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Experimental Study of

Water Lens Photovoltaic Concentrating System

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Thesis submitted in partial fulfillment of requirements of the degree

Master of Science in Renewable Energy & Sustainability

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"Experimental Study of a Water Lens Photovoltaic Concentrating System"

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Experimental Study of a Water Lens Photovoltaic Concentrating System

By: (Dania Majed Qudsi)

Experimental Study of a Water Lens Photovoltaic Concentrating System

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ABSTRACT

New technology of photovoltaic concentrators was employed, water lens that was built from cheap, easily and available materials, water and hyper elastic linear low density polyethylene plastic foil. It was an effective way of improving efficiency by a comparison of experiment with water lens and without lens as a concentrator investigated the thin film solar cell performance. It was found an increasing in output power also the efficiency because it is concentrate the light and increase in the intense light which focused in small area that lead to substitute the large area of solar cell used in traditional way in to smaller effective solar cell. series of experiment was done, it was found distilled water lens (DWL) at thickness 5cm was best lens that effect on the performance of PV cell and gives higher efficiency about 17.08%.

وصف نظام تركيز عدسة مياه الخلايا الشمسية

دانية ماجد القدسي

ملخص

خلال السنوات الأخيرة احتلت المركزات الشمسية مكاناً مهماً عند الباحثين العلميين، وذلك بسبب كمية الطاقة الشمسية الهائلة التي تستقبلها الأرض يومياً، وأيضاً بسبب التكلفة العالية في سعر الخلايا الشمسية والمركزات الشمسية في بعض الحالات والقضايا البيئية. تم تصميم عدسة مائية من مواد متاحة بسهولة، وتم استخدام الماء والبولي ايثيلين منخفض الكثافة كمُركِّز للطاقة الشمسية لأنه وسيلةٌ فعالةٌ لتحسين الكفاءة وتقليل معدل التدهور الحراري للخلايا الشمسية، والتي تسبب تحويل الطيف القريب من الأشعة تحت الحمراء، حيث أنها يمكن أن تمنع ارتفاع درجة الحرارة ويمكن أن تعمل كأداة لبعض تطبيقات الطاقة الشمسية، والتي تم إثباتها من خلال دراساتٍ سابقة. تعرض هذه الأطروحة بحثاً عن أداء الخلية الشمسية (خلية فلم رقيق) مع وبدون عدسة مياه. علاوةً على ذلك، تعرض بحثاً واسعاً عن المكثفات الشمسية ونظام التبريد.

DECLARATION

I declare that the Master Thesis entitled "**Experimental Study of a Water Lens Photovoltaic Concentrating System**" is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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DEDICATION

I dedicate this thesis to my family for nurturing me with affection and love,

and supporting me all through my academic path with patience and guidance.

ACKNOWLEDGEMENT

Firstly, I would like to extend my sincere gratitude to God for all blessings to grant me the ability to finish this project.

For my parents, my husband, my children, my brother, my sisters, my aunts, and my friends.

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Finally, I would like to express my sincere appreciation to all those who stood by me all through the way.

Thanks for your great support and continuous care.

List of Abbreviations

ACPPVC	Asymmetric Compound Parabolic Photovoltaic Concentrator
CPC	Compound Parabolic Concentrator
CPV	Concentrator Photovoltaic
CPVT	Concentrating Photovoltaic/ Thermal
DTIRC	Dielectric Totally Internally Reflecting Concentrator
EHC	Elliptical Hyperboloid Concentrator
FEM	Finite Element Method
FF	Fill Factor
HCPV	High Concentration
I_D	Current Passing Through Nonlinear Diode
I_{ph}	Photocurrent from Photovoltaic
IR	Infrared
I_{sc}	Short Circuit Current
I_{sh}	Current Through Shunt Resistance
LCPV	Low Concentration
LLDPE	Linear Low-Density Polyethylene
MCCF	Maximum Comparative Concentrating Factor
MCM	Maximum Concentration Method
MCPV	Medium Concentration
MPP	Maximum Power Point
MSDTIRC	Mirror Symmetrical Dielectric Totally Internally Reflecting Concentrator
PMMA	Polymethylmetacrylate
PPT	Power Point Tracking
PV	Photovoltaic

QDS	Quantum Dots
QDSC	Quantum Dot Solar Concentrator
RMS	Root Mean Square
SECS	Solar Energy Conversion System
SEH	Square Elliptical Hyperboloid
SPV	Silicon Photovoltaic System
STC	Standard Test Condition
UV	Ultraviolet
V_{OC}	Open Circuit Voltage

List of Figures

List of Tables

Table of Content

CHAPTER 1: Introduction

Energy is one of the most important aspects in civilization development that requires special attention. The transferred solar energy and its conversion to electricity by using a special "photovoltaic" device, could lead to certain problems in case of low and high density of light. In the case of the latter, it can make a thermal degradation to PV cell, destroy the module and cost a lot of money to reproduce it.

To stay on the safe side, we can use a water lens which consists of pure water and hyper liner low density polyethylene which is economic and can concentrate the solar radiation in case of low density of light. It can also filter out Infrared (IR) radiation, which is the main cause of the thermal degradation, whereas ultraviolet (UV) radiation from the sun light purifies the water by destroying bacteria. Most of the solar (UV) radiation is filtered out by the water, so we can adjust its properties to be like a water reservoir to utilize for cooling purpose of solar energy conversion system (SECS) as well as for silicon photovoltaic system (SPV). This can make the system more effective by rendering less heat, as infrared radiation (IR) from the sunlight is absorbed by water.

1.1 Problem Statement

Renewable energy is taking place in front of the dwindling traditional energy resources. The most important one is solar energy which can be converted to electricity directly by photoelectric effect by using a photovoltaic device. Due to our country's geographical location in the globe, solar radiation is available most of the day time during the year. From this point, the researcher of this thesis looks for the shortage in this technique and how the electric efficiency can be increased.

In this thesis, the researcher aims to investigate the effect of water lens on photovoltaic cell (thin film) performance, by focusing the experiment on these factors and how they affect the PV cell.

1.2 Approach

The approach briefly talks about the experiments that show the effect of water lens on a photovoltaic PV cell. A set of experiments, with and without using the water lens, will be done along with a comparison between their results. Finally, the researcher will conclude the effect of water lens on the PV cell.

1.3 Objectives

Studying the effect of water lens on thin film photovoltaic cell related to the experiment, will prove that the water lens acts as an effective way to save solar cell from being damaged. This is done by preventing overheat, because water absorbs (IR) radiation and filters out the near infrared spectrum, which causes high temperature to the cell and damage it on the long run. The UV solar radiation is also filtered out by water this is approved by previous study and we use this fact in this thesis to achieve our objectives. There are many objectives related to these experiments, of which we mention:

1. Study the performance of PV cell.
2. Study the effect of water lens on PV cell.

1.4 Motivation

Many experts and energy specialists see that solar energy should take a more vital place especially in the Arab world because of the fact that the sun appears almost throughout the day of the year comparing to the cold area of the world. Moreover, it should seriously consider renewable energy sources to cover the demand of electricity. The suitable option is solar energy which can be converted to electric energy by using photovoltaic device under photoelectric effect.

Many researchers studied the efficiency of PV module and the effect of some concentrators on the module to increase the density of light on the PV module which would increase the efficiency in the principle of mirror, such as parabolic mirrors or lenses like Fresnel lens.

Many types of concentrators have been discussed in this thesis. The new water lens concentrator is economic due to the plastic foil and water used in this technique. It is also available at a cheap cost.

1.5 Requirements

Hardware requirements include:

1. Thin film solar cell.
2. Solar radiation sensor: measures solar energy from the led source.
3. Temperature PV sensor: temperature on 20º C and in case of overheat airfan will start work and in case of less 20º C heater will start till achieve that temperature.
4. Sun simulator: to concentrate the light on solar cell to get the needed radiation.

1.6 Project Plan

Table 1.1: Project Plan for the First Year

Task	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Select the idea												
Preparing for the project and collecting data												
Project analysis												
Determine the project equipment requirement												
Design												
Report deadline for supervisor												
Report deadline for the high study department												

Table 1.2: Project Plan for the Second Year

Task	Months											
	13	14	15	16	17	18	19	20	21	22	23	24
Literature review												
Experiment of PV without water lens												
Experiment with water lens												
Result analysis												
Report deadline for supervisor												
Report deadline for the high study department												

CHAPTER 2: BACKGROUND

In this chapter, a review of published scientific papers related to the study will be summarized. The review is concerned about the photovoltaic cells' performance, characteristics, the external influences and parameters of water lens that affect the characteristics of photovoltaic cells and performance**.**

2.1 Photovoltaic Power Generation

Photovoltaic cell is made of semiconductor material which works on photoelectric effect, that is based on the energy of the photon. There is an inverse relationship between wavelength and energy of the photon. If the energy is more than the band gap, it will release the electron from the semiconductor to the path of electron in case connection current occurs [1].

Solar radiation has a lot of photons, some with high energy and short wavelength which is the ultraviolet radiation (UV), whereas some photons have low energy and high wavelength which is the infrared radiation (IR). It is worth mentioning that IR radiation will only lead to thermal degradation especially in the clear day with high temperature, contrary to when the photon of high energy and short wave length hits the surface of photovoltaic semiconductor, part of the energy will release the electron free and the residual of the energy will be caught by the electron. The electron may have a lot of high energy to go through a circuit and get out of the current and electricity in case of voltage difference.

Semiconductor materials, like silicon, can be doped to form P-type and N-type semiconductor. A photovoltaic cell produces negative and positive charge electron, that causes flow of current in external circuit between two electrodes depending on connection in series and parallel that gives higher voltage, so power will be produced.

After the photon has been absorbed, hole-electron pairs may be generated. The electric field in depletion region will push the hole into the p-side and push the electron to the n-side. At p-side, there will be a pile of holes and the n-side of the electron will generate a voltage difference which leads to produce a current to the load demand when connecting wire occurs. It is worth mentioning that the electron can move through the wire but never through the depletion region. After completing the cycle, the electron will go right back through the load to the n-side [2] as shown in figure (2.1).

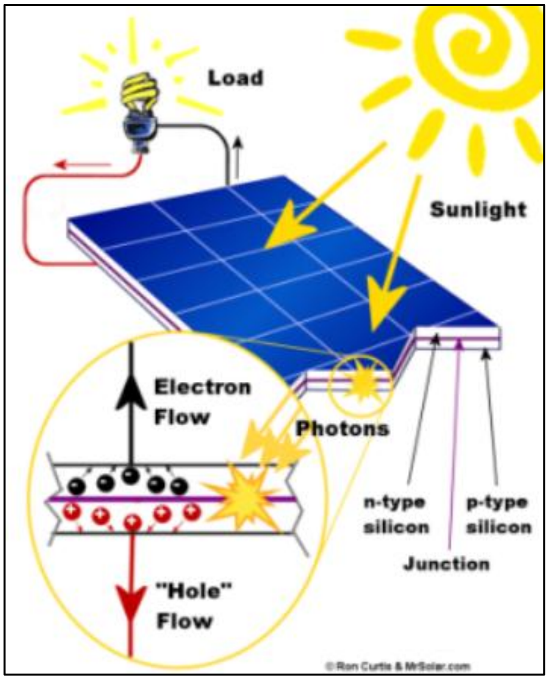

Figure 2.1: the principle work of photovoltaic solar module.

Manufacturing technology and operating conditions under Standard Test Condition (STC) appreciate the performance of photovoltaic module. STC can explain the I-V curve characteristic of photovoltaic cell to the module and array; they must be identified.

2.2 The PV Characteristics and I-V Curve under Standard Test Condition (STC)

1. Short circuit current (I_{SC}): is a function of solar radiation and depends much less on temperature. We can estimate it by connecting module terminal with ammeter [3].
2. Open circuit voltage (V_{OC}): function of illumination and temperature. We can estimate it by voltmeter when there is no current and the circuit is not closed; no load [3].
3. Maximum power point (MPP): or (PPT) power point tracking used to maximize power extraction under all conditions, measured in watt W and could be calculated by product V_{max} and I_{max} [3].
4. Maximum efficiency: is the ratio between the maximum power and incident light power.

$$\eta = \frac{P_{out}}{P_{in}} \tag{2.1}$$

5. Fill Factor (FF): is the ratio of output power at maximum power point to the power computed by multiplying I_{sc} by V_{oc}.

$$FF = \frac{Vmpp\ Impp}{Vout\ Isc} \tag{2.2}$$

More power could be produced if the array had a higher fill factor. There is also a positive relationship between output power and the fill factor [3] , I-V characteristic curve for the module as P-V characteristic curve of the load shown in figure (2.2):

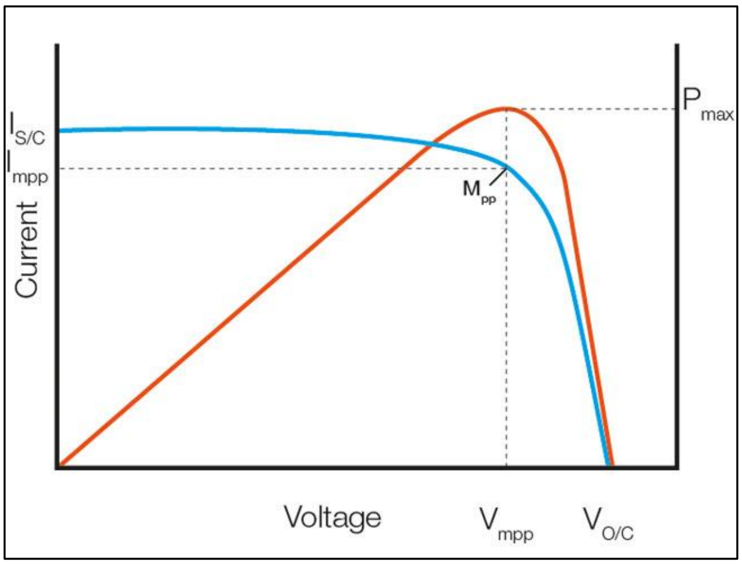

Figure 2.2: I-V Curve and P-V Curve for a PV Module. at the Maximum Power Point (MPP)

2.3 Modeling of photovoltaic cell

Modeling of the PV cell consists of one diode which is parallel with a current source. The current source produces the current I_{ph} and the current I_D flows through the diode. The current I_c could flow to the load is difference between I_{ph} and I_D [4]. R_s and R_p in the model could be obtained by fitting method based on the I-V characteristic of PV or measurement [5]. The equivalent circuit for a PV cell or module in figure (2.3) [6].

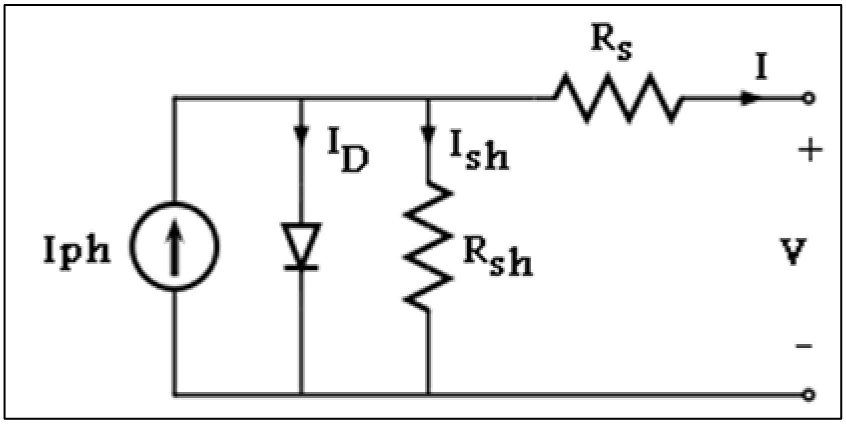

Figure 2.3: Equivalent Circuit for a PV

I_{ph} depends on both ambient and solar radiation. The load current is given by:

$$I = Iph - ID - Ish \tag{2.3}$$

Where

- I_{ph}: photocurrent from photovoltaic cell in Ampere (A).
- I_D: current passing through nonlinear diode Ampere (A).
- I_{sh}: current through shunt resistance in Ampere (A).

For I_{ph} that is a function of solar radiation and temperature is:

$$Iph = Isc + K_I(Tc - Tr) * \frac{G}{G_x} \tag{2.4}$$

Where:

- I_{sc}: is short circuit of the cell at standard test condition (STC: G_x =1000W/m^2 and T_r = 298.15º K.
- K_I: short circuit current temperature co-efficient of the cell A/K.
- T_c and T_r: working temperature of cell and reference temperature(25º C) respectively.
- G and G_x: working solar radiation and global solar radiation respectively W/m^2.

2.4 Literature Review

2.4.1 Review of the Different Types of PV Concentrators

Solar cells have, from an economic point of view, a high cost when they are installed. It is a big problem for which researchers and experts have been trying to find solutions. That is why, they turn to concentrators which are cheap cost-wise and consist of cheap raw material. Moreover, they are easy to use with solar cells because these rely first and for all on solar radiation as the most important point in this subject. It could make a lot of sunlight and concentrate it as pack of light on the solar cell in case the concentrator is used with a solar cell, which could lead to the use of a small area of the solar cell only.

Concentrators are an alternative to solar cells which occupy large areas, while producing the same amount of electrical power, which means there is an increase in efficiency. Concentration ratio could reduce the cell area, which is used when the concentrator is used, also the light intensity could increase in the same ratio.

For more than 40 years, the industry has been developing concentrators with solar cells, and they seem to spread rapidly in the world market. This is because it makes a difference with a small solar cell and it doesn’t need an extra cost for the tracking system. It is also less complicated when installing it and it deals with all the systems. Furthermore, it requires simple maintenance. In sunny areas, it makes a real difference. The efficiency could increase more than 40%, when using III-V multijunction cells and all the positive factors are present [7].

To know the advantages and disadvantages of concentrators with solar cell, Some advantages of CPV Table (2.1) [8].

Table 2.1: Advantages of Concentrating Over Flat-Plate Systems for Large PV Installations [8]

Lower cost	GaAs dish concentrators are projected to produce electricity at 7.4 cents/kWh by 2010, whereas thin-film modules are projected to be at 9.6 cents/kWh. If thin-film module prices come down from the assumed $75/m2 to $35/m2 at 12% efficiency (29 cents/W), then thin-film electricity cost would equal GaAs dish cost.
Superior efficiency	Concentrators are the only option to have system efficiencies over 20%. This reduces land utilization as well as area related costs.
Higher annual capacity factor	Tracking provides for improved energy output. Once the expense of tracking is incurred with flat plates, the leap to installing concentrator modules is small.
Less materials availability issues	Concentrators use standard construction materials for the bulk of their requirements. Flat-plate systems have serious concerns over material availability: silicon feedstock, or indium in the case of CuInSe2.
Less toxic material use	Many thin-film concepts use quite toxic materials such as cadmium, and so forth.
Ease of recycling	The trend in modern mass-product manufacturing is to make a product as recyclable as possible. Concentrators are composed mainly of easily recyclable materials, steel, aluminum, and plastic. Recycling flat-plate modules will be much more difficult.
Ease of rapid manufacturing capacity scale-up	Existing semiconductor manufacturing capacity is more than sufficient to supply projected cell requirements. The remaining manufacturing is comprised of rather standard mechanical components. This greatly reduces capital requirements compared to flat plate.
High local manufacturing content	Aside from the cells, the remaining content of concentrator systems can be manufactured worldwide, and close to the final point-of-use.

