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EXPERIMENTAL AND NUMERICAL STUDY TO IMPROVE THE PERFORMANCE OF SOLAR CELL USING WATER COOLING SYSTEM

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2022

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

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سورة البقرة:آية (32)

DISCLAIMER

I confirm that the work submitted in this thesis is my own work and has not been submitted to another organization or for any other degree.

Signature:

Name: Sarah Yahya Hattam

Date: / / 2022

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SARAH YAHYA HATTAM

2022

SUPERVISOR CERTIFICATION

We certify that this thesis titled **"Experimental and Numerical Study to Improve the Performance of Solar Cell Using Water Cooling System"** which is being submitted by Sarah Yahya Hattam was prepared under our supervision at the Power Mechanical Engineering Techniques Department, Engineering Technical College/Najaf, AL-Furat Al-Awsat Technical University, as a partial fulfillment of the requirements for the degree of Master in thermal mechanical engineering.

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In view of the available recommendation, we forward this thesis for debate by the examining committee.

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Date: / / 2022

Committee Report

We certify that we have read this thesis titled **“Experimental and Numerical Study to Improve the Performance of Solar Cell Using Water Cooling System"** which is being submitted by Sarah Yahya Hattam and as Examining Committee, examined the student in it is contents. In our opinion, the thesis is adequate for the degree of Master of Technical in Thermal Engineering.

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ABSTRACT

PV Panel are a great solution to the worldwide energy shortage. The efficiency of the PV panel suffers a noticeable decrease with the increase in the temperature of the PV panel. Thus a cooling system is needed due to decreasing the PV panel's temperature. This work studied the effect of reducing the working temperature of the plates in order to increase the conversion efficiency using distilled water immersion cooling technique. The theoretical and practical parts of study were conducted on the effect of cooling the PV panels by immersing (PV) in closed cycle parallel flow distilled water forced circulation from (above and below) PV panel. A numerical results obtained by using Comsol program 5.5. The experimental results were conducted at the Technical Engineering College of Najaf with indoor test conditions that were controlled. The numerical study was conducted to determine the best depth of immersion of the panel to give the minimum base temperature of PV panel, simulation results showed that the best depth of immersion is (5mm). Two mono-crystalline silicon solar panels were used, one of which was cooled to obtain the PV/T system and the other PV panel was used to compare with the results of the cooled panel. Based on the results obtained from the simulation, the PV\T system was fabricated from a material (hard foam) with high thermal insulation. The water flow channel is one of the most important parts of the PV/T system and which fixed on the above and below of the PV module. PV/T system length (900mm), width (600mm), thickness (25mm), the distance above and below the PV module to passage water was 5 mm. At the terminals of the channel, a hole is designed to inlet and outlet the water flow, by use water pump. The amount of solar radiation received was in different amounts (600-1000) W/m^2 and flow rate (1-5) LPM. Finally, an increase in electrical (efficiency and an enhancement) was gained from numerical and experimental results (38.4) %, (14.72) %, (38) % and (14.642) % respectively.

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NOMENCLATURE

Symbol	Definition	Unit
PV	Photovoltaic Cell	-
PV/ T	Photovoltaic Cell Thermal Collector	-
T_s	Surface of solar cell temperature	℃
T_{amb}	Ambient temperature	℃
Re	Reynolds number	----
pr	Prandtl number	-
K	Thermal conductivity	W/m.K
CFD	Computational Fluid Dynamics	-
$\emptyset$	Volume Fraction	%
ρ	density	Kg/m^3
A_m	Area of the (PV)module	m2
T_b	Base cell temperature	℃
u	velocity component at x-axis	m/s
v	velocity component at Y-axis	m/s
w	velocity component at Z-axis	m/s
Ac	Area of the Photovoltaic Cell	m
η_c	Electrical efficiency	%
Pmax	maximum power	Watt
G	solar radiation	W/m^2
FF	Fill factor of the PV module	-
I_{sc}	Short circuit current of the PV module	A
V_{oc}	Open circuit voltage of the PV module	V
PF	Packing factor of the PV module	-
Nc	Number of the cells	-

A_{in}	cross sectional area	m^2
P_{in}	perimeter of inlet channel collector respectively	-
η_{el}	Electrical efficiency	%
STC	Standard Test Condition	-
η_r	reference efficiency =15% at STC	%
β	temperature coefficient (β = 0.0045°C)	°C
TC	Solar cell temperature	°C
Tr	Reference temperature	°C
S	Absorbed solar energy	W/m^2
α	Coefficient of absorption by solar radiation	-
GT	Glazed with tedlar	-
τ	Transmittance of solar cell	-

Chapter One

Introduction

Chapter One

INTRODUCTION

1.1 General Overview

The life style of people in any country usually depends on the facilities keeping pace with the development in several sectors in our life, such as energy and technology. The ease of accessibility and utilization of energy make the life more comfortable where people always seek to do so. Most sources of energy used by countries are fossils fuels such as coal, oil, and gas. However, they cannot be readily obtained. Moreover, these types of raw fuels are not valid for the use if they are not converted for usable products. A process of fuel conversion produces pollution, harming the environment and leading to the global warming. The global warming considers one of the most dangerous man-made phenomena’s for the whole world [1].

As a result, more emissions will be generated and launched to air, resulting in highly polluted weather. Owing to the problem of pollution, researchers keep looking for alternative energy sources which do not produce any kind of emissions during the operation. There is another reason, it is pushing the energy industry to find sources of the sustainable energy. The sun is the best candidate source of energy to provide the power for all customers across the globe. The sun based energy (i.e., solar energy) is the environmentally friendly energy source where a lot of scientists and researchers have been attracted across the globe to work on [2].

