5400							12.6	5.3	1.9	0.5	
100	6000								6.5	2.3	0.6	0.1
125	7500								9.8	3.4	0.9	0.1
150	9000									4.8	1.3	0.2

Table 16: Pressure Friction Head Loss

To calculate the suction friction head, based on the table above,

Rated pump flowrate = 2000L/h

$$= (2000L/h)(\frac{0.264 gallon}{litre})$$
$$= 528 GPH$$

Taking 600 GPH for ¾ in pipe, head friction loss per 100 feet is = 19.0 ft

$$H_{FS} = (19.0\,ft)(\frac{3.56\,ft}{100\,ft})$$

$$H_{FS} = 0.68\,ft$$

Total suction head,

$H_S = H_{SS} + H_{PS} - H_{FS}$

$H_S = 3.2$ ft + 0 – 0.68 ft

= 2.52 ft

Discharge head calculation:

Static discharge head,

$H_{SD} = 4.9$ ft

The discharge tank (top tank) is considered atmospheric pressured, so

$H_{PD} = 0$

Discharge friction head,

$$H_{DF} = (19.0\,ft)(\frac{3\,ft}{100\,ft})$$

$$H_{DF} = 0.57\,ft$$

Total discharge head,

$H_D = H_{SD} + H_{PD} + H_{FD}$

= 4.9 ft + 0 + 0.57 ft

= 5.47 ft

Total system head needed to overcome by pump,

$H = H_D - H_S$

$= 5.47 \text{ ft} - 2.52 \text{ ft}$

$= \mathbf{2.95 \text{ ft}}$

The chosen pump rated maximum head (ft) is 5.2 ft, which is more than enough to overcome the system head of 2.95 ft.

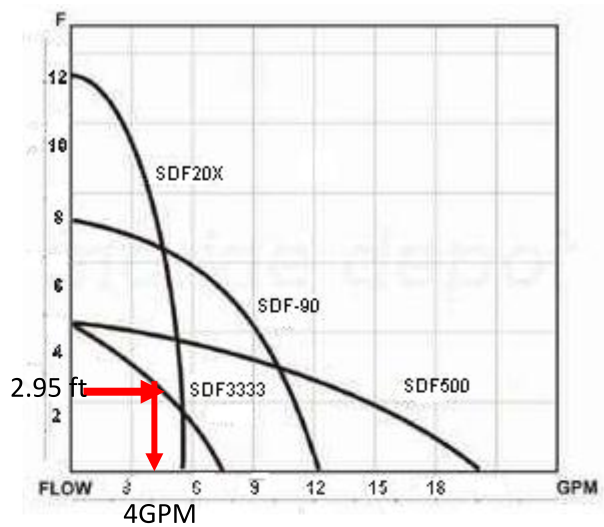

Figure 41: Pump performance chart for SDF-3333 model

From the above performance graph, at head of 2.95 ft the flow for the solar rig system is 4GPM, or 0.536 ft^3/minute.

Appendix II:Gantt Chart for Final Year Project II

Suggested Milestone for Final Year Project II

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project work continues	■	■	■					Mid-semester break							
2	Submission of Progress Report 1				●											
3	Project work continues				■	■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)									●						
6	Project work continues									■	■	■	■	■	■	■
7	Poster Exhibition												●			
8	Submission of Dissertation Final Draft															●
9	Oral Presentation									During study week						
10	Submission of Dissertation (hard bound)									7 days after oral presentation						

● Suggested milestone

■ Process