Optical characteristics could lead to make a comparative between the concentrators such as the concentration factor, focal shape, distribution of illumination, and optical standard.

Concentration factor for CPV [9] (equation (2.5)), which is the main important thing because it represents an indicator for the number of times the light of solar concentration hit the solar cell.

$$X = \frac{G_X}{G} \tag{2.5}$$

According to the normal light without concentration, there are three classifications for concentration [10] which are:

1. Low concentration (LCPV): (1–40x), systems concentrate the light between 1 and 40 times.
2. Medium concentration (MCPV): (40–300x), system concentrates the light between 40 and 300 times.

3. High concentration (HCPV): (300–2000x), system concentrates the light between 300 and 2000 times.

Output power of photovoltaic applications is proportional directly to the incident solar radiation. The output power from the photovoltaic device will increase when the radiation incident level increases using concentration effectively, as well as the production cost of electricity. Conversion efficiency (Ƞ), which is the ratio of the optimal electric power delivered by the PV cell (P_{max}), to the area of the PV cell exposed to sunlight (A_r) will decrease and solar insolation received (G_X) is described in Equation (2.6) [11].

$$\eta = \frac{P_{max}}{A_r G_X} \tag{2.6}$$

A. Fresnel Lens

Fresnel lens concentrators are used in solar energy concentration systems since the 1960s and are the invention of the Fresnel lens in 1822. It is made of polymethylmetacrylate (PMMA) which has a good transmissivity and resistance for sunlight. It also has a free maintenance and compact [12] which could also benefit at installation and operation. Fresnel lenses systems include:

1. Imaging Fresnel lens solar concentration systems: designed as focusing devices and the research has focused on the improvement of their evaluation technologies under solar radiation using ray tracing technology commonly.
2. Non-imaging Fresnel: has convex shape as solar concentrators could collect the solar energy not reproducing an accurate image of the sun. It is more commonly used and the research is directed to develop it more and use it for concentration. It has many advantages to make it commonly used because of its high optical efficiency, cost effectiveness and light weight [13].
3. By referring to the last review in 2018, we notice that there is still a gap that needs to be improved in the future which is the lack in climate measurement for experimental work. There is also few projects that implement Fresnel projects on a large scale in our planet with thiere climate measurements [14].

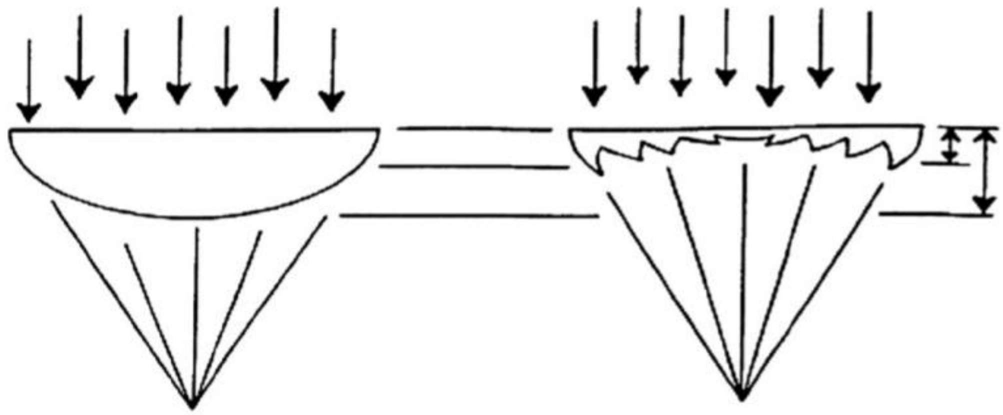

Figure 2.4: Conventional Lens and Fresnel Lens

The concentration of flux is represented as:

$$C_{max} = \frac{n^2}{\sin\theta \sin\psi} \quad (2.7)$$

Where:

- C_{max} is the maximum concentration of optical flux (unitless);
- n is the real component of the refractive index (unit less);
- θ (acceptance angle along the plane of the azimuth)
- ψ (the acceptance angle of the altitude) are the acceptance angles.

It is worth mentioning that there are many applications applied for solar concentration using Fresnel lens such as thermal application, thermal heating, solar cooking [15-17], photocatalytic [18-19], solar building [20-21] [22-24], solar-pumped laser [25-28], lighting [21, 29-32], in last surface modification of metallic materials [33-36]. There are two types of Fresnel lenses which are circular[37] and linear lenses [38-39].

B. Quantum Dot Solar Concentrator

Quantum Dot Solar Concentrator or (QDSC) is based on non-tracking solar concentration. It embraces quantum dots (qds) dole out in materials such as plastics and glasses, which concentrate and diffuse solar energy on the photovoltaic cells [40, 41]. (QDSC) may consist of three main parts; first is a flat transparent sheet of glass or plastic fixed with quantum dots (qds). Second is a reflective mirror that is placed on three different edges along with the back surface and third a PV cell attached to the exit space. Figure (2.5) shows the affected concentrator surface at the time when the sun radiation hits, where part of this radiation will be diverted by a bright material and absorbed by quantum dots (qds); photons are reemitted isotropically at a lower frequency and guided to the PV cell [42].

The size of quantum dots, which are made of nanostructures, typically varies from tens to hundreds of nanometers in size. There is some restriction for developing qds because it could have vehement requirements of the luminescence dyes such as high quantum efficiency, suitable absorption spectra, red shifts, and illumination stability [43]. On the other hand, there is a problem related to the organic dyes which could be fixed by replacing it with qds that have the advantages of less degradation and high luminescence [44].

It is worth mentioning that quantum dot containing nanocomposite coatings supersede the production of planar quantum dot solar concentrators as Schueler [45] and Gallagher [11] determine and discuss the concentration ratio by comparative analysis for different types. A maximum comparative concentrating factor (MCCF) determined for specific solar intensities by equation (2.8):

$$\text{MCCF} = \frac{P_{dev-max}}{P_{max-ref}} \tag{2.8}$$

Where power maximum for the test device for $P_{dev-max}$, and $P_{max-ref}$ for power maximum which is for the reference devices.

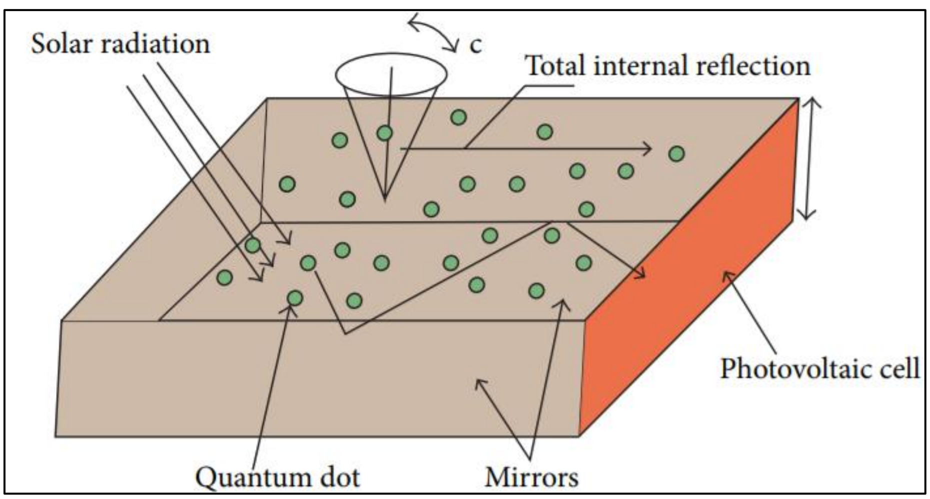

Figure 2.5: Principle of the QDC [42]

C. Parabolic Concentrator

It is the most recognized technology because it has a low-cost unit and high dispatch ability. The principle of these concentrators is that the parabolic shaped mirror could focus sunlight on the receiver tube which is placed at a focal point of the parabola [46]. A lot of factors could affect this concentrator’s performance such as mirrors’ reflectivity, tracking error, incident angle, intercept factor, and absorptivity of the receiver.[47-48]. It has several applications as mentioned in [49-50]. It is to mention that optical efficiencies of parabolic trough collector also depend on slope error, collector assembly and image quality of the mirror [51].The performance of the parabolic trough collector depends on heat loss from receiver as well as the design of the receiver [47, 52-54].

One of the tools used to increase heat loss is to put porous inserts in the inner surface of the receiver. Then, the heat transfer is increased by increasing the effective fluid thermal conductivity and augmenting the mixing between the receiver's wall and the fluid. It is also increased through rebate thermal resistance by promoting the layer's boundary of the thinner hydrodynamic [46].

It is worth mentioning that the concentration ratio of the parabolic concentrator in figure (2.6) could be as in equation (2.9) [55-56].

$$C = \frac{\sin \varphi_R}{\pi \sin \theta_\alpha} \tag{2.9}$$

Where:

- θ_α is half the acceptance angle.
- φ_R is the rim angle.

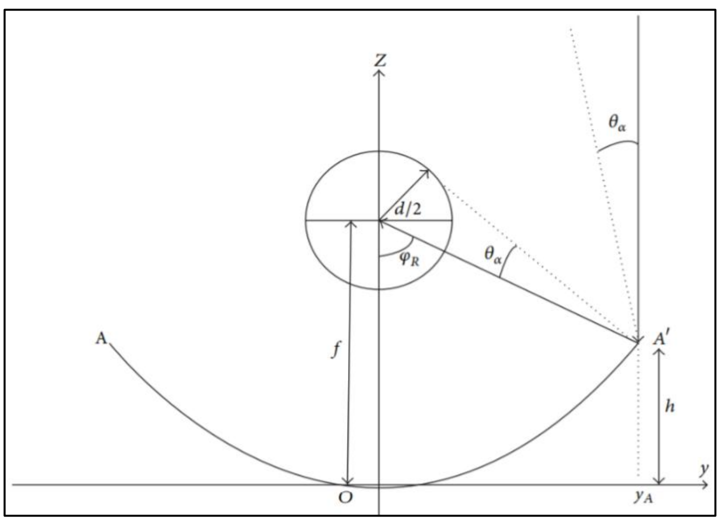

Figure 2.6: Schematic View of the Parabola

D. Compound Parabolic Concentrator (CPC)

It collects and concentrates the distant light source efficiently with acceptance angle, figure (2.7) shows the configuration of CPC.

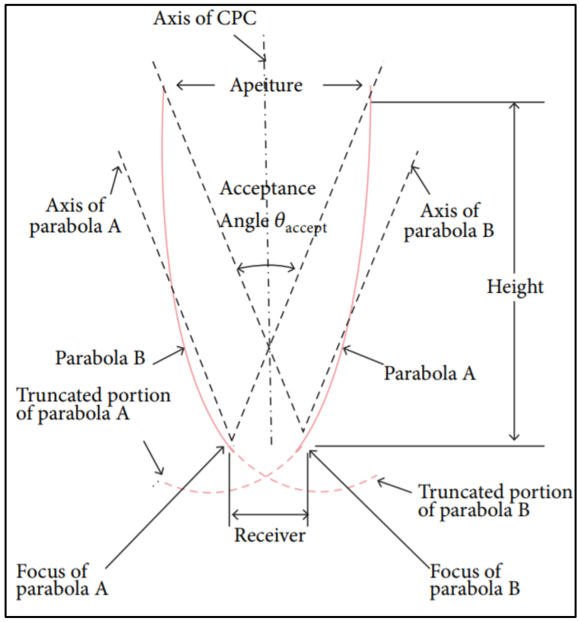

Figure 2.7: Cross section of CPC [57]

On the other hand, there are geometrical concentration ratio and theoretical maximum possible concentration ratio of CPC which in equation(2.10) and equation (2.11) [56, 58, 59].

$$CR = \frac{A_a}{A_r} \quad (2.10)$$

$$CR_{max,3D} = \frac{1}{sin^2(1/2)\theta_{max}} \quad (2.11)$$

Where the A_a , $A_r$and θ_{max} are the aperture area, reciever area and maximum acceptance angle.

Suzuki and Kobayashi's [55] studied the 2-D dimensional configuration of CPC and concluded that 26 degree is the optimum half acceptance angle and the CPC is the ideal application solar collecting system. Senthilkumar et al [60] found that 3-D dimensional configuration of CPC is more efficient than the last because it has higher concentration ratio. Yehezkel et al [61] dissect the losses using empirical linear model to facilitate design and system optimization by analytical methods without having recourse to a ray-tracing procedure which is related to reflection properties and calculated the effect of that losses on concentration ratio. Khalifa and Al-Mutawalli [62] concluded that gaining energy of CPC collector could be increased by a two-axis tracking system and the best amendment at 25 to 45 kg/hrs. as range of flow rate.

Mallick et al [63] conducted experimentally outdoor that 62% increasing of maximum power by using ACPPVC related to similar non-concentrated PV panel.

E. Dielectric Totally Internally Reflecting Concentrator (DTIRC)

Ning et al [64] concluded that DTIRC is one of the most important non-imaging optical concentrators. Moreover, they use it for IR detector [65] and for the system of communication for optical wireless [66, 67].

As shown in figure (2.8), DTIRC consists of three parts, they are: the curve front surface, totally internally reflecting profile and exit aperture [67]. It is worth mentioning that the rays that could reach the exit aperture depend on an important factor which is designing the acceptance angle of the concentrator, so that when a set of rays strike the front of the curved surface at acceptance angle, it could be refracted and directed to exit aperture.

Ning et al [64] debate the two stage photovoltaic concentrators. The first with Fresnel lens and the second is dielectric totally reflecting non-imaging. They conclude that the two stage concentrator gives more uniform flux distribution and more concentration than Fresnel lens point focusing. In addition to the above, Muhammad-Sukki et al [68] qualified the design of (DTIRC) as they applied maximum concentration method (MCM) and concluded that with simulation MATLAB to optimize designing of that concentrator. They conclude from MATLAB that the MCM gives higher geometrical concentration earning at parallel with incommodious increase with the size of concentrator.

It is to mention that the advantage of DTIRC in comparison with compound parabolic concentrator is working with and without a cooling presence, flux tailoring, and higher in both concentration ratio and efficiency too. On the other hand, DTRIC couldn’t expeditiously pass all of the solar energy which it accepts into depress index media [69]. Muhammad Sukki et al [70] present a study about a mirror symmetrical (MSDTIRC) that could be a new sort of (DTIRC) and also civilize a method to calculate the concentration gain for (MSDTIRC) system.

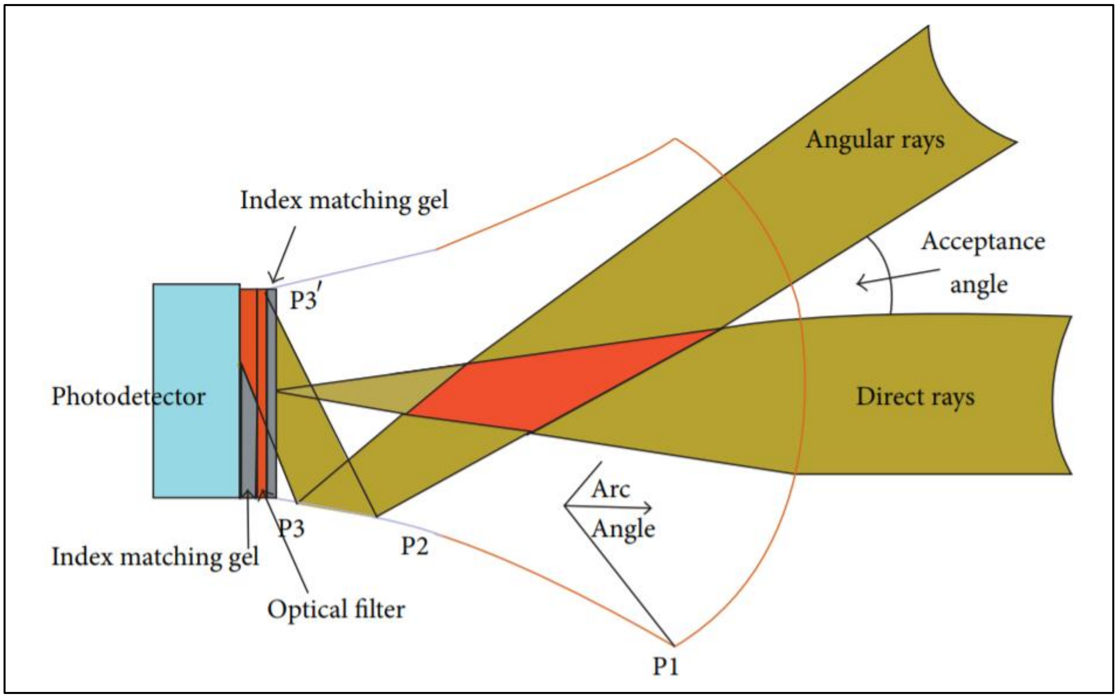

Figure 2.8: Side View of a DTIRC [67]

F. Hyperboloid Concentrator

As shown in figure (2.9) there are two-dimensional hyperboloid concentrators. The incident light could enter the aperture to hyperboloid concentrators and may reach the receiver or reflect out of it [71]. Figure (2.10) shows a 3-D of elliptical hyperboloid concentrators which have an advantage as they are very built-in. Because of only truncated particular form this concentrator needs to use, it must be considered as a secondary concentrator[72]. Garcia-Botella et al [73] disclose that hyperbolic concentrator, which is of one sheet, is an exemplary 3D asymmetric concentrator since its shape couldn't niggle the flow of lines of elliptical disk and couldn't need tracker for the different acceptance angle which is longitudinal and transversal direction.

Sellami et al [74] destined a 3D concentrator and picked the square elliptical hyperboloid (SEH) to insert in glazing window in other world frontispiece and for the facades photovoltaic application, concluded that this design could compile both direct and diffuse beam of radiation and also SHE size is really the optical efficiency. Garcia-Botella et al [75] show the 3D solar concentrator which is gained from the hyperboloid. It has the ability to concentrate all of the rays that get in. Gordon [76] concluded that the ideal concentrator consists of a rampage of hyperbolic types which is an euphonium concentrator.