There are two kinds of energy that can be generated using sun light. The first kind is the electrical energy produced by converting the light to electricity utilizing photovoltaic (PV) cells, whereas the second kind is the thermal energy by converting the sun light to heat [3]. Figure 1-1 shows the ground mount array diagram.

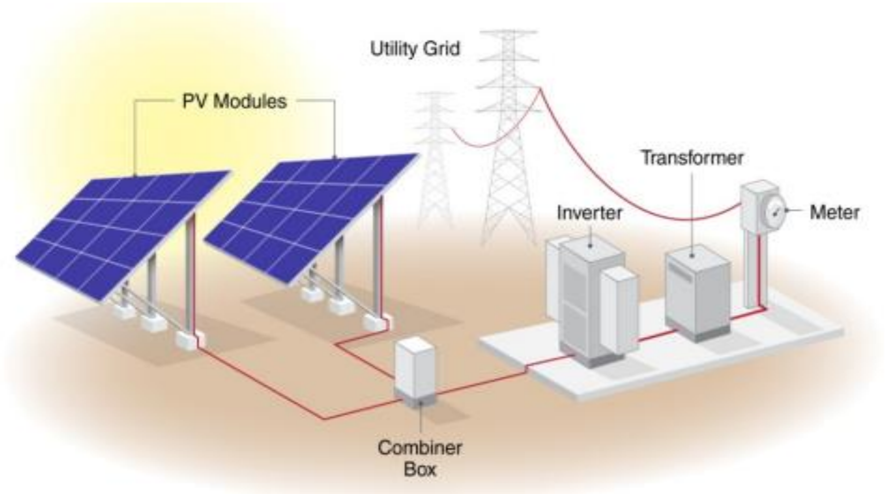


Figure1-1 Main solar energy system components (Ground-mounted array diagram) [4].

1.2 Photovoltaic (PV) cells

Photovoltaic (PV) cells are solid-state devices that convert sunlight directly into electricity without the use of a thermal engine or other machinery. Because the photovoltaic cell's components contain no moving parts, it requires no additional maintenance and has a long lifespan. It is possible to develop units with virtually all of the required energy, from small units to megawatt power plants, and one of the advantages of photovoltaic cells is the ease with which additional cells can be added to enhance the amount of energy produced. Above all, photovoltaic cells are highly reliable and can be used as stand-alone production systems [5].

The photovoltaic cell is manufactured from a semi-conductor silicon material and is formed from two thin layers of semi-conductor materials The PV cell contains of a wide range of attached and closed cells that are covered with a layer of glass to be the PV panel that produces the required electrical power[6]. Photovoltaic panels have no negative impact on the environment because they do not emit any gases during their operation. Photovoltaic cells are also preferred over other renewable energy sources because they are simple to install in a variety of locations, including surfaces and public spaces [7, 8]. Figure 1-2 shows the generation of electricity from a photovoltaic cell.

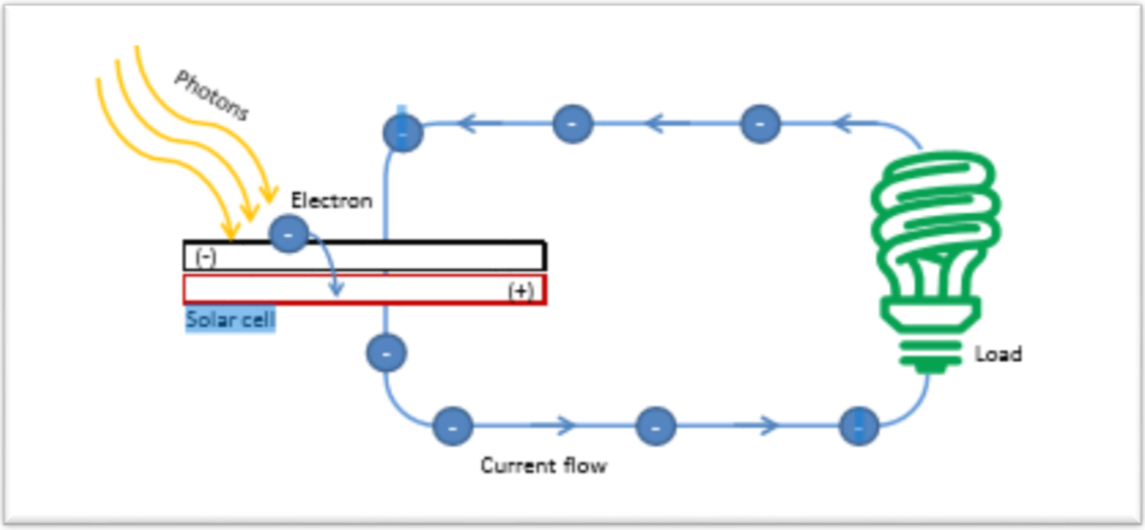


Figure1-2 Electricity generation from a (PV) cell [4]

1.2.1 Technical Types of Photovoltaic Panel

The photovoltaic cell can be arranged into two types as follows:

1- Crystalline silicon, which includes crystalline lattice pieces, is the first type of photovoltaic cell. Impurities are the drawbacks of this type, but comparing to other types, they are effective and have efficiencies with ranging from (14-15 %) and may reach higher than that. The name of this type is Mon-crystalline Silicon Cells. Because of the complexity of production processes, which increases the initial cost, it has a highly relative cost. In such a type, the effect of cell temperature on the electrical efficiency is considered, so when the cell temperature rises one degree above the standard, the efficiency of the electrical cell decreases by (0.4-0.5 %). Monoclonal silicon cells are affected by solar radiation relative to thin-film cells that are not affected by the efficiency of solar radiation, and are less efficient in low absorption conditions.