Chen et al. [77] concluded that the concentration of solar flux could be double when the concentration tracking errors could exist in case the solar concentration consists of primary paraboloidal and hyperboloidal mirrors as secondary when ray tracing method is used. Saleh Ali et al.[78] produced a study about 3D solar elliptical hyperboloid concentrator (EHC) and they submitted an equation for styling hyperboloid concentrators which is [78] shown in figure (2.11):

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z^2}{c^2}=1$$

$$y_{1}=\left[\left\{\left(\frac{x^2}{a^2}\right)-1\right\}\times\{H^2\times(CR-1)\}\right]^{0.5},$$

$$A=(CR\times(a)^2)^{0.5}, \tag{2.12}$$

$$y_{2}=\left[\left\{\left(\frac{x^2}{b^2}\right)-1\right\}\times\{H^2\times(CR-1)\}\right]^{0.5},$$

$$B=(CR\times(b)^2)^{0.5},$$

$$CR=\frac{A_p}{A_r},$$

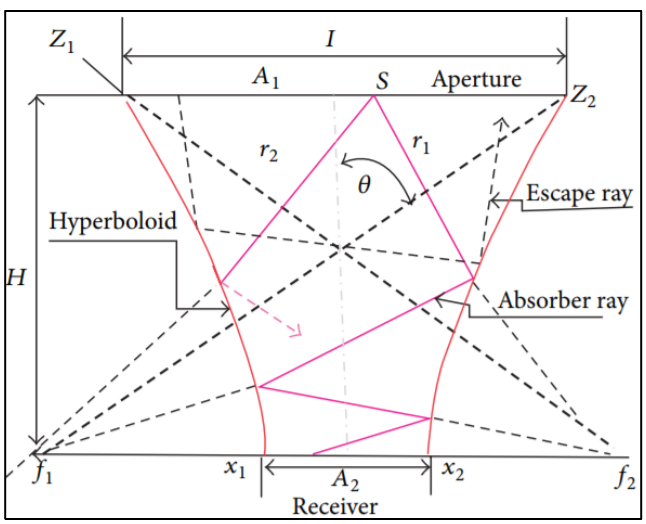

Figure 2.9: Hyperboloid Concentrator [71]

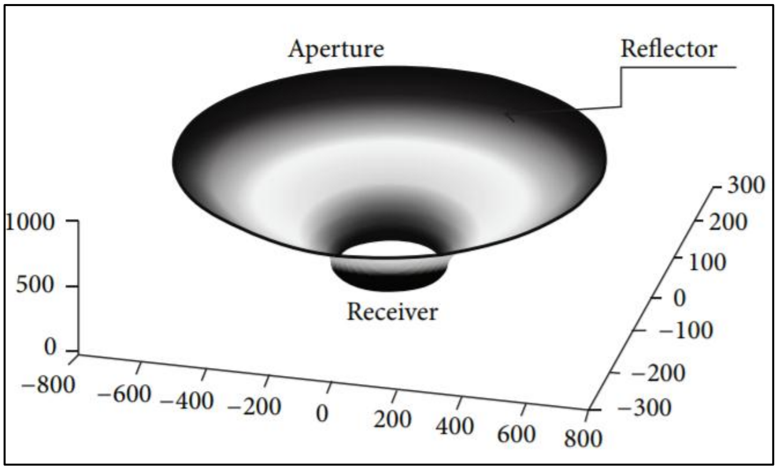

Figure 2.10: 3-D Elliptical Hyperboloid Concentrator

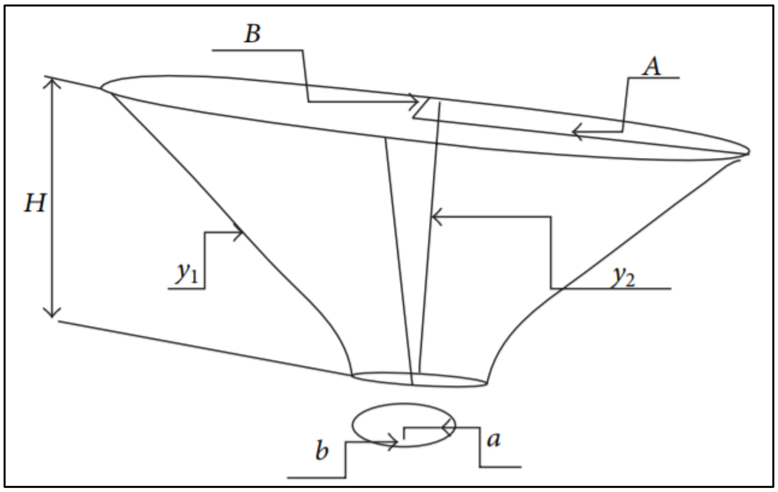

Figure 2.11: Geometrical Parameters of an Elliptical Hyperboloid Concentrator [78]

G. RR, XX, XR, RX, and RXI

Minano [79] concluded that these configurations could give high concentration for cells since these new concentrators carried out acceptance angle concentration that was maximum theoretical achieved.

Minano [80-81] inspected that the performance could be acceptable for the rotational RX while the angular spread of the input bundle is small. Benitez [82] presents analysis for RX concentrator performed and concluded that while the field of view is small whereas less than 6 degrees full angle and even for concentrations up to 95% of maximum theoretical, normal incidence of an $f/3.7$ could be analogous to imaging performance (in MTF terms).

Minano [83] carried out a research for RX and RXI concentrators and concluded that the performance in 3D could be very good while the acceptance angle of the concentrator is less than 5 degrees for source at infinity, furthermore the RX could be designed to finite source and RXI could be designed to infinity source.

H. Water Lens Review

1. Ren and Wu conducted an adaptive liquid filled lens by using elastic membrane, solid late and an annular sealing ring. The radius of the last was changeable till reaches the positive variable focus lens which is lightweight, easy to fabricate, and has very weak color dispersion [84].
2. Yang et all [85] conducted numerical and small modeling of fluid, driven polymer lenses by finite element model (FEM) and strain versus pressure. It was found that the conic constant and radius of curvature of standard optical shape can be accurately predicted and strain reduces the variation of conic constant and the sensitivity of the membrane shape to the edge clamping.
3. Nguyen [86] conducted a review for micro optofluidic lenses which are classified to out of plane and in-plane families based on tenability of liquid which can be tuned by manipulating the refractive index of this liquid and shape of lens. It was found that the parameters of micro-optofluidic lenses reported are discussed and compared.
4. Ren et al [87] explain a tunable focus liquid lens by using of a servo motor which can control the focal length by pushing the liquid into the lens chamber and shrinking elastic periphery without changing the aperture of liquid lens. It was found that we can operate liquid lens electrically rather than mechanically by choosing a suitable electrically controllable actuator.
5. Ren and Wu [88] explain a variable-focus liquid lens by applying a pressure to outer membrane inward to form a Plano convex lens induced the particle of the liquid redistribute. The focal length controlled mechanically, or piezoelectric actuator and the aperture size is determined by identity and solidity of the PDMS film. It was Found that the resolution of the lens is better than 25 lp/mm and response time is ~40 ms.
6. Alvarado et all [89] conducted design, simulation using FEM and analysis of mechanical behavior of three variable focal length liquid lens which depend on quantity of water and different profile, which is flat, spherical and conic. Genetic Algorithm was used to obtain the geometrical parameter of lens, which was used to simulate optical behavior of the lens and analyzed using OSLO commercial ray trace program. It was found that simulation can predict the behavior of VFLLFL made up of membranes with specific profiles, without having necessarily to build them physically.

7. Wang et al [90] conducted a method to create a variable focus lens with a high performance and large optical aperture 26mm-diameter and low optical power region in plane pretension force was applied to a membrane. Comparing membranes in a simulation by the FEM. a Shack-Hartmann sensor measured the wave front behavior, infinite focal length with wave front error of 105.1nm RMS was achieved.
8. Sugiura Morita [91] fabricated a liquid-filled lens and evaluated experimentally and calculated theoretically a lens shape and the deformation of that shape by gravity, aberration calculated too and observed to be negligibly small compared with the normal convex spherical single-glass lens. They found the effect of gravity negligible when the pressure at liquid pump more than 30 times at bottom of lens by gravity.
9. Duerr et al [92] conducted a quantitative investigation of wave optical of solar concentration by using a plane Fresnel lens design and analysis of the miniaturization's influence on the obtained concentration performance. Found that we can optimize the design in non-imaging optics in several applications.
10. Ren et al [93] explained the effect of electrophoretic on a tunable focus liquid lens by applying a voltage to dielectric liquid droplet, which could be converted to an inhomogeneous surface profile and focal length will be reshaped and changed respectively due to a dielectric force. Lenses with different aperture were fabricated and their performance evaluated. They found that the lenses which use continuous electrode are easy to fabricate and have a simple structure.
11. Radziemska [94] conducted experiments to investigate the electric parameter of crystalline silicon solar cell and solar module. He found out that there is a decrease of output power (-0.65%/K), of the fill-factor (-0.2%/K) of solar cell with an increase in temperature. Moreover, the conversion efficiency of the PV module was (-0.08%/K).
12. Grindley [94] and Lind conducted pressure, volume and temperature for water and mercury up to 8000 bar 30°c-150°c by electromagnetically detection changing in length of a column of fluid.
13. Odeh and Behnia[95] conducted an experiment and proposed a cooling technique of the solar system by a water pumping system with long term performance modeling. The study focused on cooling of the PV by inlet cool water tube on upper surface of the PV panel. It was found that there is a 4- 10% increase in the solar system output and the same percentage is due to cooling by direct contact between water and PV module surface.

14. Mondol et al [96] conducted experimental and theoretical study to investigate the properties of large scale water lens. The study dealt with the focal lengths and light intensities in the focal spot of the water lens. Several shapes of the lens were also investigated. It was found that maximum volume which is 16 litters shows maximum intensity, smallest focal length and maximum concentration factor. Water lens shape mimics the ideal aspheric lens shape. It can be useful for more flexibility of the lens control, good performance and cost reduction.
15. Bashkatov and Genina [97] conducted a simple approximation of water with spectral range 200 to 1000 nm wavelength and different temperature. By using Cauchy formula for each temperature obtained from calculation, obtained coefficients are documented.
16. Delin et al [98] conducted an experimental study of behavior of the stress relaxation of polyethylene both high and low density. The study focused on volume change during the relaxation, process using extensometer and measuring the volume with a specially designed liquid stress dilatometer. Relation to poisons ratio was approximately linear during relaxation with log time as similar as that occurring during the process of physical ageing.
17. KEITA et al [99] conducted experimental and numerical simulation to survey the feasibility of the water lens as a condenser and the contingent applicability for solar light thermoelectric (TE) conversion is evaluated. It was found that the shape of a thin lens can enhance the condensing ratio and the width of light condensing is as large as the width of TE module.
18. Royne and mills [100] conducted experimental passive and active cooling system of different solar concentrator systems and the performance of micro-channel and impinging jets. The study focused on single cell, densely packed cells and it was found that passive cooling for single cell is feasible and most efficient solution for concentration. Meanwhile, heat pipe-based solution is one way to increase the passive cooling performance, and for densely packed cell only active cooling is a feasible solution.
19. Du and Kolhe [101] conducted experimental performance of active water cooling system for concentrated photovoltaic system (CPV). The study focused on investigated different parameter temperature, power output and efficiency for fixed and concentration solar cell. It was found that the output electricity at solar noon from concentration solar cell was more than fixed solar cell. The efficiency drops because of the increase of the solar cell temperature, but with cooling more heat exchanging so cell temperature decreases while the efficiency increases.
20. Green et al [102] presented the efficiency for solar cells and modules by showing four tables that listing of the highest independently, thin film always has have a higher efficiency.

One of the major points which is worth to be mentioned here, is a review about absorption, scattering and attenuation properties of distilled water as a function of wavelength from the UV to the near infrared region of the spectrum. Inherent optical properties (IOPs) of water in general are scattering, absorption and refractive index (real part) that depend on temperature (T) and salinity (S). For distilled water, only change with (T) is wavelength-dependent, that leads to major changes at precise wavelengths by large or simply changes of (T). Due to the distilled water strong absorption in IR region and very low scattering, the effect of (T) and (S) on absorption of distilled water are deliberated to be inadequate to the mid VIS and NIR region. At shorter of wavelength, the absorption is less than that at long wavelength and for other parts (phytoplankton pigments, humic substances) is meaningfully larger as tap water length Morel [103]

Daimon et al [104] concluded that as wavelength increases, the absorption increases, and vice versa. At visible spectrum, there is a narrow transparency, so it doesn't absorb visible light 400-700nm because there is no physical mechanism that produces transition in that region. In pure water, joint interactions amid the intermolecular force the mechanisms of absorption. In IR, there is a strong absorption, and at UV due to photoelectric effect, the absorption is successive.

Hulburt et al [105] concluded that scattering of pure water is a result of groups of molecules and ions that are smaller than wavelength of spectrum. As wavelength decreases the scattering increases, refer to Rayleigh scattering is conversely proportional to the fourth power of wavelength. That means for UV region water will scatter more than at IR region. It is worth mentioning that there is no change in the energy of particle or photon opposite to the case of absorption.

For attenuation which could happen by either scattering or absorption, in visible part of spectrum there is a cute minimum, 450-500nm which is in blue region that is a minimum attenuation as Morel [103].

Refractive index of water is 1.333 which means that the light goes faster in vacuum 1.333 times as in water. It is inversely proportional to wavelength and (T) at the time that only frequency of the light will be constant, while the speed and wavelength change when the light travels from medium to other. The velocity of light decreases as wavelength of light decreases [106].

I. Linear Low-Density Polyethylene Review

1. Linear low-density polyethylene (LLDPE) produced by a low-pressure process with a density <965 kg/m^3, Polyolefins are produced from olefin (alkene) monomers because the olefins contain a reactive double bond. The starting material, ethylene, is called the monomer and the final product consisting of many thousands of bound ethylene units is called the polymer. Co-monomers (higher alpha olefins such as butane, hexane, octane) are used to control the density and other physical properties [94].
2. Two main techniques are used for the production of LLDPE:
   i. The polymer is produced at low temperature (70-110°C) and low pressure (1-5 MPa) in a saturated hydrocarbon medium. The polymer forms suspension or mobile slurry. The reaction medium is removed, and the polymer separated from the hydrocarbon inert diluent. The obtained powder is mixed with stabilizers and extruded into pellets [107].
   ii. Gas phase polymerization: A gas phase reactor is essentially a fluidized bed of dry polymer particles maintained either by stirring or by-passing gas (ethylene) at high speeds through it. Pressures are usually relatively low at ~2MPa and temperatures are usually in the range of 70-110°C. The molten polymer is mixed with stabilizers and generally extruded into pellets [107].
3. Mechanical properties of Linear Low-Density Polyethylene (table 2.2):

Table 2.2: Mechanical properties of Linear Low-Density Polyethylene [108]

Factor	Value
Density, g/cm^3	0.91 - 0.925
Crystallinity	30 % to 50 %
Tensile strength, psi	600 – 2300
TENSILE Elongation, %	100 % - 650 %

2.5 Cooling Systems

One of the major problems faced during the designing process of a photovoltaic system is the cooling to be used. It is known that there is an inverse relationship between temperature and efficiency of photovoltaic cell and non-uniform temperature also have some effect on the PV cell [109, 110]. As it is known to researchers, workers and scientists, cell degradation occurs if the temperature exceeds appointed limits [100]. Moreover, the thermal properties of the coolant are a major factor for deciding which cooling system is appropriate for the PV system. For instance, the thermal properties of water make it more efficient for the cooling in comparison to the air [81] and it couldn't aggress or erode the wrapper or wick in the absence of a chemical reaction between wrapper and the working fluid which does not emit any condensable gas (NCG) [111]. One of the common technologies used as cooling systems is the heat pipes when the concentration system is used. Heat pipes are considered a vacuum tight device that consists of working fluid and cord structure[111]. The additional and rejected heat could transfer through working fluid by condensation processes. However, heat pipes are made of copper or aluminum; Table (2.3) presents the compatible working fluid for copper and aluminum [111 -112].

Table 2.3: Fluids Compatible with Copper and Aluminum, Based on Heat Pipe Life Tests

	Copper	**Aluminum**
Compatible	(i) Water (ii) Methanol (iii) Ethanol	(i) Ammonia (ii) Acetone (iii) Toluene (iv) n-Butane (v) n-pentane (vi) n-heptane
Incompatible	(i) Ammonia (ii) Acetone	(i) Water (ii) Methanol, other alcohols (iii) Benzene (carcinogen) (iv) Naphthalene

Akbarzadeh and Wadowski [113] present a report on parabola trough which use heat pipes for cooling and occur when it has been built in a vertical manner at the end of a thermosyphon using a pipe made of copper that contains a specific area for condensing process. Each cell is mounted vertically at the end of a thermosyphon which is made of a flattened copper pipe with a finned condenser area. The cell temperature does not go beyond 46° C on sunny days with the concentration ratio of 20 suns; which was 84° C without the use of fluid in this system.

Horne cooling system is based on focusing the light onto cells, which has been used for a paraboloidal dishyb [114]. The method operates by sending water to the receiver using a central pipe, which then flows behind the cell. This way it can absorb a large amount of UC radiation that may reach the cells in addition to its role as a cooler to the cells.

A Fresnel lenses presented by Russell uses a heat pipe system for cooling purposes that focuses a direct light onto a set of cells that are placed on top of the pipe to the end of its length linearly. The panel formation is done by using multiple pipes arranged in a linear order [115], figure (2.12).

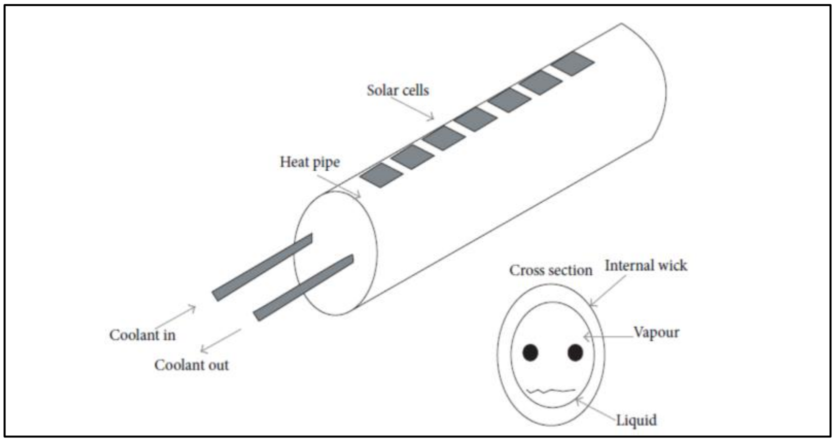

Figure 2.12: Heat Pipe-Based Cooling System [115]

In order to extract the thermal energy out of the pipe, a coolant circuit that exists inside the heat pipe is used, where the inlet and the outlet lines are placed in the same entrance of the pipe to ensure that the temperature is the same along the pipe.

Another type of linear Fresnel lens described by Chenlo and Cid [116], which uses a galvanized pipe made of steel for cooling using flow of water through the pipe. A soft weld is used to connect the cells to a wire contains two layers of copper and one layer of aluminum in between that are also welded to a rectangular pipe that shows the thermal and electrical models for illumination of non-uniform and uniform cell. Another experiment presented by Du et al [101], explains an analysis of how the water is used for cooling a photovoltaic system with 8.5 concentration ratio.

The water-cooling device consists of two pipes attached with an aluminum plate that are placed at the back of the solar module. They proved that the CPV system will perform better by using a cooling system, especially when the water flow rate is increased. The more water flows, the better efficiency of such module we get.

Farahat [101] had compared between another two types of cooling systems for the purpose of providing a cool environment for the photovoltaic systems that have a high concentration of light. The two techniques (i.e.: water cooling and heat pipe) were compared, and the final recommendation was to the benefit of the heat pipe cooling technique that is considered to be the best option for HCPV.

Geng et al. [117] is the one who had applied a mathematical study (both numerical and experimental) along with performing some experiments on a high concentrated photovoltaic cooling system by applying a fluctuated heat pipes to act as a cooling system. The distribution of the temperature has been analyzed using the numerical study by using different heat change and some other outdoor conditions. Then concluded that heat pipes as a method of cooling was reliable, uniform, simple and the cheapest. The thing that makes the fluctuated heat pipes suitable for HCPV systems is that it doesn't need an air fan or pump, and it does not have power consumption. A study has been conducted by Chong and Tan [118] on how to apply an automotive radiator to act as the cooling system for the dense array concentrator photovoltaic system.

In order to make a flow, they used a computational fluid dynamic (CFD), and they made an analysis for the heat transfer for the cooling system of the mentioned CPV. They formed an experimental technique by using 377 suns as a concentration ratio for the feasibility study and evaluation. The observations they got is that if they apply the cooling system while the temperature for the cell reduced from 59.4° C to 37.1° C, then the efficiency will successfully improve from 22.39% to 26.86%. As a result, it seems that heat sinks are used by many researchers when they conduct their studies about using it as devices through cooling processes for CPV systems, hence this way became very popular during the past decades.

The following study conducted by Karathanassis et al. [119], in order to optimize the micro-channel, plate-fin heat sink to cool down the linear parabolic trough concentrating photovoltaic/ thermal (CPVT) system. The result of this study shows that the use of micro-channel heat sinks is an ideal way to remove the high heat flux, specially that they have achieved a low value for the thermal resistance (0.0082K/W). Also, they have a 1-D model that can predict the transfer of the heat and the flow within the micro-channel.

A proposed correlation for the thermal resistance done by Do et al [120], as they designed a tool for a natural heat sink convective for concentrating photovoltaic (CPV) with plate-fins. Different heat sink geometries such as input powers, and inclination angles were investigated using different experiments. The prediction of the effect for the inclination angles and the spacing of the fin could be done using their correlation.

A focus point of Fresnel lens array under passive cooling system [121]. A set of linear fins arranged on the surface of the heat sink made up the cooling device. The conditions that the passive heat sink puts the cells within is that the temperature of the cell will be below 150∘C, and a 90 suns concentration level, even on days that are extreme.

In another investigation done by Natarajan et al. [122], about the numerical explanation about the solar temperature , he explained how to use it with the concentrated PV using Fresnel lenses with a 10x concentration ratio (with or without a passive cooling system). The results of the simulation revile that the favorable conditions for the aforementioned CPV is using four fins with a 1mm thickness and 5mm height.

Kumar and Reddy [123] made an investigation about the properties of the porous disc receivers by applying water as working fluid. To determine the friction factor and the Nusselt number for the porous disc receiver, a practical correlation was developed. There was an enhancement done to the receiver configurations by Satyanarayana et al [124] in order to increase the transfer rate of the heat.

A special cooling system experimental study was proposed by Drabiniok and Neyer [125] for the PB cells based on a bionic method, that is done using porous compound polymer foil, where the foil was coated right on silicon substrates, in order to provide the water with a good thermal contact.

From this experiment, it was noticed that the temperature has been reduced up to 11.7∘C, and the water flow was able to be self-regulated within the presented system, as well as with the cooling rate resulted from the direct dependency in environmental conditions, such as air velocity and temperature. An interesting experimental study done by Sun et al. [126] about heat dissipation of linear concentrating photovoltaic, which had performed using dimethyl silicon oil by applying a direct liquid-immersion cooling method. As a result, the cell temperature rose up from 0 to 35, which is a linear increase with oil temperature.

This method is quite appealing because it uses the direct liquid-immersion cooling and the difference between the average cell temperature and heat transfer temperature, it can be maintained within the range of 20∘ C – 31∘ C and 5∘ C - 6∘ C respectively, using a direct normal irradiance (about 910W/m^2, 15∘ C silicon oil inlet temperature), and Re numbers varying from 13,602 to 2720. At their final report, they stated that there is no substantial efficiency degradation, and after 270 days of silicon oil immersion the electrical performance was considered to be stable.

Following the experimental studies, an experiment that has been done by Teo et al. [127], in order to analyze the effect on the efficiency of the PV modules through the use of the active cooling system. What they have done, is applying a parallel array of ducts with a modified designs inlet /

outlet for distribution uniform air flow that are connected to the back of the module. Here, they found that the efficiency rose from 8 – 9 % to 12% - 14% by using this type of cooling system which is active. Ji et al. [128] applied their own experimental and numerical study, on how to use a jet impingement/ channel receiver for cooling tightly packed PV cells under a paraboloidal dish concentrator.

They indicated that the required working performance for the proposed system is there and considered to be a good possible application to be used for the PV cells cooling that are exposed to a high heat flux. Brideau and Collins [129] concluded that the coefficient of the heat transfer could be increased between air and the PV cells, by using an impinging jet in order to propose a hybrid PV/ T system.

Table (2.4) shows the main description of different cooling systems.

Table 2.4: Description of Different Cooling Systems

Type	Discription	Reference
Heat pipe	(i) Simple (ii) Reliable (iii) Uniform (iv) Costless (v) Needs no air fan, pump, or energy consumption (vi) Suitable for HCPV	[130] [117]
Microchannels	(i) Low thermal resistance (ii) Low power requirement (iii) Ability to remove a large amount of heat in a small area	[100] [131]
Forced air	(i) Less efficient than water (ii) More parasitic power	[81]
Porous	High temperature reduction with appropriate attachment	[125]
Impinging jet	Applying the coolant for hybrid system	[129]

Advantages and disadvantages of different types of the solar concentrators showed in table (2.5). It is worth mentioning that Swanson [8] fulfill review study about characteristics of concentrated photovoltaic systems.

Table 2.5: Advantages and Disadvantage of Different Types of Solar Concentrators

Type of concentrator	Advantage	Reference	Disavvantage	Reference
Fresnel lens	(i) Small volume (ii) Light weight (iii) Mass production	[13]	(i) Imperfection on the edges of the facets, causing the rays to be improperly focused at the receiver (ii) Possibility of lost light due to incidence on the draft facet (iii) Luminance is necessarily reduced in order to minimize the upper disadvantages	[132] [133]
Quantum dot	(i) Nontracking	[11] [134]	Developing QDCs was restricted	[43] [135]

concentrator	concentrator (ii) Have less problems of heat dissipation (iii) Sheets are inexpensive and are suitable architectural components		by stringent requirements of the luminescent dyes	
Parabolic trough	Make efficient use of direct solar radiation	[136]	(i) Use only direct radiation (ii) high cost (iii) low optical and quantum efficiencies	[136]
Compound parabolic concentrator	Most of radiation within the acceptance angle can transmit trough the output aperture into receivers	[137]	Needs good tracking system in order to get maximum efficiency	[138]
Dielectric totally internally reflecting concentrator	(i) Higher efficiency and concentration ratio than CPC (ii) Work without any needs of cooling features	[69]	Cannot efficiently pass all of the solar energy that it accepts into a lower index media	[69]
Hyperboloid concentrator	Very compact	[72]	Need to introduce lens at the entrance aperture to work effectively	[72]
RR, XX, XR, RX, and RXI	(i) Achieving the theoretical maximum acceptance angle concentration (ii) High concentration (iii) Lighter weight (iv) Less expensive tracking system	[79] [139]	The size of the cell must be kept to minimum to reduce shadowing effect	[139]

Table (2.6) summarized this study which represents different CPV with their characteristics [8, 72].

Table 2.6: Different CPV Projects with Specifications [8, 72]

Companies/ institutions	Type of concentrator	Type of focus	Concentration Ratio	Tracking	System	Cooling	system Efficiency Cost	Reference
Sun power corporation	Fresnel lens	Point	25–400	—	—	27%	—	[8]
Solar research corporation	Parabolic dish	Point	239	Yes	Yes	22%	—	[140]
Photovoltaics International	Fresnel lens	Linear	10	Yes	—	12.7%	4–6 cent kwh (110MW/yr production rate)	[141]
Polytechnical University of Madrid	Flat concentration devices (RXI)	Point	1000	No	—	—	Low cost (need no tracking system due to high acceptance angle)	[142]
Fraunhofer-Institut fur Solare Energiesysteme	Parabolic and trough	Linear and Point	214	Yes	Yes	77.5%	—	[143]
Entech	Fresnel lenses	Linear	20	Yes	—	15%	7–15 cent Kwh (30MW/yr production rate)	[144]
BP Solar and the Polytechnical University of Madrid	Parabolic trough	Linear	38	Yes	Yes	13%	13 cent kwh (15 MW/yr production rate)	[145]
Australian National University	Parabolic trough	Linear	30	Yes	—	15%	—	[146]
AMONIX and Arizona Public Service	Fresnel lens	Point	250	Yes		24%	—	[147]

This thesis presents a clear visualization of water lens as a concentrator of light with photovoltaic cell, which can be considered as the first work of its kind which presents and contributes to previous studies for current research. While there is a lack of knowledge in the water lens as a concentrator of light with photovoltaic cell, many experiments with water lens (Tap, Distilled), oil lens and without lens could be done to prove the increase in efficiency when using a water lens, and illustrate performance of photovoltaic cell with water lens.

CHAPTER 3: BLOCK DIAGRAM DESCRIPTION AND EQUIPMENT'S

This chapter shall describe the block diagram for the thesis as well as discuss the experiment procedure and tools.

3.1 Block diagram

Figure (3.1) demonstrates the system which will be used in the experiments in this project.

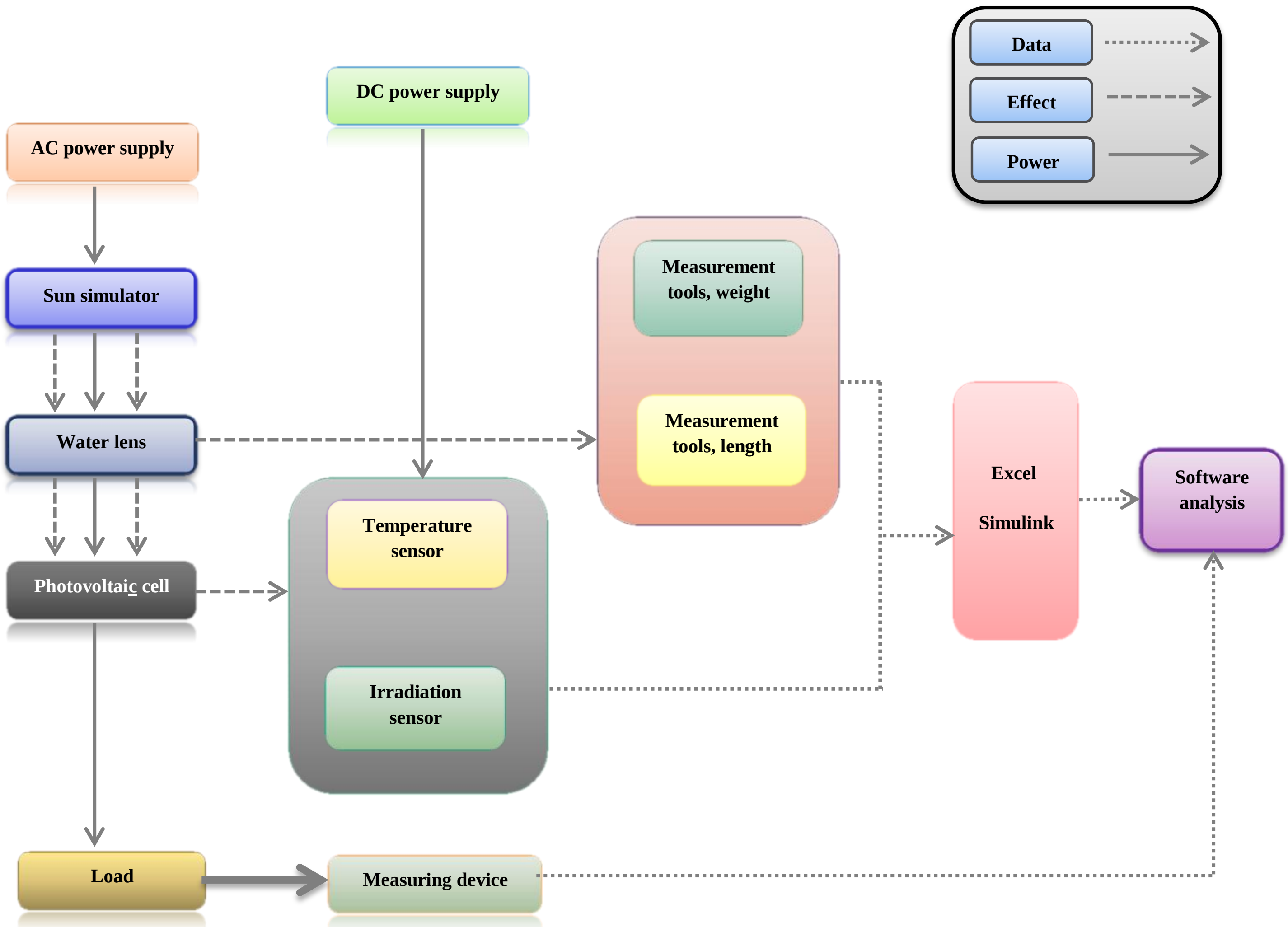

Figure 3.1: Block Diagram Parameter

The data that we need is temperature, irradiation, voltage and current by used of related devices for each one, that will be done after connecting the AC power supply for each device. Also, it should be known the weight of water and lens height each time when we make a new experiment. All the data we obtained it will enter excel to make the analysis and explore the differences between the experiments and come out the results. also, a mathematical model of water lens was done by used of MATLAB, it will give us a clear view about the lens itself and it will be a step for the researchers whom like to do more about this topic in the future.

3.2 Tools and Materials

1. Solar Cell

A thin film solar cell was used to investigate the performance. When the sun is shining brightly on it at a correct angle, it is extremely efficient. So, this solar cell works best in bright sunshine with the sun is shining directly on it. It has a uniform black color because it absorbs most of the light. Thin film solar cell as shown in figure (3.2).

Figure 3.2: Thin film Solar Cell

A. Electrical Characteristics

Table 3.1: Electrical Characteristics of Thin film Cell

Maximum output power	0.2128 W
Maximum power voltage	6.09 V
Maximum power current	0.03846 A
Open circuit voltage	8.28 V
Short circuit current	0.1104 A
Efficiency	4.7%

B. Mechanical Characteristics

Table 3.2: The Mechanical Characteristic of thin film Solar Cell

Size	Length Width	0.05m 0.09m
Weight	Weight	28 g

2. Lamps Sun Simulator

An LED lamp figure (3.3) with 50w was used as a source of irradiation instead of sun rays beam for the indoor experiment, it was connected with a solar cell vertically.

Figure 3.3: 50 W LED lamp

3. Power Supply

It will be used to supply AC power supply for the load.

4. **Digital Multimeter:** to measure volts (1–100 volts) and amps (0.01–10).
5. **Several alligator clip leads:** red, black, one another color.
6. **Light source:** such as a 50-watt incandescent bulb in a gooseneck lamp.
7. **Masking tape.**
8. **Metric ruler or meter.**
9. **Variable resistant.**
10. **Irradiation and temperature sensor.**
11. **Lens:** double stand, plastic foil, wood ring, vicious circle wood to use an effective diameter as lens to avoid any false or error in the result.

3.3 Measurement Instruments

1. **Irradiation Sensor:**

Figure 3.4: TM-206 Solar Power Meter

2. **Temperature Sensor:**

Figure 3.5: Temperature Sensor

3. **Digital Multimeter:**

The Digital Multimeter is an electronic measuring instrument that combines several measurement functions in one unit. A typical Digital Multimeter may include features such as the ability to measure AC and DC voltage, current and resistance. In this experiment, two Multimeters will be used. One used to measure the cells current while the second used to measure the cell voltage.

Figure 3.6: Digital Multimeter Device

CHAPTER 4: MATHEMATICAL MODEL

This chapter will illustrate mathematical modeling of the surface of the water lens.

4.1 Mathematical Model

The stone of project from point of view of author was water lens which is consist of plastic foil LLDPE and wood ring, after pouring the water in it and referring to the weight of water the lens will be formed as shown in figure 4.1.

Figure 4.1: Side View of Water Lens

The aspheric lens height y (vertical axis) is a function of the distance from the optical axis x (horizontal axis) and can be represented by the following equation [148]:

$$y(x) = \frac{cx^2}{1+\sqrt{1-(1+k)c^2x^2}} + \sum_{i=0}^{10} D_{2i}x^{2i} \tag{4.1}$$

Where:

- y: sag of surface parallel to the optical axis
- x : radial distance from the optical axis
- k: Conic constant.
- c: Curvature, inverse of radius
- D_{2i}: are best fit aspheric coefficients.