2- Other types of photovoltaic cells are made of polycrystalline silicon, which is created by pouring the polycrystalline silicon into alloys after melting and then cutting them into chips using a lot of monocrystalline silicon during the production process. Compared to the first type of PV, this type of photovoltaic cell is manufactured with low cost, since the production process is simpler and less complicated.

Although, its efficiency is slightly less than the first type. It has efficiency of about (13-15%) with the same coefficient of cell temperature effect on cell efficiency for two types of (PV) module.

Cell temperature 25°C and solar radiation 1000 W/m^2 are the standard conditions that measure the efficiency of photovoltaic cells to provide the highest possible electrical efficiency, which give the PV cell the highest possible electrical power production. Since more than (80%) of solar radiation is not exploited in the generation of electricity, depending on the cell specification, the low conversion efficiency of ultra-low photovoltaic does not exceed (9-20%) and most of the solar radiation energy is converted to thermal energy [9,10]. The resulting heat contributes to an increase in the PV cell temperature, leading to a reduction in the electrical efficiency of the PV cells. The effect on PV cells with a high temperature is undesirable and affects the output of the PV cell negatively and decreases electrical efficiency [11].

It is also necessary to perform calculations to determine the usefulness of the use of photovoltaic cells and knowledge of energy produced at different locations and loads to make the necessary improvement for obtaining the appropriate electrical energy [12, 13].

Figure (1.3) shows the influence of temperature on the electrical efficiency of the PV cells.

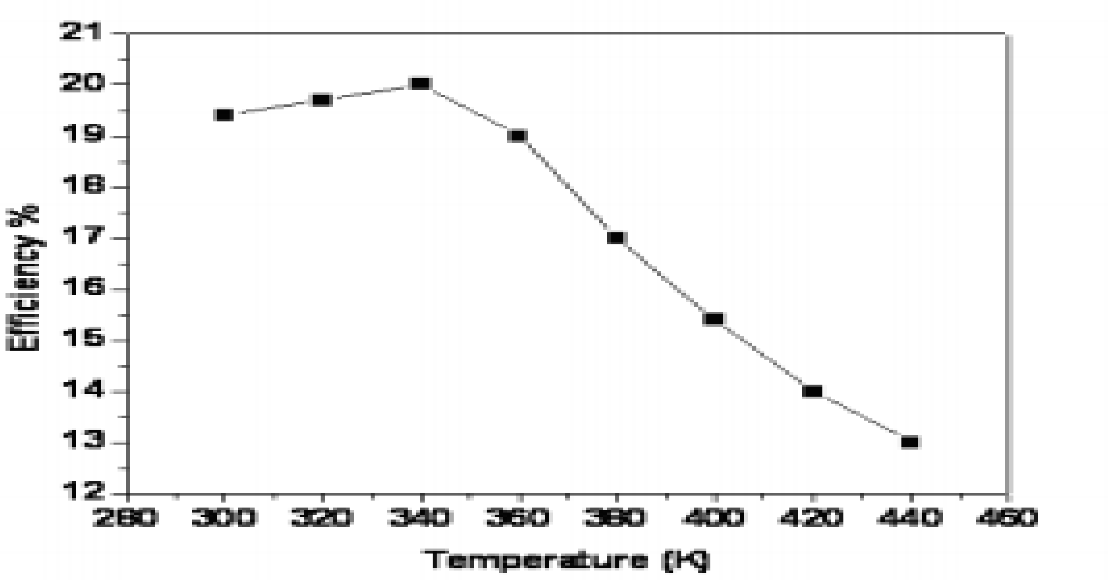


Figure 1-3 A graph of temperature effect on the electrical efficiency of the cell [14].

3- A thin-film silicon photovoltaic cells (PV) are the less efficient alternative for the crystalline silicon (PV) panels. The thin-film silicon panels are more power to (size/weight) ratio it is originally designed and developed for the space application with high-quality materials.

The thin-film photovoltaic cells manufacturing processes quicker and easier than the other kinds of (PV) panels. The thin-film photovoltaic cells suffer from a low conversion ratio. In all types of thin-film PV panels, the conversion efficiency is less than (10%). The thin-film silicon panels are produced by painting or spraying a thin layer of semi-conductor of (PV) material onto metal, glass or plastic foil. The overall thickness of all of these layers is less than the equivalent crystalline cell [15]. Figure (1-4) shows the types of photovoltaic cells.

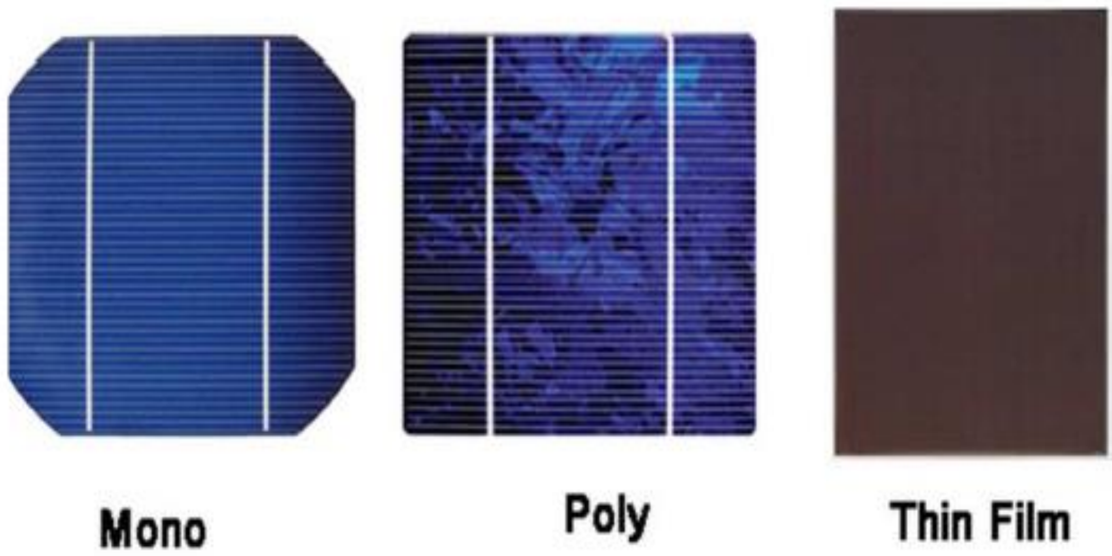


Figure 1-4 Types of PV Panels [16].