The first part of equation (4.1) was fitted using MATLAB and gave the following coefficients table (4.1):

Table 4.1: c, k Variables of Aspherical Equation

Variables	Value	Range
c	0.2145	(-36.41, 36.34)
k	0.03372	(-2.095e+05, 2.095e+05)

A conic section k >0 indicates that the surface is an ellipse (surface is an oblate spheroid)

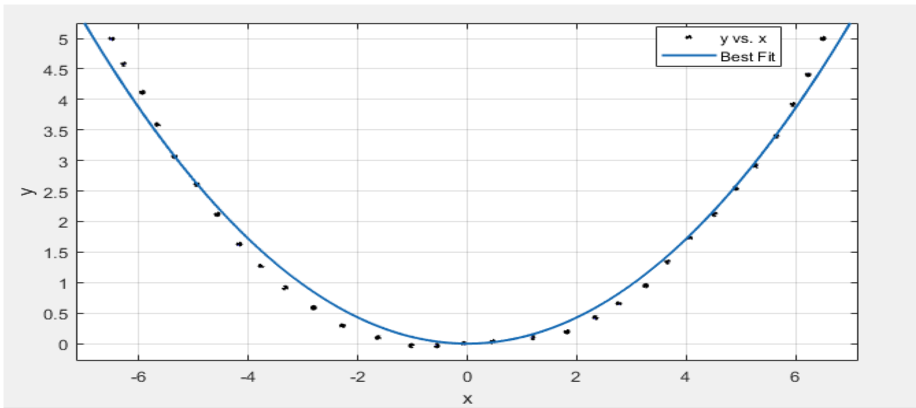

Figure 4.2: Best fit for the first part of equation 4.1

Coefficients (with 95% confidence bounds):

c = 0.2145 (-36.41, 36.84)

k = 0.03372 (-2.095e+05, 2.095e+05)

Goodness of fit:

SSE: 1.426

R-square: 0.9835

Adjusted R-square: 0.9829

RMSE: 0.2145

The best fit for the full equation gives the following Coefficients (with 95% confidence bounds):

Coefficients (with 95% confidence bounds):
D0 = -0.00014 (-0.08373, 0.08345)
D10 = -4.22e-08 (-1.838e-07, 9.94e-08)
D2 = -0.6181 (-3.425e+05, 3.425e+05)
D4 = 0.007789 (-0.00108, 0.01666)
D6 = -0.0003367 (-0.0008974, 0.000224)
D8 = 6.471e-06 (-8.479e-06, 2.142e-05)
c = 1.234 (-4.338e+05, 4.338e+05)
k = 0.8052 (-3.222e+05, 3.222e+05)

Goodness of fit:
SSE: 0.1397
R-square: 0.9984
Adjusted R-square: 0.9979
RMSE: 0.07477

The best fit function and the corresponding x, y data of the aspherical lens according to equation 4.1 are shown in figure (4.3)

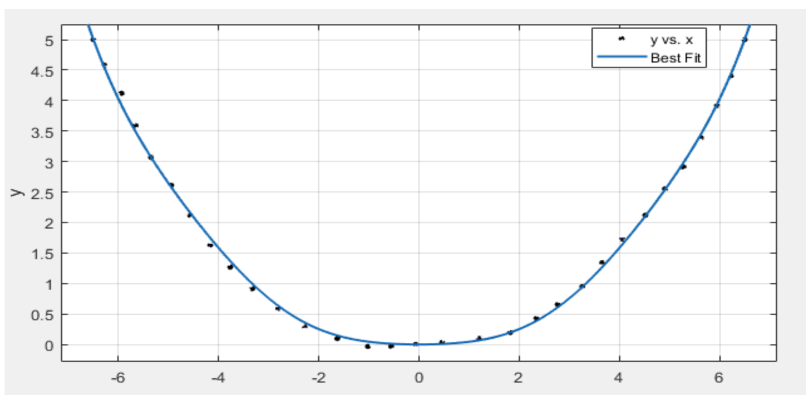

Figure 4.3 Best fit of x, y data of the aspherical lens according to equation 4.1

It should be noted that c and k in this second case are just coefficients for the best fit and are no longer interpreted as the curvature and conic constant of the base surface, respectively.

Furthermore, the scale of all x-axis and y-axis in figure 4.2 and 4.3 are in cm, where the depth of water lens was 5 cm, and then the picture that enters AutoCAD was at same scale to be sure that our estimation was accurate. so we extract from the last software to the Excel software the data point of both x-axis and y-axis, after that we import it to Mat lab. The aspherical lens equation was written on Mat lab, and best fit for first part of equation was applied to extract the value of both c and k, then by substitute the value of both and applied the best fit for all of equation we come out the coefficient and we conclude that the aspheric lens surface has an ellipse(oblate spheroid).

CHAPTER 5: EXPERIMENTAL PROTOTYPE

Experimental work is a very important method to determine the efficiency for PV cell with water lens which concentrate UV radiation. By comparison with other experiments, we were able to select the best experiment to help us conclude the efficiency for PV cell with water lens. It goes without saying that every step taken in this experiment was carried out with utter care and accuracy to give out the best results.

5.1 Aim of Experiment

1. Study the performance of PV with water lens.

2. Study the effect of water lens in several shapes on PV. Shape of water lens changes such water weight changes. In this experiment, two shapes of water were employed.

It is worth mentioning that from previous study as in literature review use water lens as a filter of light to produce a UV & IR radiation which was approved. UV, which is filter out of the water, purifies and treats the water. At the same time, water in normal cases (figure 5.1) will completely absorb IR radiation.

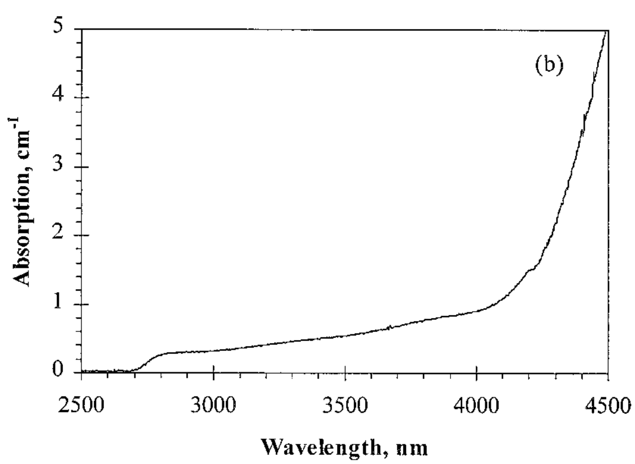

Figure 5.1: Typical absorption curve

3. Investigate parameter of PV performance.

5.2 Prototype

Figure 5.2 is an experimental prototype. It consists of two stands, one with two layers, first to hold a light bulb and the second layer to hold a water lens. Second stand for PV cell which could control the distance between the cell and water lens. There was a long ruler along a column of the first stand to estimate the distance between light source and the detector position which is PV cell, normally there was two distant 30cm and 70cm. The measurement of the device connected to the PV cell as shown in figure (5.3) which is an equivalent circuit for PV cell.

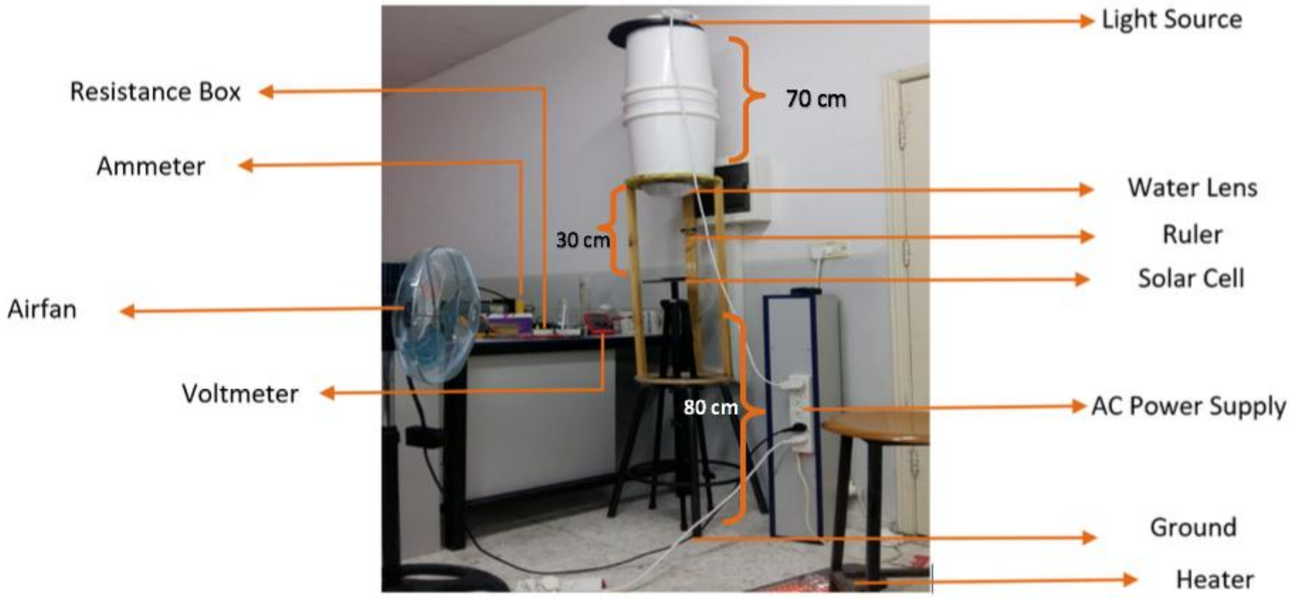

Figure 5.2: Experimental Prototype

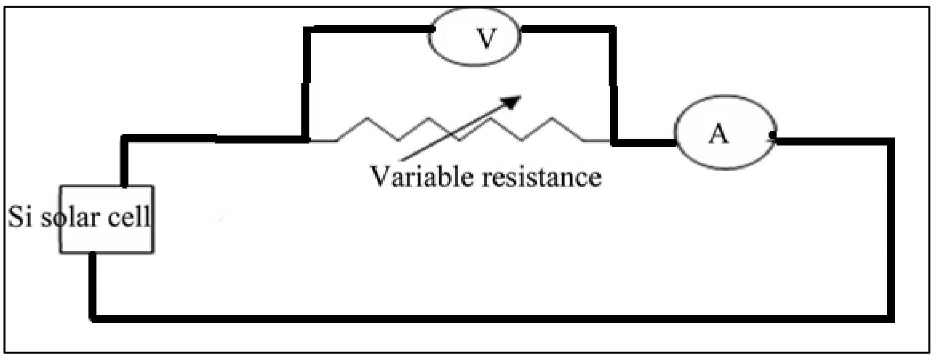

Figure 5.3: Connection diagram for PV Cell

Water lens consists of a plastic foil, which could contain water so water lens could become ready to use as a concentrator for light. The thickness of the lens fixed on 2.5cm and 5cm for every case of experiment.

We came up with results about the focal point, focal length at which could cover the PV cell area at 30cm for both 2 thickness of lens. It is worth mentioning that the temperature of the PV cell was taken for every reading of (V) and (I), and we control it by heater and fan to be 20° C at every reading regarding to our hypothesis.

We assume that the experimental set up such as figure (5.4) drawn by word software, so we can see double stand, light source, water lens, PV cell and meter, so we can control the distance between the lens and PV cell.

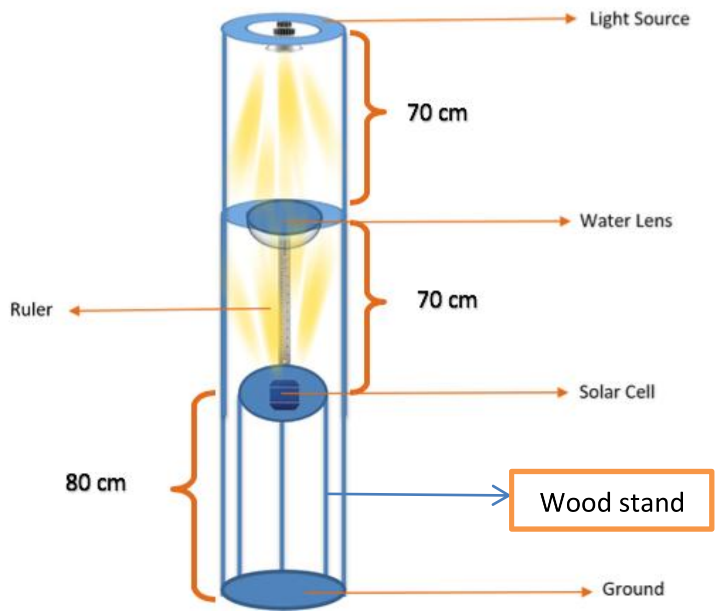

Figure 5.4: Prototype WPVC of experimental setup

5.3 Experiment Procedure

Figure 5.4 is an experimental prototype. It consists of two stands, one with two layers, first to hold a light bulb, second layer to hold water lens itself, the measurement of the device connected to the PV cell 5cm* 9cm, that hold by other stand.

1. V_{OC}, I_{SC} could measure for the cell and the result could be compared without water lens WL of the cell detector position 30cm and 70cm. For V_{OC} connecting parallel voltmeter with PV, and for I_{SC} connecting series ammeter and PV.
2. Set the light source to obtain I_{SC} and V_{OC} at WL condition.
3. The temperature of the cell could be 20ºc by thermometer for PV test device.
4. Take the reading of voltmeter and ammeter.
5. After connecting the circuit of PV as figure (5.4), reading of (V) and (I) was taken as resistance variable.

6. Max current I_m and max voltage V_m could be found from measuring device, with Excel max-function for all data of current and voltage.

   $P_{max} = V_m * I_m$. (5.1)

   Where:

   - V_m: maximum value of volt measured when load varying.
   - I_m: maximum value of ampere measured when load varying.
7. Fill factor could be calculated by the equation 2.2 as was mentioned.
8. Maximum efficiency of PV cell could be measured by the equation:

   $$\eta(\eta\ max) = \frac{Pmax\{\ maximum\ output\ power\}}{E\{incident\ irradiation\ flux\} * Ac\ \{area\ of\ collector\}} \quad (5.2)$$

   The result of this experiment could be used as a reference to other cases.
9. The performance of PV cell at different value of focal point with Different liquid lens.
   A. At focal spot.
   B. At suitable detector position, that covers PV cell area.

   Procedure of experiment for Water lens photovoltaic concentrator system (WPVC).

   1. Connect the lamp.
   2. Measure the distance after light source alarm between PV cell and light source.
   3. Measure the intensity of light by W/m^2 measurement device, to notice how the difference could be in intensity while water lens exist.
   4. Take in account that the temperature of solar cell could be estimated by thermometer also controlled on 20° C by using of electrical heater for the environment of experiment and air fan too.
   5. Connect the circuit of PV cell and two digital multimeters {voltmeter, ammeter}.
   6. Measure V_{OC} and I_{SC} for the cell.
   7. Change the value of variable resistor module and measure V & I for different range of R and plot I-V and P-V curve by Excel.
   8. Repeat previous step several times at different distance at different lens of Oil lens OL, Tap Water Lens TWL according to that result with water lens experiment to make a comparison between them at different thickness and detector position.
   9. Estimate FF and efficiency for every case (length, W/m^2, I_{SC}, V_{OC}, P_{max}, FF, η, Temp).

Finally, it is important to state that Blackbody space radiation is an expression used to characterize the relationship between a body's, object's and substance's temperature, and the wavelength of electromagnetic radiation it releases. When electromagnetic radiation comes in contact with a black body, it will absorb all electromagnetic radiation so a black body could be an ideal object. Then, it emits thermal radiation in a continuous spectrum according to its temperature after reaching 1000 Kelvin, there is an appositive relationship between spectrum and fourth order to temperature in normal cases, regardless the material of the blackbody. As shown in figure (5.5), the solar radiation is almost identical to that of the black body radiator at about 5,800 K. As the sun travels and passes through the atmosphere, the sun is weak by dispersion and absorption; the more atmospheric it passes, the weaker it becomes.

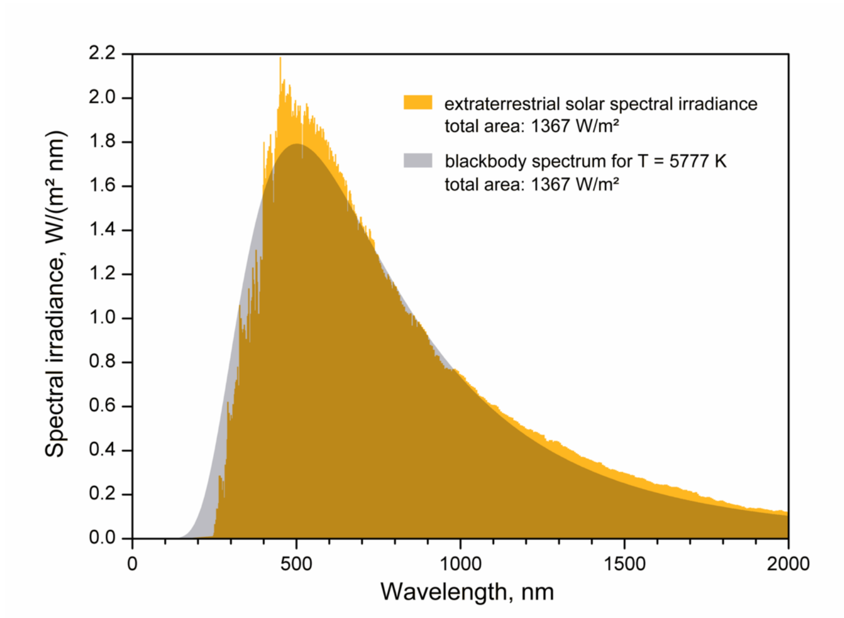

Figure 5.3: The sun spectrum and its relation to blackbody radiation

CHAPTER 6: RESULTS AND ANALYSIS

In this chapter, general experiments for a point focus water lens PV Concentrator (WPVC) system were conducted. In addition, the changes in the PV cell parameter open circuit voltage (V_{OC}), short circuit current (I_{SC}), maximum power (P_{max}) and efficiency (η) of PV cell will be shown in this chapter. It is worth mentioning that all of the experiment was done in the same environmental conditions, as temperature and room is completely isolated from external light. The open circuit voltage was the maximum reading in data which was extracted from practical experiment, and it could decrease as short circuit current increase when variable resistance changes from maximum to minimum value.

6.1 The performance of PV cell with different lens at 2.5cm thickness, and at different detector positions (DP).

In this section, the performance of the PV cell at different detector position (DP) with water lens while the thickness of the lens was 2.5cm which has been investigated. The analysis dealt with the effect of water lens on the open circuit voltage V_{OC}, short circuit current I_{SC}, maximum power and efficiency of PV cell.

a. Detector position 30 cm:

Figures (6.1) and (6.2) illustrated I-V and P-V curves respectively at 30 cm detector position and 2.5 cm thickness (thick) of tap water lens (TWL), distilled water lens (DWL), Oil lens (OL) and without lens (WL) that 30 cm from detector position. The analysis dealt with the effect of different kind of lens on V_{OC}, I_{SC}, P_{max} and η of PV cell. From the experiment we conclude that TWL gives the best reading when it was compared with the rest in this case while thick 2.5 cm. The efficiency for the TWL, OL, WL and DWL is 5.47%, 3.12%, 2.42% and 0.78% respectively. Depending on the results, WL as water lens could increase the intensity of light so the efficiency could increase too, P_{max} increased to 126.28% of TWL and 28.90% of OL, decreased to -67.65% of DWL. All data (I, V, P, η, FF) can be founding appendix A.

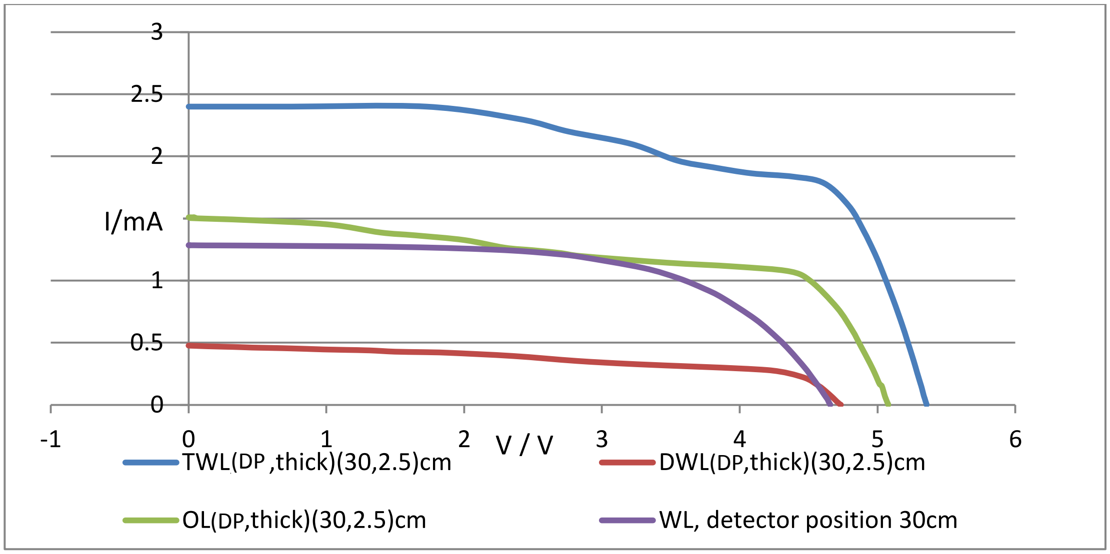

Figure 6.1: I-V curve of WCPVS cell, thick 2.5cm of different lens detector position:30 cm and without lens

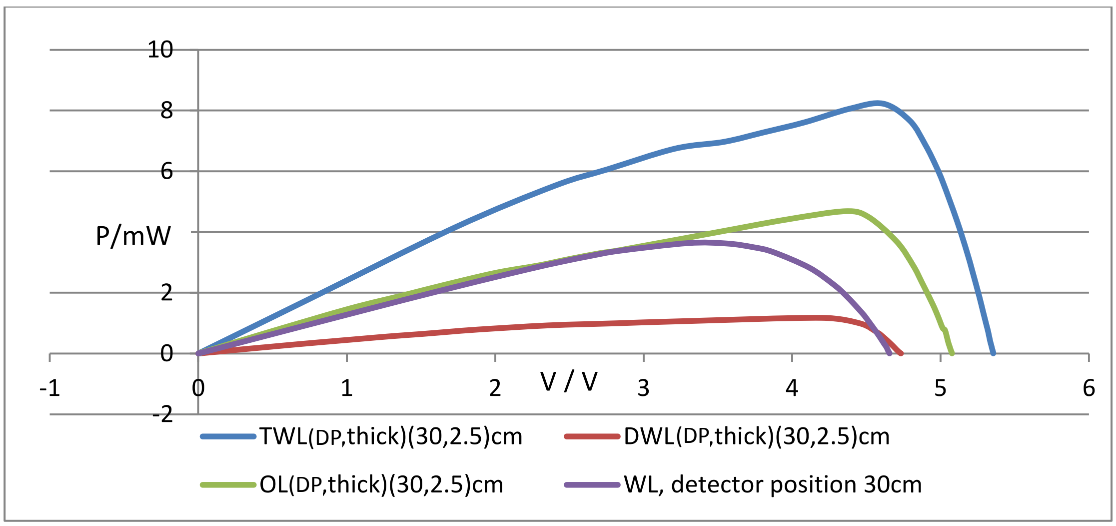

Figure 6.2: P-V curve of WCPVS cell, thick 2.5cm of different lens detector position:30 cm and without lens.

b. Detector position 70 cm:

Figures (6.3) and (6.4) illustrated I-V and P-V curves respectively at detector position: 70cm and thick: 2.5 cm of (TWL (DWL), (OL) and (WL) that 70 cm from detector position. The analysis dealt with the effect of different kind of lens on the open circuit voltage V_{oc}, short circuit current I_{sc}, maximum power P_{max} and efficiency Ƞ of PV cell. From the experiment, we conclude that TWL gives us the best reading when compared with the rest. However, there is no scientific explanation for this result. The efficiency for the TWL, DWL, OL, WL is 2.74%, 1.96%, and 1.01% respectively. Depending on the results WL as water lens could increase the intensity of light so the efficiency could increase too, in case of TWL, DWL, and OL P_{max}

increased to 171.89%, 94.50%, and 1.40% respectively. All data (I, V, P, Ƞ, FF) can be found in appendix A.

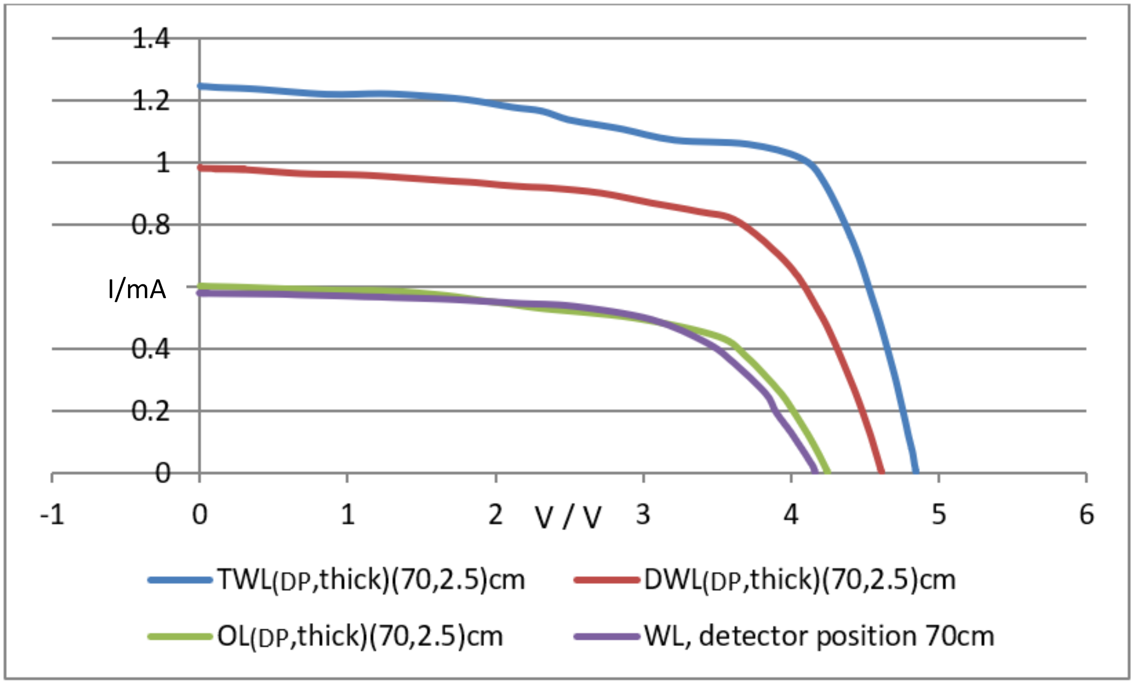

Figure 6.3: I-V curve of WCPVS cell, thick 2.5cm of different lens detector position:70 cm and without lens

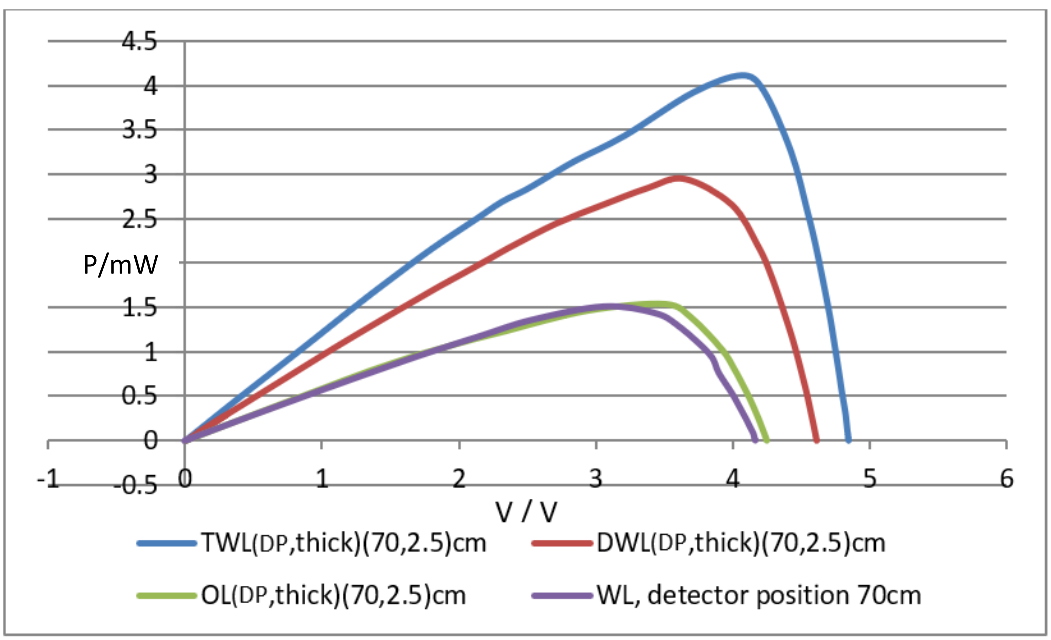

Figure 6.4: P-V curve of WCPVS cell, thick 2.5cm of different lens detector position:70 cm and without lens

6.2 The Performance of PV Cell with Different Lens at 5cm Thickness and at Different Detector Positions.

In this section, the performance of the PV cell at different detector position with water lens while the thickness of the lens was 5cm which has been investigated. The analysis dealt with the effect of water lens on the open circuit voltage V_{OC}, short circuit current I_{SC}, maximum power and efficiency of PV cell.

a. Detector position 30cm:

Figures (6.5) and (6.6) illustrated I-V and P-V curves respectively at 30cm detector position and 5cm (thick) of (TWL), (DWL), (OL) and (WL) that 30cm from detector position. The analysis dealt with the effect of different kinds of lens on V_{OC}, I_{SC}, P_{max} and Ƞ of PV cell. From the experiment we conclude that DWL gives the best reading when compared with the rest in this case while thickness of the lens is 5cm; as they didn't have any plankton or salts. The efficiency for the DWL, TWL, WL, and OL is 9.80%, 6.36%, 2.42%, and 1.91% respectively. Depending on the results, WL as water lens could increase the intensity of light so the efficiency could increase too, in case of DWL and TWL P_{max} increased to 305.33% and 163.09% respectively and decreased to 21.06% in OL. All data (I, V, P, Ƞ, FF) can be found in appendix A.

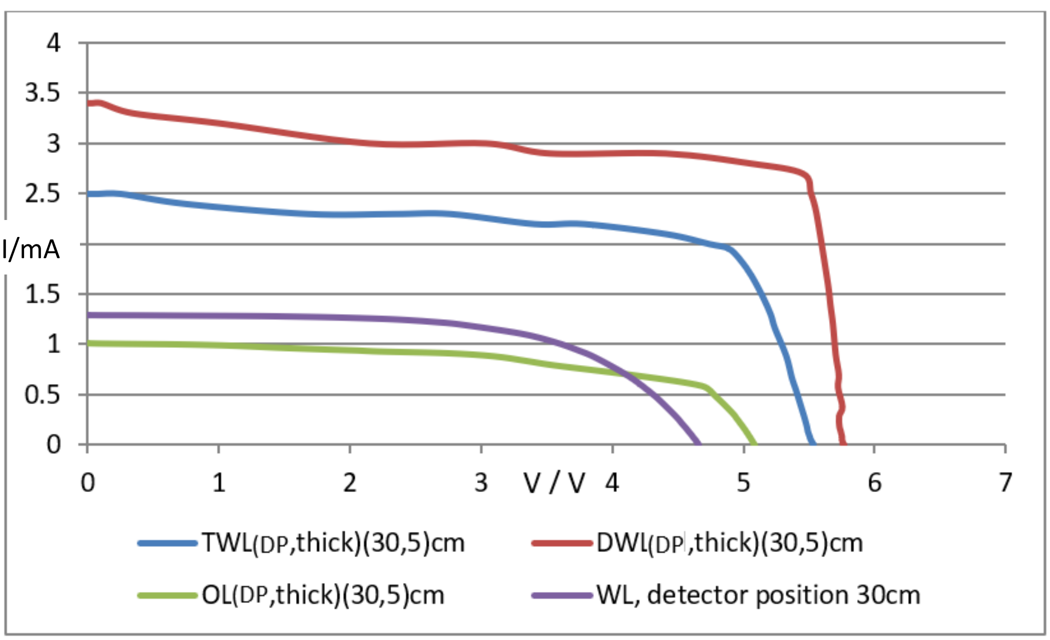

Figure 6.5: I-V curve of WCPVS cell, thick 5cm of different lens detector position:30 cm and without lens

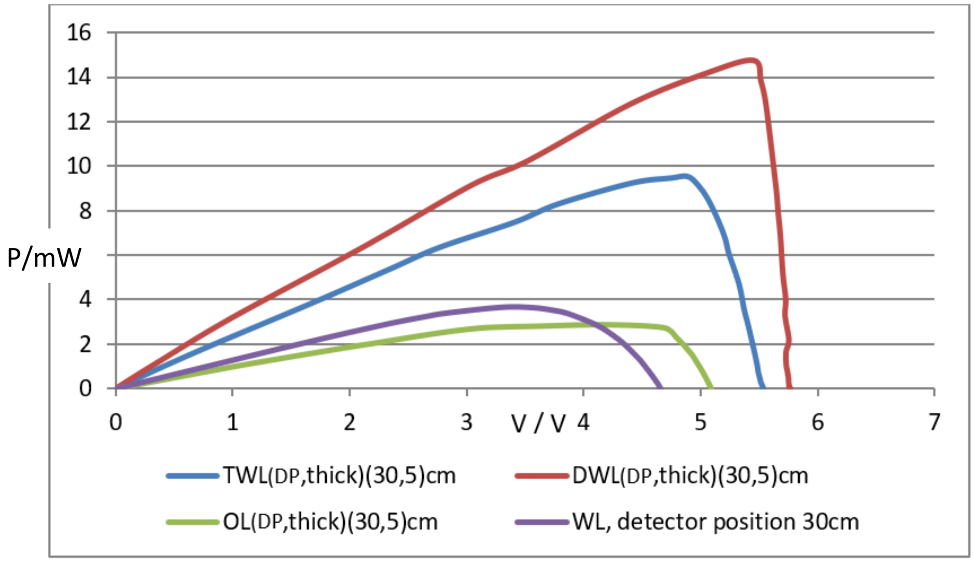

Figure 6.6: P-V curve of WCPVS cell, thick 5cm of different lens detector position:30 cm and without lens

b. Detector position 70cm:

Figures (6.7) and (6.8) illustrated I-V and P-V curves respectively at 70cm detector position and 5cm (thick) of (TWL), (DWL), (OL) and (WL) that 30cm from detector position. The analysis dealt with the effect of different kinds of lens on V_{OC}, I_{SC}, P_{max} and Ƞ of PV cell. From the experiment, we conclude that DWL gives the best reading when compared with the rest in this case while the thickness of the lens is 5cm; as they didn’t have any plankton or salts. The efficiency for the DWL, TWL, OL, and WL is 8.47%, 5.32%, 2.81% and 1.01% respectively. Depending on the results, WL as water lens could increase the intensity of light so the efficiency could increase too, in case of DWL, TWL and OL P_{max} increased to 739.79%, 427.82%, and 178.54% by compared to without lens experiment. All data (I, V, P, Ƞ, FF) can be found in appendix A.

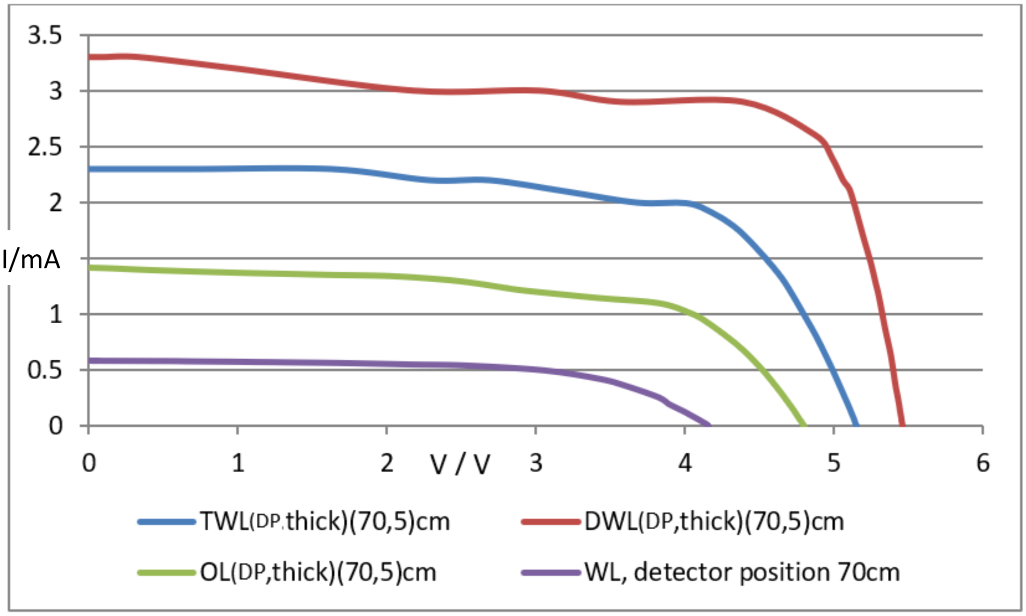

Figure 6.7: I-V curve of WCPVS cell, thick 5cm of different lens detector position:70 cm and without lens

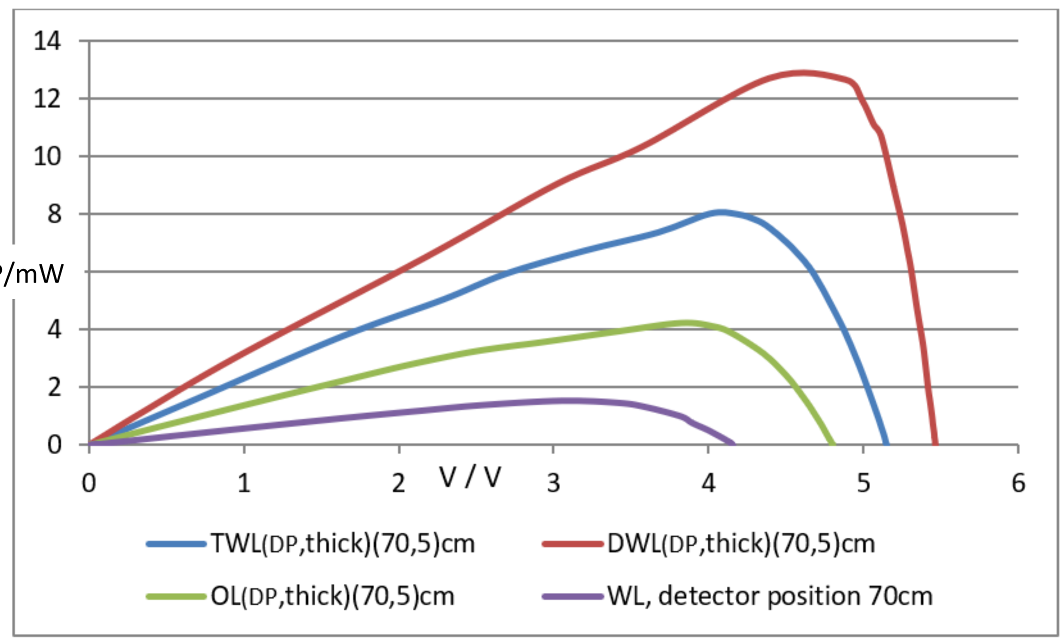

Figure 6.8: P-V curve of WCPVS cell, thick 5cm of different lens detector position:70 cm and without lens

6.3 The Performance of PV Cell with DWL at 5cm Thickness and at Different Detector Positions

A very important point was while a series of other experiments of DWL with a lens of 5cm thickness got, figures (6.9) and figures (6.10) illustrated I-V and P-V curves respectively, three scenarios. First scenario was while detector position at focal spot, more than focal spot and less than focal spot at that point when the light could cover all the PV cell area. Focal spot was at 26cm by experiment, V_{oc} is 5.56 V and I_{sc} is 1.095 mA and P_{max} is 3.128 mW the efficiency is 2.08% which is the lowest reading in the last cases because the light didn't cover all the area of the PV cell led to a drop in efficiency.