1.2.2 Effect of temperature on the efficiency of photovoltaic

All photovoltaic cells are manufactured to operate under standard conditions at a temperature of (25C°) and solar radiation of (1000 w/m²) [17]. The highest efficiency achieved by photovoltaic in converting sunlight into electrical energy, with a rate of (20%). As the efficiency of the (PV) panels decreases, this dramatically increases in the surface temperature of the (PV) panels. The efficiency of (PV) panels decreases by about (0.5%) for each one Celsius above 25 C°.

A lot of energy is then lost due to the increase in the surface temperature of the (PV) panels. Various techniques have been used to reduce the surface temperature of the panels [18].

Cooling the solar cell panel can boost its electrical production because cooling prevents the PV cells from reaching temperatures that damage the PV panels. One of the important parameters that affects the energy output of the PV module is the operating temperature. The efficiency and output power are inversely proportional to the temperature. The efficiency of a commercial panel mounted in water is improved by two important facts, reduction of light reflection "due to lower refraction index" and removal of thermal heat. Both water and air are suitable for use as the cooling fluid to cool the PV module in order to prevent a decrease in electrical efficiency [19].

1.3 Problem Statement

The performance of (PV) panels depended on the cell temperature where the (PV) module giving the higher efficiency at (25 °C and 1000 W/m^2). The module efficiency reduces in each the (PV)cell temperature increase, which decreases the productivity of the cell for electrical power, and the percentage of solar radiation converted to electrical energy ranges between (13-20) % and most of the solar radiation absorbed by the cell is converted into an unwanted thermal energy rises cell temperature and decreases efficiency. The main problem of (PV) panels is the decreases cell efficiency and cell performance, due to the increase in the cell base temperature. To overcome this limitation, there is a strong motivation to decrease cell base temperature through heat transfer and disposal methods in the fastest and simplest technique.

1.4 Objectives of Research

The objectives of research are as follows:

1. Enhancing the PV performance with the using of PV cooling systems by immersing the PV panels in water where the immersion process operates to:
   a. Reducing the overall surface temperature of the PV cell which leads to high sunlight absorption
   b. Cleaning up the dust deposited on the PV surface which reduces the overall sunlight absorption

2 . Comparing the experimental and numerical results of the performance of the PV cooling system by immersion water.

3. Evaluating the performance of the PV cooling system by immersion water.

4. Increasing the productivity of electrical energy by increasing the electrical efficiency of solar panels.

5. Less space is used to install solar panels with high production capacity compared to traditional solar panels.

6. Preparing a mathematical model to choose the best suitable depth for cooling the photovoltaic panel.

7. After choosing the best cooling depth for the photovoltaic panel, the heat-absorbing thermal collector was manufactured from the solar panel

Chapter Two

Literature Review

Chapter Two

LITERATURE REVIEW

2.1 Introduction

Many studies have been conducted theoretically and experimentally related to the topic of cooling of the (PV) panels to increase their production efficiency. It is important to understand the various scientific approaches about the (PV) panels cooling system is to get acquainted with the different cooling methods. The method of using air and water and a combination of air and water method is the most popular and applied technologies.

2.2 Cooling Techniques of the Photovoltaic Cells

To highlight on research dealing with techniques of the cooling systems of the PV cells, here various techniques have been reviewed and summarized to provide readers with a glance of what types of techniques are investigated nowadays. As the performance of the cooling systems increases, the PV's power generation will be boosted. It is thus worthwhile to present some of those important researches as given below:

2.2.1 PV Cooling Systems Using the Water as a Coolant

Moharramand et al [20] used a spraying water method to decrease water amount used in the PV panel cooling plant. The temperature decreased (45 °C) to (35 °C).

Loredana Dorobantu et al [21]: Investigate the effect of spraying water on the front face of the photovoltaic panels to clean and reduce the surface temperature. The results showed that by using a thin film of water to extract the heat, the photovoltaic performance could be enhanced by 9.5%.

Abdellatif et al [22] conducted experimental studies to verify three photovoltaic cooling techniques. The first membrane of the water cooling technology is applied on the front surfaces of the PV cells, where it was found that the surface temperature of the photovoltaic cells has decreased to 16°C. The second technique is cooling with attaching direct contact back water. It was found that the surface temperature of the photovoltaic cells has decreased to 18°C, while the third technique is a combination of the back cooling and film cooling. It was found that the surface temperature of the cells has decreased to 25. The experimental results were obtained by an infrared camera. It shows the daily energy output of the PV cooling has increased by a ratio up to 22%, 29.8%, and 35% for film, back and combined film–back cooling modules, respectively, compared to the non-cooled PV module.

Ozgoren, Rawat and Yazdanpanahi, [23, 24, 25] designed collector and an absorber placed on the rear end and back of the coolant. The electric efficiency can be enhanced 8.5, 12-14 and 8 %.