The next scenario was while detector position more than focal spot at 57cm V_{oc} is 5.55 V and I_{sc} is 5.1 mA and P_{max} is 20.019 mW and the efficiency are 13.32%, we concluded that this scenario is better than the previous case because the light covers all the area of PV cell. P_{max} increased to 540.09%.

The final scenario was while detector position less than focal spot at 10cm V_{oc} is 5.604 V and I_{sc} is 7.3 mA and 25.677 mW of maximum power and efficiency of 17.08% which is the best scenario that gives the best efficiency where there is no plankton or salts in distilled water that could scatter the radiation or absorb it. P_{max} increased to 720.98%.

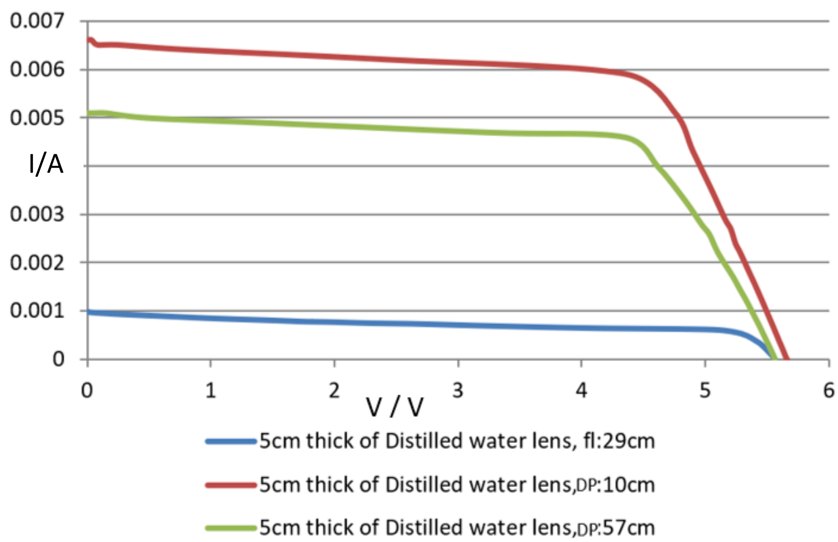

Figure 6.9: I-V curve of DWL of PV cell, thick 5cm of different detector position.

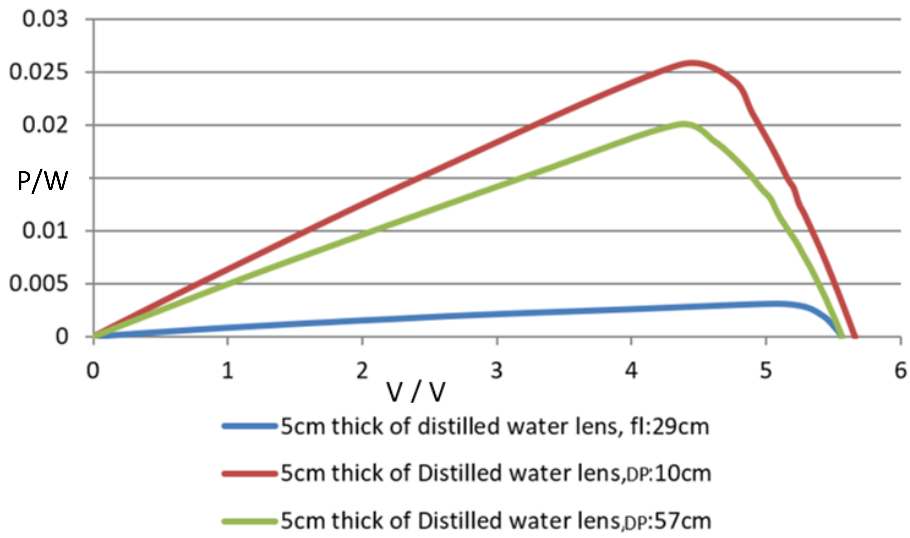

Figure 6.10: P-V curve of DWL of PV cell, thick 5cm of different detector position.

This thesis provides a wide range of valuable information and data that wasn't available before in any previous study. A lot of data was extracted from previous experiments talking about different concentrators. The researcher here added new types that could be useful to other researchers and academics.

In this tjesis, we passionately worked on several experiments, using different types of lenses, to prove that water lens can be used as a concentrator of sunlight with photovoltaic cell.

The researcher has foreseen that the method of water lens as a concentrator of sun light could increase the intensity of radiation when it hits the PV cell surface, because the optical properties of water itself absorb IR radiation and filter out UV radiation. Also, the researcher has foreseen that the intensity of light increased when the lens thickness increased.

Small amount of energy loss in visible spectrum, moderate in UV range and greater in IR region, these properties of water itself could enhance the efficiency of thin film photovoltaic device. Maximum water volume V_{max} was at 660ml, it shows the best performance for the investigated water lens systems as a concentration of light on thin film solar cell because it demonstrates maximum intensity. Smallest focal length and maximum lens height increased when the radius increased. An increase in water height led to larger aperture and more curvature, whereas lowest water volume led to lowest lens height from ground surface as reference. When the diameter is extended as a result of increasing volume of water then subjected to more amount of solar radiation; more energy of solar as well as more volume of water pretend higher concentration ability causing an up shift in the intensity profile.

The concentration of light comes as a result of intensity spectrum, led to absorption loss so higher intensity can be caused by higher water volume.

6.4 Errors Affect the Experiments

Every time an experiment is done, experimental errors could occur because the measurements may vary from time to time; hence we can’t take any physical quantity and measure it with a perfect certainty. For instance, if we measure some quantity, and repeat the measurement again, we will most probably have a different value.

In this experiment, the researcher took greater care when taking measurements and applied more refined experimental methods, in order to reduce the amount of errors that may occur. In addition to that, she recorded a lot of readings to make the results more precise and accurate as much as possible to make sure the measurements are closer to the true value.

The kinds of errors that faced the researcher during the experiments can be illustrated in two cases:

1. Human errors: which lead to an error in the experiment itself, such as incorrect wiring in the multimeter or voltmeter devices or connecting with the wrong terminal of the solar cell during the experiment procedure.
2. Systematic errors: while it is known that the equipment used in the experiment will never be 100% accurate, but it should give very close values. That is why it is very important to check the equipment and utilize it in the analysis of the data, which done by testing multimeter with known resistance, and reduce the leak from wires, resistors in the multimeter, and thermometer.

CHAPTER 7: CONCLUSION & RECOMMENDATIONS

7.1 Conclusion

The effects of water lens as a concentrator on PV cell were investigated at radiation G=33.4 W/m^2). A series of intensive and rigorous experiments were conducted in order to investigate the effect of the lens as a function of volume and focal length on the performance of PV cell. First, the PV cell was tested without a lens WL at 30cm and 70cm detector position. This case was used for comparison purpose. The PV characteristic, the I-V and P-V curves were evaluated. It was found that the I_{sc} is 1.284 mA and V_{oc} is 4.67 V and I_{sc} is 0.591 mA V_{oc} is 4.16 V respectively and efficiency is 2.42% and 1.01% respectively too.

Then, the performance of PV cell at different lens distilled water lens (DWL), tap water lens (TWL), and oil lens (OL) has been investigated with 2.5cm and 5cm thickness and at two detector positions, one 30cm and the other is 70cm. The analysis targets the effect of these lenses on the open circuit voltage V_{oc} short circuit current I_{sc}, maximum power and efficiency of PV cell. It has been found that when one uses DWL, one concludes that an increase in thickness of lens could increase the intensity of light. more power and efficiency could result-at thickness 5cm while fl:30cm, and 70cm the V_{oc} was 5.77 V and 5.461 V respectively, I_{sc} 3.48 mA and 3.4 mA respectively, the efficiency was 9.80% and 8.47% and P_{max} was 14.7312 mW and 12.725 mW respectively, so V_{oc} could increase when the distance is lower because the intensity of light is more.

However, while thickness was 2.5cm, fl:30cm and 70cm the V_{oc} was 4.84 V and 4.608 V respectively, I_{sc} 0.748 mA and 1.02 mA respectively, the efficiency was 0.78% and 1.96%, P_{max} was 1.17572 mW and 2.947 mW respectively. In this case, the efficiency was more at 70cm detector position while the light covered the full area of PV cell and the characteristic of the lens at 2.5cm gives this performance for the PV cell. We conclude that efficiency was more when thickness is 5cm at 30cm fl because The Aura of light covers all the area of PV cell.

After that, when using TWL, it was concluded that an increase in thickness of lens, could increase in the intensity of light so more power and efficiency could result.

At thickness 5cm while fl:30cm and 70cm, the V_{oc} was 5.53 V and 5.15 V respectively, I_{sc} 2.5 mA and 2.3 mA respectively, the efficiency was 6.36% and 5.32% and P_{max} was 9.562 mW and 7.998 mW respectively, so V_{oc} could increase when the distance is lower because the intensity of light is more. But while thickness was 2.5cm while fl:30cm and 70cm the V_{oc} was 4.7 V and 4.8 V respectively, I_{sc} 2.5 mA and 1.3 mA respectively, the efficiency was 5.47% and 2.74% and P_{max} was 8.224 mW and 4.12 mW respectively. In this case, the efficiency was more at 30cm detector position and in both cases of thickness, while the characteristic of this lens at 5cm thick gives the performance for the PV cell more than at 2.5cm.

Another point to be concluded is that when using OL that increases in thickness of the lens and increase the intensity of light, so more power and efficiency could result. At thickness 5cm while fl:30cm and 70cm the V_{oc} was 5.11 V and 4.83 V respectively, I_{sc} 1.016 mA and 1.431 mA respectively, the efficiency was 1.91% and 2.81% and P_{max} was 2.86896 mW and 4.221 mW respectively. So, V_{oc} could increase when the distance is lower because the intensity of light is more. When thickness was 2.5cm while fl:30cm and 70cm the V_{oc} was 5.08 V and 430 V respectively, I_{sc} 1.51 mA and 0.635 mA respectively, the efficiency was 3.12% and 1.02% and P_{max} was 4.685 mW and 1.536504 mW respectively. In this case OL, the efficiency was more at 70cm detector position because the aura of light covers the PV cell at this thickness, while the characteristic of this lens at 2.5cm and fl: 30cm gives the best results on the performance for the PV cell.

According to that case without lens (WL) which was a base for comparison with the (TWL), (DWL), (OL).

1. 2.5cm thick, detector position:30cm
   Efficiency increased to 126.28% of TWL and 28.90% of OL, decreased to -67.65% of DWL
2. 2.5cm thick, detector position:70cm
   In case of TWL, DWL, and OL efficiency increased to 171.89%, 94.50%, and 1.40% respectively.
3. 5cm thick, detector position:30cm
   In case of DWL and TWL efficiency increased to 305.33% and 163.09% respectively and decreased to 21.06% in OL.
4. 5cm thick, detector position:70cm
   In case of DWL, TWL and OL efficiency increased to 739.79%, 427.82%, and 178.54% respectively.
5. Finally, the result of DWL at thickness of 5cm as the best lens that effects on the performance of PV cell gives higher efficiency for the rest. Most importantly, 2.5cm thick, detector position:30cm

Efficiency increased to 126.28% of TWL and 28.90% of OL, decreased to -67.65% of DWL

6. 2.5cm thick, detector position:70cm

   In case of TWL, DWL, and OL efficiency increased to 171.89%, 94.50%, and 1.40% respectively.

7. 5cm thick, detector position:30cm

   In case of DWL and TWL efficiency increased to 305.33% and 163.09% respectively and decreased to 21.06% in OL.

8. 5cm thick, detector position:70cm

   In case of DWL, TWL and OL efficiency increased to 739.79%, 427.82%, and 178.54% respectively.

Focal spot was at 26cm V_{oc} is 5.56 V and I_{sc} is 1.095 mA and P_{max} is 3.128 mW the efficiency is 2.08% which is the lowest reading in the last cases because the light didn't cover all the area of PV cell, so some shading happened which led to a drop in efficiency.

The next scenario was while the detector position was more than the focal spot at 57cm V_{oc} is 5.55 V and I_{sc} is 5.1 mA and P_{max} is 20.019 mW and the efficiency were 13.32%. We concluded that this scenario is better than the previous case because the light covers all the area of PV cell.

The final scenario while the detector position was less than the focal spot at 10cm. V_{oc} is 5.604 V and I_{sc} is 7.3 mA and 25.677 mW of maximum power and efficiency of 17.08%. This is the best scenario that gives the best efficiency where there is no plankton or salts in the distilled water which scatter the radiation or absorb it.

7.2 Recommendations

The result of this study focuses on electrical output. Based on that, we recommend the following:

1. Apply the concentrating system on PV panel.
2. Design a tracking system in order to perform the experiment outdoors.
3. Investigate concentrated thermal as a thermal technology.
4. Design a cooling system to avoid rising temperature of PV panel.
5. Make an economical study to clarify how much it would cost using DWL system when the experiment is applied outdoors with a PV panel.
6. Use spectrometer to estimate the percentage of IR radiation filtered by the water lens that refers to whole irradiation hit PV cell.

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Appendix A: Experimental data

Table A1: Without lens DP:30cm

Without lens 30cm		
P mW	V	I mA
0.001285	0.001	1.285
0.00771	0.006	1.285
0.001669	0.0013	1.284
0.050076	0.039	1.284
0.164224	0.128	1.283
0.491006	0.383	1.282
1.138698	0.891	1.278
1.610325	1.263	1.275
1.920481	1.511	1.271
2.370036	1.878	1.262
2.78304	2.23	1.248
3.014635	2.441	1.235
3.217536	2.646	1.216
3.382896	2.838	1.192
3.634396	3.298	1.102
3.622044	3.558	1.018
3.499704	3.739	0.936
3.336375	3.875	0.861
2.827692	4.116	0.687
2.28766	4.276	0.535
1.910994	4.363	0.438
1.337128	4.472	0.299
1.026267	4.521	0.227
0.69464	4.57	0.152
0.523716	4.594	0.114
0.305118	4.623	0.066
0.213256	4.636	0.046
0.106858	4.646	0.023
0.06975	4.65	0.015
0.051172	4.652	0.011
0.027924	4.654	0.006
0.018624	4.656	0.004
0.009314	4.657	0.002
0.004657	4.657	0.001

Table A2: without lens DP:70cm

Without lens 70cm		
P mW	V	I mA
0	0	0.582
0.001746	0.003	0.582
0.003492	0.006	0.582
0.009894	0.017	0.582
0.033174	0.057	0.582
0.009935	0.0171	0.581
0.230442	0.398	0.579
0.325414	0.563	0.578
0.388224	0.674	0.576
0.482734	0.841	0.574
0.576004	1.007	0.572
0.63555	1.115	0.57
0.695887	1.223	0.569
0.755811	1.333	0.567
0.935168	1.664	0.562
1.070595	1.929	0.555
1.191352	2.174	0.548
1.36367	2.53	0.539
1.51528	3.055	0.496
1.441925	3.425	0.421
1.290232	3.604	0.358
0.975885	3.827	0.255
0.766921	3.893	0.197
0.53466	3.99	0.134
0.407636	4.036	0.101
0.241546	4.094	0.059
0.168797	4.117	0.041
0.087024	4.144	0.021
0.0581	4.15	0.014
0.04153	4.153	0.01
0.024924	4.154	0.006
0.016624	4.156	0.004
0.008316	4.158	0.002
0.00416	4.16	0.001

Table A3: oil lens, thick: 2.5cm, DP:70cm

2.5 oil lens 70		
P mW	V	I mA
0	0	0.601
0.001803	0.003	0.601
0.003606	0.006	0.601
0.010818	0.018	0.601
0.036	0.06	0.6
0.142324	0.238	0.598
0.28215	0.475	0.594
0.34928	0.59	0.592
0.417837	0.707	0.591
0.519204	0.883	0.588
0.621046	1.058	0.587
0.684442	1.166	0.587
0.74529	1.274	0.585
0.803957	1.379	0.583
0.95475	1.675	0.57
1.05228	1.896	0.555
1.138671	2.097	0.543
1.221461	2.309	0.529
1.463622	2.939	0.498
1.536504	3.508	0.438
1.373442	3.702	0.371
1.026516	3.918	0.262
0.805809	4.009	0.201
0.55692	4.095	0.136
0.426008	4.136	0.103
0.2511	4.185	0.06
0.176568	4.204	0.042
0.088746	4.226	0.021
0.059262	4.233	0.014
0.046607	4.237	0.011
0.025446	4.241	0.006
0.016968	4.242	0.004
0.008488	4.244	0.002
0.004246	4.246	0.001