Rosa-Clot and Rosa-Clot [26] submerged the panel of silicon mono-crystalline, at different depths of water in a pool. Data analysis shows that the electrical efficiency has been increased (11%) at a depth of 4cm and the increase ratio becomes only 15% at a depth of 40 cm of water compared to PV panels without any cooling systems.

Gakkhar et al [27] used the liquid to cooling photovoltaic cell on together edges of a panel. Also for Concentrated (PV) liquid submerged cooled method along with the Parabolic during the collector, a new model is introduced. The thermal Transmission Fluid flows through both the absorber tube both in and out of, thus cooling the Concentrator cells for better output from both sides. Results indicate that fluid inside the annulus is stronger in which sides of both the cells can easily carry heat away. The operational performance of Concentrator cells was then improved.

Shenyi and Chenguang [28] designed a passive cooling method which used rainwater as cooling media and a gas expansion device to distribute the rainwater. The gas was thermally expanded from receiving solar radiation as such the amount of water it pushes to flow up the PV panels is proportional to the solar radiation received. The passive cooling system reduced the temperature of the cells and increased electrical efficiency of the PV panels by 8%.

Han et al [29] compared the immersion in various cooling fluids. The immersion occur in an isolated liquid, organic fluids and deionized water. The results showed that the electrical efficiency raises up to 14.9 %.

Kordzadeh et al [30] cooled PV cells using thin film of water flown over PV surface. He observed that panel temperature decreases approximately by 40% and efficiency increases along with pump flow rate up to certain point.

Hosseiniand et al [31] have utilized the water spray technology to cool their solar cells panels. The effectiveness of this technique was studied instead of using water constantly on a top of the solar cells. The results show that the increase in the electrical efficiency of solar cells is by 17%.

Raad et al [32] used a water cooling technique to enhance the electrical performance of a PV module to tackle the rise in the operating cell temperature. It was observed that the electrical efficiency does not exceed 8% before cooling process. At optimum water flow rate 0.2 L/s, the cell temperature reduced, thus electrical efficiency increased more than 9.6% and thermal efficiency reached to 12.3%.

Mehrotra et al [33] studied the immersion technique of water cooling. The photovoltaic were immersed in water and monitored under real conditions with a cell surface temperature of (31C^o to 39C^o). At a depth of 1cm, the efficiency is improved by 17%.

Amine Hachicha et al [34] used different water cooling methods: front, rear, and double cooling. The spray technology was used for front cooling, while direct contact water technology was used for rear cooling. The results were compared with a non-cooling (PV) panel to determine the performance of the (PV) module in different water cooling methods and to find the best module. The result showed that the front type is more effective than the rear cooling which could reduce the temperature of the PV module in larger scale.

Nahar et al [35] used the COMSOL program for studying the heat transfer on absorber plate system under photovoltaic thermal PV/T. Effects of irradiation level from 200 to 1000 W/m^2, a depth of flow channel (0.02, 0.015, 0.01m), and many other parameters such as Reynolds number from 200 to 1600, and Prandtl number from 4 to 6.5 on electrical and heat transfer performance were developed and studied. The results obtained from the model display that (PV/T) thermal efficiency and electrical performance have increased with PR and Re number.

By increasing channel depth respectively and Re number, a rate of the heat transfer has increased to (25.5%) and cell temperature has decreased to10.2°C.

Ben Cheikh et al [36] used COMSOL to realize a three-dimensional method model of PV collector relying on the FEM algorithm determine the thermal behaviors and analyze electrical performances for absorber-integrated in the back-side of the PV panel. The mass flow rate is from 0.0001 to 0.4 Kg/s on the electrical energy, and the cell temperature is analyzed and studied experimentally and a numerically.

The results show when the flow rate increases, the (PVT) collector temperature reduces, leading to the increase in electrical energy produced by the PV panel. The PV temperature and electrical power obtained from the PV panel are 23.845C° and 59.434 W, respectively, when the mass flow rate reaches 0.0256 Kg/s.

Grubisic-Cabo et al [37] used water spray technology for Single Side Cooling, cooling was applied on the front side and the rear side. For the front side only, the power output was 40.1 W, and for the rear side, 39.9 W was observed.

Nizetic et al [38] sprayed water using nozzles on both side of PV mono-crystalline module. Assembly of nozzles ensured proper distribution of water spray. Total of 20 nozzles were installed, 10 on each side. The back nozzles were installed perpendicular to the surface and front nozzles were at an angle of 40°C, in order to avoid shadowing effect of wire frame and also it ensured wider distribution of water spray over the surface. The average panel temperature reduced to 24° C from 52° C. The electrical efficiency increased by 14.15%.

Lupu et al [39] used water cooling technology from the top and back of the photovoltaic panel. The back of the panel was cooled by pipes connected to a water reservoir, the front panel was cooled by direct water cooling. The results showed a decrease in the cell temperature from (50 to 39 ^{o}C).

Sainthiya and Beniwal [40] studied the effect of cooling on the front surface of the plate during summer and winter in India. The results showed that the electrical efficiency in the winter season reaches (11-14%) and in the summer (9-12%).

Hassan et al [41] studied the effect of lowering the cell surface temperature on the conversion tool and efficiency. Water spray technique was used, four types of nozzles with different diameters (2, 3, 4, 5) mm were used. The results showed that the cell temperature was reduced to (50%) of its temperature when using a nozzle with a diameter of 2 mm.

2 .2.2 PV Cooling Systems Using Air as a Coolant

A.Crăciunescu and et al.[42] used forced air on the (PV)cell , the study found that when the (PV)cell was exposed to solar radiation for the first time without cooling the voltage decreased. The PV was exposed to solar radiation with cooling, the voltage increased. The research found that when the PV is exposed to solar radiation, the temperature of the PV rises, negatively affecting the PV performance.

Revati and Natarajan [43] studied influence of a temperature on the performance of photovoltaic cells under different circumstances such as solar cells with air cooling, solar cells in a grass field and solar cells without cooling techniques. Panel temperature, cell surface temperature, short circuit current and open circuit voltage were presented.

High values of short circuit current and open circuit voltage were achieved when air cooling was used, due to the photovoltaic cells temperature reduction.

Hussein M. Maghrabie and et al.[44] studied the effect of air forced cooling on (PV) cells by air blower to rectangular channel installed on the rear of the PV module.

The results showed a decreasing in cell temperature by (11%) when the air passes on the back of the PV unit, and the PV temperature drops by (10%) when the air passes on the front of the PV. The rate of increasing in PV efficiency is (3.7%).

A.Alsayah et al [45] studied the effect of cooling on the base of the photovoltaic panels, through the forced air flow on the base of the photovoltaic panel. Using air guides, the largest amount of air was directed to the base of the panel. The results showed a decrease in the temperature of the base by (37.22 %).

Farshchimonfared et al [46] studied the performance of a PV/T air collector under the effect of different parameters, such as optimized channel depth and air mass flow rate per unit area. Different collector areas and different length to width ratios for constant temperature rise 10℃ were considered in the proposed model. It was noticed that by increasing the length to width ratio and collector area causes an increase in the optimum depth of the collector.

Toe et al [47] used air cooling to reduce the surface temperature of the photovoltaic cells and therefore increased the electrical efficiency. The results achieved were increase in efficiency from (8 to 14 %).

Tonui and Y. Tripanagnostopoulos [48] studied the efficiency of Solar photovoltaic collectors utilizing force or normal air motion to take out heat. Two methods to enhance heat convert from the pipe wall to airflow have improved the air conduit. At the center of the tube, the first inserted the thin metallic layer, and the second linked rectangular fin at the rear of the channel

2.2.3 PV Cooling Systems Using a Combination of Air and Water as a Coolant

Jailany et al [49] utilized four photovoltaic cells, two cells with air cooling and the rest with water cooling. By comparing the results, the cooling systems using water have higher efficiency than systems operating with air. A temperature became 9 C° and the efficiency was increased by a ratio of 9.27% for the former cooling way.

Aziz et al. [50] studied the effect of cooled (PV) panel by using water and air at the same time by passing air through a channel installed at rear of the (PV) panel, water was passed in front of the (PV) panel. The results were analyzed through (ANSYS) simulation program, and showed a reduction in air cooling temperature of (19%), and (53%) by cooling water.

Syafigah et al [51] conducted two studies to discuss and examine the photovoltaic cells with air and water cooling system. On the back-side of the photovoltaic cells, an air cooling system was installed using a DC fan that generates wind speed of 3.07m/s and a water cooling system was installed on the front surface of the photovoltaic.

An engineering model was designed using the Solid-Work program and thermal analysis using the ANSYS program. The air cooling system was able to reduce the temperature to 53.6C°, while the temperature became 31.15C° when using the water cooing systems.

2.3 Observations from Previous Studies

Having demonstrated the most related works using the cooling systems throughout this chapter, it is evident that the researchers sought to enhance the overall performance of the PV panels via increasing the electrical efficiency employing different sorts of cooling systems. Moreover, it can be concluded the cooling systems operating with water are more effective than cooling systems operating with air, thereby having higher efficiency. This motivates us to work on improving the PV panels by immersing them in water. Simplicity, low cost, and abundance of water everywhere are other reasons attracting researchers to adopt the water cooling systems in their research.

2.4 The aim of this study

This study investigates numerically and experimentally the effect of solar panel cooling on conversion efficiency and power output. The research methodology is based on a direct comparison between conventional and quenching-improved PV panels in order to:

1- Increasing the electrical energy generated by water cooling.

2- Calculating the maximum efficiency that can be achieved by cooling the plate from the top and from the bottom with distilled water.

3- In the numerical study, the absorber thermal collector configurations of photovoltaic were designed. Volumetric flow rate ranges ranged from 1-5 LPM and were performed using a modified solar thermal collector (PV/T) test unit in an internal control test case, Site, Technical College of Engineering - Al-Awsat Technical University, Najaf, Iraq.

Chapter Three

Theoretical Study

Chapter Three

THEORETICAL STUDY

3.1 Introduction

This chapter discusses the methodology in detail to fulfill the objectives mentioned in Chapter One. The methodology adopted here in this research will be elaborated numerically and experimentally. However, this chapter deals only with the numerical part. The main goal of the methodology is to optimize the heat transfer in the PV thermal collectors relying on a depth of the water flow in their channels. Strategies utilized to carry out the research methodology will be explained in this chapter to provide readers with a comprehensive guide about what is going on in this research work.

3.2 Physical Model

The thermal channel collector of the PV/T system can be realized using several shapes of geometries. Modifying the rectangular channel of the proposed thermal collector depends on changing the depth of water flow; see Figure 3-1, where the distilled water used as an working fluid is forced to circulate from the upper part to the lower part of the PV module.

The following assumptions were made in the analysis and simulation:

1. Three dimension (CFD) simulation.
2. The outer surfaces of a channel are completely insulated except the top surface of the PV / T system which is exposed to solar radiations.
3. Laminar flow
4. Heat transfer with the fluid flow.

5. Incompressible flow
6. Constant heat flux
7. Study of state condition
8. The ambient temperature equal to temperature of the inlet water.