Table A4: oil lens, thick: 2.5cm, DP:30cm

2.5 oil lens 30		
P mW	V	I mA
0.001509	0.001	1.509
0.010563	0.007	1.509
0.024144	0.016	1.509
0.069368	0.046	1.508
0.022695	0.0151	1.503
0.665728	0.448	1.486
1.469424	1.012	1.452
1.932091	1.393	1.387
2.24378	1.645	1.364
2.653326	2.001	1.326
2.900645	2.293	1.265
3.112488	2.502	1.244
3.300363	2.703	1.221
3.40232	2.84	1.198
3.96968	3.47	1.144
4.410819	3.963	1.113
4.684788	4.362	1.074
4.49342	4.516	0.995
3.676167	4.707	0.781
2.8902	4.817	0.6
2.372664	4.872	0.487
1.63251	4.947	0.33
1.240518	4.982	0.249
0.837505	5.015	0.167
0.764712	5.031	0.152
0.363816	5.053	0.072
0.25806	5.06	0.051
0.126725	5.069	0.025
0.086224	5.072	0.017
0.065962	5.074	0.013
0.035532	5.076	0.007
0.02538	5.076	0.005
0.015231	5.077	0.003
0.005078	5.078	0.001

Table A5: Distilled water lens, thick: 2.5cm, DP:70cm

2.5 Distilled lens 70		
P mW	V	I mA
0.000986	0.001	0.986
0.004915	0.005	0.983
0.00983	0.01	0.983
0.2943	0.3	0.981
0.096138	0.098	0.981
0.287826	0.294	0.979
0.654948	0.678	0.966
0.923517	0.959	0.963
1.10112	1.147	0.96
1.352322	1.422	0.951
1.59198	1.69	0.942
1.744694	1.862	0.937
1.886799	2.031	0.929
2.037061	2.207	0.923
2.185382	2.378	0.919
2.446227	2.709	0.903
2.65655	3.05	0.871
2.842596	3.372	0.843
2.947187	3.643	0.809
2.656008	3.988	0.666
2.186663	4.181	0.523
1.8404	4.28	0.43
1.293894	4.401	0.294
0.998592	4.458	0.224
0.6768	4.512	0.15
0.512794	4.538	0.113
0.29692	4.568	0.065
0.21068	4.58	0.046
0.105662	4.594	0.023
0.068985	4.599	0.015
0.055212	4.601	0.012
0.032221	4.603	0.007
0.023025	4.605	0.005
0.009212	4.606	0.002
0.004607	4.607	0.001

Table A6: Distilled waterless, thick: 2.5cm, DP:30cm

2.5 Distilled3 lens 30		
P mW	V	I mA
0	0	0.477
0.000954	0.002	0.477
0.002385	0.005	0.477
0.00714	0.015	0.476
0.022325	0.047	0.475
0.066882	0.142	0.471
0.152382	0.327	0.466
0.21206	0.46	0.461
0.251991	0.549	0.459
0.310536	0.681	0.456
0.36612	0.81	0.452
0.400957	0.893	0.449
0.436188	0.978	0.446
0.471528	1.062	0.444
0.506532	1.146	0.442
0.576408	1.316	0.438
0.640716	1.497	0.428
0.719104	1.696	0.424
0.790234	1.886	0.419
0.925515	2.355	0.393
0.996166	2.822	0.353
1.062423	3.249	0.327
1.17572	4.199	0.28
0.993911	4.457	0.223
0.695248	4.574	0.152
0.53107	4.618	0.115
0.308088	4.668	0.066
0.220242	4.686	0.047
0.108284	4.708	0.023
0.075456	4.716	0.016
0.056628	4.719	0.012
0.033075	4.725	0.007
0.02364	4.728	0.005
0.009462	4.731	0.002
0.004734	4.734	0.001

Table A7: Tap water lens, thick: 2.5cm, DP:70cm

2.5 Tap lens 70cm		
P mW	V	I mA
0.001247	0.001	1.247
0.00747	0.006	1.245
0.016185	0.013	1.245
0.04731	0.038	1.245
0.154008	0.124	1.242
0.460164	0.372	1.237
1.04432	0.856	1.22
1.48473	1.215	1.222
1.769518	1.454	1.217
2.1654*	1.8	1.203
2.492648	2.116	1.178
2.694626	2.311	1.166
2.83362	2.49	1.138
3.009204	2.682	1.122
3.169341	2.863	1.107
3.443264	3.212	1.072
3.925713	3.707	1.059
4.119882	4.063	1.014
3.95414	4.22	0.937
3.263436	4.422	0.738
2.576448	4.544	0.567
2.135356	4.612	0.463
1.475172	4.698	0.314
1.127168	4.736	0.238
0.759066	4.774	0.159
0.570248	4.792	0.119
0.332442	4.818	0.069
0.231648	4.826	0.048
0.116016	4.834	0.024
0.077408	4.838	0.016
0.058068	4.839	0.012
0.033873	4.839	0.007
0.02421	4.842	0.005
0.009686	4.843	0.002
0.004843	4.843	0.001

Table A8: Tap water lens, thick: 2.5cm, DP:30cm

2.5 Tap lens 30cm		
P mW	V	I mA
0.0024	0.001	2.4
0.0264	0.011	2.4
0.0624	0.026	2.4
0.1824	0.076	2.4
0.5976	0.249	2.4
1.7904	0.746	2.4
4.1424	1.726	2.4
5.52	2.4	2.3
6.061	2.755	2.2
6.7431	3.211	2.1
6.969081	3.543	1.967
7.27516	3.805	1.912
7.612218	4.086	1.863
8.06004	4.39	1.836
8.22393	4.615	1.782
7.657615	4.795	1.597
6.8551	4.9	1.399
6.17274	4.97	1.242
5.5973	5.02	1.115
4.360536	5.112	0.853
3.350166	5.178	0.647
2.732136	5.214	0.524
1.852576	5.263	0.352
1.40079	5.286	0.265
0.93987	5.31	0.177
0.707826	5.322	0.133
0.40546	5.335	0.076
0.283126	5.342	0.053
0.144423	5.349	0.027
0.096336	5.352	0.018
0.069589	5.353	0.013
0.04284	5.355	0.008
0.02678	5.356	0.005
0.016068	5.356	0.003
0.005356	5.356	0.001

Table A9

Temperature 20°c								
width(m)	0.09							
length(m)	0.05							
thickness	2.5cm	2.5cm	2.5cm	2.5cm	2.5cm	2.5cm		
Lens Type	Tap	Tap	Distilled	Distilled	Oil	Oil	without	**without**
DP(cm)	30	70	30	70	30	70	30	**70**
$G(w/m^2)$	113	19.6	111.8	15.9	90.4	7.2	12.1	**6.5**
$V_{oc}(v)$	4.7	4.8	4.84	4.608	5.08	430	4.67	**4.16**
$I_{sc}(A)$	0.0025	0.0013	0.000748	0.00102	0.00151	0.000635	0.001284	**0.000591**
$P_{max}(w)$	0.008224	0.00412	0.00117572	0.002947	0.004685	0.001536504	0.003634	**0.001515**
FF	0.699909	0.660238	0.324755823	0.629508	0.610326	0.005627189	0.606108	**0.616328**
η	0.054717	0.027411	0.007822488	0.019609	0.03117	0.010222914	0.024181	**0.010082**

Table A10: without lens, DP:30cm

Without lens 30cm		
P mW	V	I mA
0.001285	0.001	1.285
0.00771	0.006	1.285
0.001669	0.0013	1.284
0.050076	0.039	1.284
0.164224	0.128	1.283
0.491006	0.383	1. 82
1.138698	0.891	1.278
1.610325	1.263	1.275
1.920481	1.511	1.271
2.370036	1.878	1.262
2.78304	2.23	1.248
3.014635	2.441	1.235
3.217536	2.646	1.216
3.382896	2.838	1.192
3.634396	3.298	1.102
3.622044	3.558	1.018
3.499704	3.739	0.936
3.336375	3.875	0.861
2.827692	4.116	0.687
2.28766	4.276	0.535
1.910994	4.363	0.438
1.337128	4.472	0.299
1.026267	4.521	0.227
0.69464	4.57	0.152
0.523716	4.594	0.114
0.305118	4.623	0.066
0.213256	4.636	0.046
0.106858	4.646	0.023
0.06975	4.65	0.015
0.051172	4.652	0.011
0.027924	4.654	0.006
0.018624	4.656	0.004
0.009314	4.657	0.002
0.004657	4.657	0.001

Table A11: without lens, DP: 70cm

Without lens 70cm		
P Mw	V	I mA
0	0	0.582
0.001746	0.003	0.582
0.003492	0.006	0.582
0.009894	0.017	0.582
0.033174	0.057	0.582
0.009935	0.0171	0.581
0.230442	0.398	0.579
0.325414	0.563	0.578
0.388224	0.674	0.576
0.482734	0.841	0.574
0.576004	1.007	0.572
0.63555	1.115	0.57
0.695887	1.223	0.569
0.755811	1.333	0.567
0.935168	1.664	0.562
1.070595	1.929	0.555
1.191352	2.174	0.548
1.36367	2.53	0.539
1.51528	3.055	0.496
1.441925	3.425	0.421
1.290232	3.604	0.358
0.975885	3.827	0.255
0.766921	3.893	0.197
0.53466	3.99	0.134
0.407636	4.036	0.101
0.241546	4.094	0.059
0.168797	4.117	0.041
0.087024	4.144	0.021
0.0581	4.15	0.014
0.04153	4.153	0.01
0.024924	4.154	0.006
0.016624	4.156	0.004
0.008316	4.158	0.002
0.00416	4.16	0.001

Table A12: oil lens, thick: 5cm, DP:70cm

5 oil lens 70		
P mW	V	I mA
0.001422	0.001	1.422
0.008532	0.006	1.422
0.021315	0.015	1.421
0.06106	0.043	1.42
0.201072	0.142	1.416
0.5922	0.423	1.4
1.339821	0.973	1.377
1.87005	1.37	1.365
2.202411	1.623	1.357
2.719593	2.019	1.347
3.117604	2.369	1.316
3.297262	2.558	1.289
3.429461	2.737	1.253
3.544852	2.908	1.219
3.929514	3.414	1.151
4.220592	3.823	1.104
4.09654	4.036	1.015
3.85584	4.155	0.928
3.173337	4.353	0.729
2.518884	4.482	0.562
2.084816	4.552	0.458
1.44304	4.64	0.311
1.10027	4.682	0.235
0.746392	4.724	0.158
0.559792	4.744	0.118
0.324224	4.768	0.068
0.229392	4.779	0.048
0.114984	4.791	0.024
0.07672	4.795	0.016
0.057552	4.796	0.012
0.033593	4.799	0.007
0.024	4.8	0.005
0.009604	4.802	0.002
0.004803	4.803	0.001

Table A13: oil lens, thick: 5cm, DP:30cm

5 oil lens 30		
I mA	V	P mW
1.006	0	0
1.005	0.004	0.00402
1.004	0.01	0.01004
1.003	0.031	0.031093
1.001	0.1	0.1001
0.998	0.3	0.2994
0.993	0.697	0.692121
0.985	0.978	0.96333
0.977	1.165	1.138205
0.961	1.436	1.379996
0.948	1.701	1.612548
0.94	1.882	1.76908
0.933	2.055	1.917315
0.923	2.224	2.052752
0.906	2.742	2.484252
0.876	3.095	2.71122
0.829	3.348	2.775492
0.785	3.565	2.798525
0.688	4.17	2.86896
0.584	4.681	2.733704
0.481	4.788	2.303028
0.329	4.908	1.614732
0.249	4.957	1.234293
0.167	5.004	0.835668
0.125	5.026	0.62825
0.072	5.053	0.363816
0.051	5.063	0.258213
0.026	5.075	0.13195
0.017	5.079	0.086343
0.013	5.081	0.066053
0.007	5.084	0.035588
0.005	5.085	0.025425
0.003	5.086	0.015258
0.001	5.087	0.005087

Table A14: distilled water lens, thick: 5cm, DP:70cm

5 Distilled lens 70		
P mW	V	I mA
0.0066	0.002	3.3
0.0495	0.015	3.3
0.1188	0.036	3.3
0.3399	0.103	3.3
1.1022	0.334	3.3
3.1136	0.973	3.2
6.531	2.177	3
9.06	3.02	3
10.353	3.57	2.9
12.7252	4.388	2.9
12.6828	4.878	2.6
11.9688	4.987	2.4
11.1342	5.061	2.2
10.731	5.11	2.1
8.736	5.2	1.68
7.656832	5.248	1.459
6.794073	5.279	1.287
6.114359	5.303	1.153
4.691154	5.343	0.878
3.570992	5.378	0.664
2.891184	5.394	0.536
1.94904	5.414	0.36
1.470717	5.427	0.271
0.984459	5.439	0.181
0.73494	5.444	0.135
0.425256	5.452	0.078
0.294516	5.454	0.054
0.147366	5.458	0.027
0.098262	5.459	0.018
0.070967	5.459	0.013
0.043672	5.459	0.008
0.027295	5.459	0.005
0.01638	5.46	0.003
0.005461	5.461	0.001

Table A15: distilled water lens, thick: 5cm, DP:30cm

5 Distilled lens 30		
I mA	V	P mW
3.4	0.002	0.0068
3.4	0.016	0.0544
3.4	0.036	0.1224
3.4	0.106	0.3604
3.3	0.344	1.1352
3.2	1.003	3.2096
3	2.15	6.45
3	3.039	9.117
2.9	3.53	10.237
2.9	4.409	12.7861
2.8	5.06	14.168
2.7	5.456	14.7312
2.5	5.519	13.7975
2.3	5.561	12.7903
1.6	5.648	9.0368
1.4	5.666	7.9324
1.2	5.686	6.8232
0.9	5.707	5.1363
0.7	5.731	4.0117
0.571	5.725	3.268975
0.382	5.758	2.199556
0.288	5.733	1.651104
0.191	5.735	1.095385
0.143	5.744	0.821392
0.082	5.755	0.47191
0.058	5.755	0.33379
0.029	5.76	0.16704
0.019	5.76	0.10944
0.014	5.761	0.080654
0.008	5.77	0.04616
0.006	5.77	0.03462
0.003	5.77	0.01731
0.001	5.771	0.005771

Table A16: Tap water lens, thick: 5cm, DP:70cm

5 Tap lens 70cm		
I mA	V	P mW
2.3	0.001	0.0023
2.3	0.011	0.0253
2.3	0.025	0.0575
2.3	0.072	0.1656
2.3	0.237	0.5451
2.3	0.707	1.6261
2.3	1.629	3.7467
2.2	2.285	5.027
2.2	2.69	5.918
2.1	3.198	6.7158
2	3.677	7.354
1.995	4.009	7.997955
1.909	4.182	7.983438
1.803	4.311	7.772733
1.699	4.401	7.477299
1.511	4.534	6.850874
1.327	4.647	6.166569
1.179	4.718	5.562522
1.06	4.77	5.0562
0.814	4.875	3.96825
0.619	4.948	3.062812
0.501	4.99	2.49999
0.337	5.045	1.700165
0.255	5.072	1.29336
0.17	5.1	0.867
0.127	5.113	0.649351
0.073	5.13	0.37449
0.051	5.136	0.261936
0.026	5.142	0.133692
0.013	5.145	0.066885
0.013	5.146	0.066898
0.007	5.147	0.036029
0.005	5.148	0.02574
0.003	5.149	0.015447
0.001	5.15	0.00515

Table A17: Tap water lens, thick: 5cm, DP:30cm

5 Tap lens 30cm		
I mA	V	P mW
2.5	0.001	0.0025
2.5	0.011	0.0275
2.5	0.027	0.0675
2.5	0.078	0.195
2.5	0.254	0.635
2.4	0.749	1.7976
2.3	1.682	3.8686
2.3	2.337	5.3751
2.3	2.766	6.3618
2.2	3.406	7.4932
2.2	3.784	8.3248
2.1	4.408	9.2568
2	4.741	9.482
1.959	4.881	9.561879
1.848	4.971	9.186408
1.685	5.059	8.524415
1.47	5.147	7.56609
1.3	5.205	6.7665
1.163	5.237	6.090631
0.889	5.323	4.732147
0.671	5.366	3.600586
0.542	5.399	2.926258
0.364	5.441	1.980524
0.274	5.462	1.496588
0.183	5.481	1.003023
0.137	5.488	0.751856
0.078	5.504	0.429312
0.055	5.509	0.302995
0.028	5.522	0.154616
0.019	5.525	0.104975
0.014	5.525	0.07735
0.008	5.528	0.044224
0.006	5.529	0.033174
0.003	5.53	0.01659
0.001	5.531	0.005531

Table A18

Temperature 20°c								
width(m)	0.09							
length(m)	0.05							
thickness	5cm	5cm	5cm	5cm	5cm	5cm		
Lens Type	Tap	Tap	Distilled	Distilled	oil	oil	without	**without**
DP(cm)	30	70	30	70	30	70	30	**70**
$G(w/m^2)$	158	35	171.6	58.5	>200	17.2	12.1	**6.5**
$V_{oc}(v)$	5.53	5.15	5.77	5.461	5.11	4.83	4.67	**4.16**
$I_{sc}(A)$	0.0025	0.0023	0.00348	0.0034	0.001016	0.001431	0.001285	**0.000591**
$P_{max}(w)$	0.009562	0.007998	0.0147312	0.012725	0.00286896	0.004221	0.003634	**0.001515**
FF	0.691637	0.6752178	0.733640112	0.685352	0.552598733	0.610642	0.605637	**0.616328**
η	0.063619	0.0532133	0.098011976	0.084665	0.019088224	0.028081	0.024181	**0.010082**

Appendix B

Table B1**: AutoCAD data for Aspherical lens**

X	Y
0	-12.12
0.66	-11.75
1.38	-11.3
2.1	-10.83
2.82	-10.31
4.19	-9.22
4.91	-8.59
5.63	-7.9
6.65	-6.87
7.37	-5.93
8.08	-4.69
8.45	-3.86
8.93	-2.23
-9.14	-0.17
-9.03	-1.31
-8.45	-3.86
-8.08	-4.36
-7.37	-5.6
-6.65	-6.54
-5.63	-7.56
-4.91	-8.25
-4.19	-8.89
-2.82	-9.98
-2.1	-10.49
-1.38	-10.97
-0.66	-11.41
0	-11.79

Table B2: Data of Solar Cell

P_{max}: 0.2128 W	@1000w/m^2, AM1.5, 25°c
Ip_{max}: 0.03846 A	Weight: 28 g
Vp_{max}: 6.09 V	
I_{sc}: 0.1104 A	Ƞ: 4.7%
V_{oc} : 8.28 V	
product dimension:90*50*2mm	