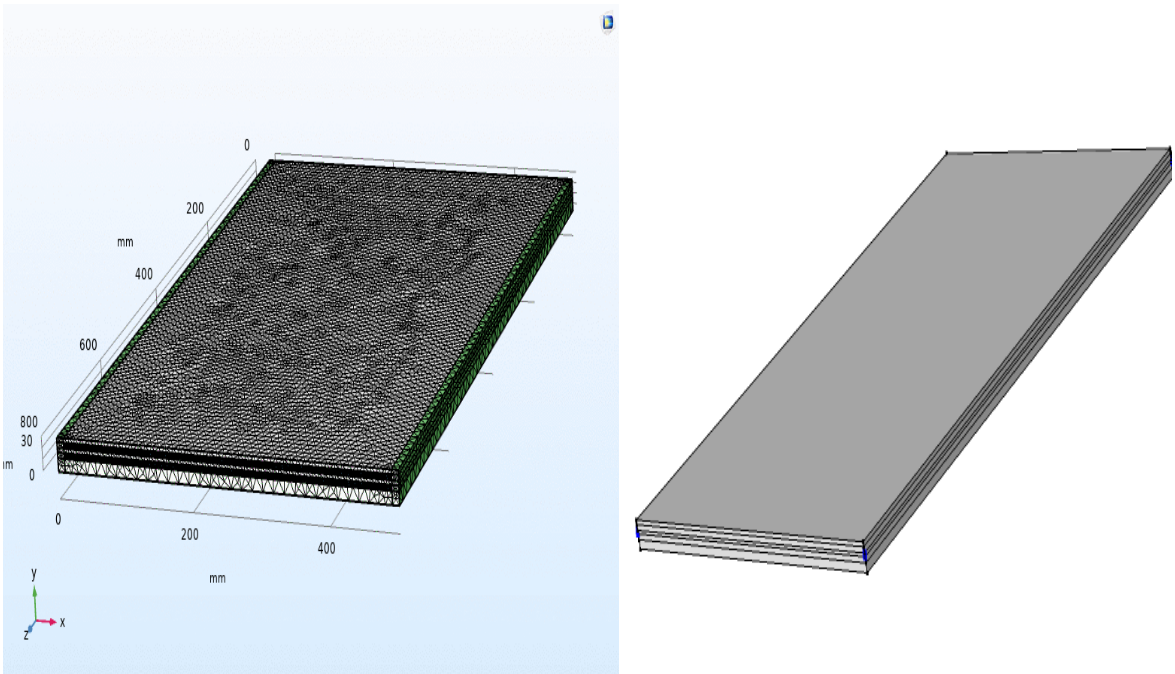


Figure 3-1Suggested thermal collector channel design by sold work program.

3.3 Grid Independence Test (GIT)

In any simulation and analysis, network architecture is an important factor to consider in determining the appropriate type, number and places of the mesh faces. We can solve partial differential equations with convergent solutions if we use the right mesh. Depending on the complex geometrical form of the project or the working state, coarse or fine mesh faces may be used. The grid independence test was performed in this simulation to determine the mesh is most appropriate face size.

As shown clearly in Figure 3-1, the mesh for the absorber collector which has [h= 5mm] and volume flow rate of 1 LPM and 27^{o}C inlet temperature at 1000 W/m^{2} of solar radiation. All mesh faces were used to plot the mean fluid temperature which passed through PV/T system. Figure 3-2 shows the number of mesh face structured against the base temperature of the PV module.

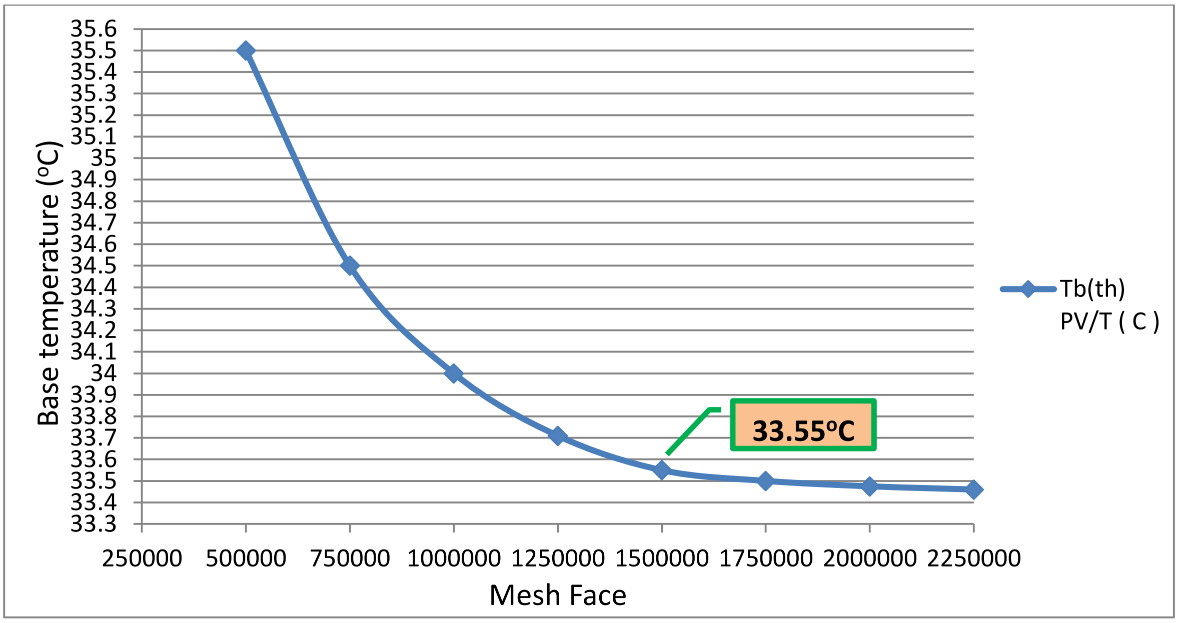


Figure 3-2 Average base temperature of the PV/T system versus a number of the mesh faces for grid independence test.

3.4 Numerical Model and Governing Equations

All numerical calculations conducted in this research were evaluated at steady-state conditions by using the commercial available COMSOL software, installed on own researchers' computers. The governing partial differential equations (PDEs) of the momentum, continuity and energy equations were solved in case of the stationary, laminar and incompressible flow.

The semi-implicit technique for pressure-linked equations algorithm influenced coupled heat transfer in velocity–pressure and fluid. All these equations mentioned above must be set properly to complete the numerical analysis of the PV/T system. The Computational fluid dynamic simulation under all these considerations was governed by the 3D steady state computational domain of the time-averaged incompressible Navier–Stokes continuity and energy equation. These equations could be expressed as [52], in the Cartesian tensor system.

Continuity equation:

$$\nabla(PV) = 0 \tag{3-1}$$

Momentum equation:

$$\rho \frac{DV}{Dt} = -\nabla P + \rho . g \tag{3-2}$$

Energy equation:

$$\nabla.(K_w.\nabla T_W) = 0 \tag{3-3}$$

3.5 Computational Fluid Dynamic (CFD) Theories

The (CFD) technique is used to study and solve complex fluid flow and heat transfer problems in (PV/T) system. The (CFD) is a computer based program that simulates the behavior of a (PV/T) system, including (fluid flow, heat transfer, with fluid heat transfer, and other physical processes). As a (CFD) simulator, the COMSOL Multiphasic software was employed. The COMSOL Multiphasic software was used as a CFD simulator program.

It operates to solve multi equations for fluid flow in an algorithm manner over a study region of interest, with the (initial and boundary) condition. The (CFD) theories enable to obtain a reliable solution to compare the experimental ones. Also, the (CFD) can solve many system configurations at the same time with a low cost.

In the current study, the (CFD) simulation technique will be used as a tool to investigate the effects on the (PV/T) system designs when operating as a thermal absorber collector. The distilled water will be forced to circulate (i.e., getting out and in) in order to cool the (PV/T) system, thereby leading to enhance the performance of the (PV/T) system [52].

3 .6 Numerical Validation

Validation is a very important step, in any numerical work. A comparison of numerical current results and past studies was undertaken to validate the numerical model proposed in this study. Using the results presented in research [44], their design was re-simulated as shown in Figure 3-3 to validate the CFD results with our current work. This requires determining the average outlet water temperature (T_{out}) of the PV/T system. The average temperature for the water getting out from the PV/T panel is shown in Figure 3-4. As can be clearly seen, a temperature reduces with an increase in the mass flow rate. The error percentage between the (CFD) validation results and [53] was less than 5%. It is possible to say that the results of the current research are in a good agreement with results of other researchers. The boundary conditions can highly influence on an accuracy of the results, and they can be used to approximately predict the (PV/T) thermal collector performance.

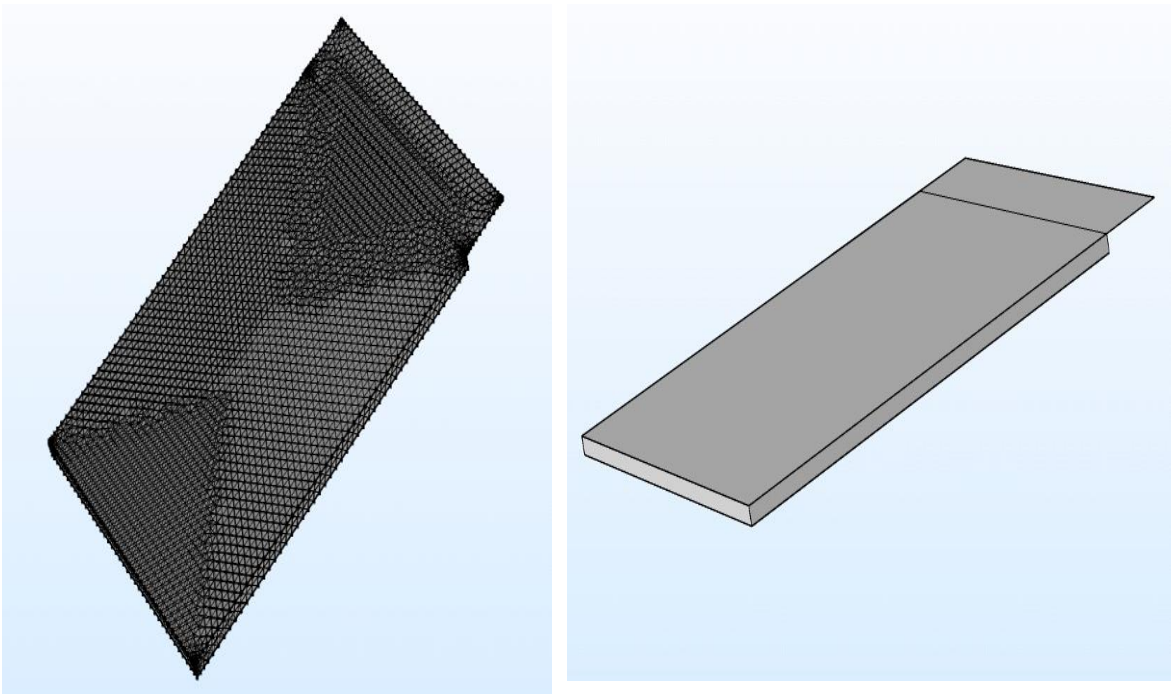


Figure 3-3 Front view of the simulation model mesh and surface temperature.

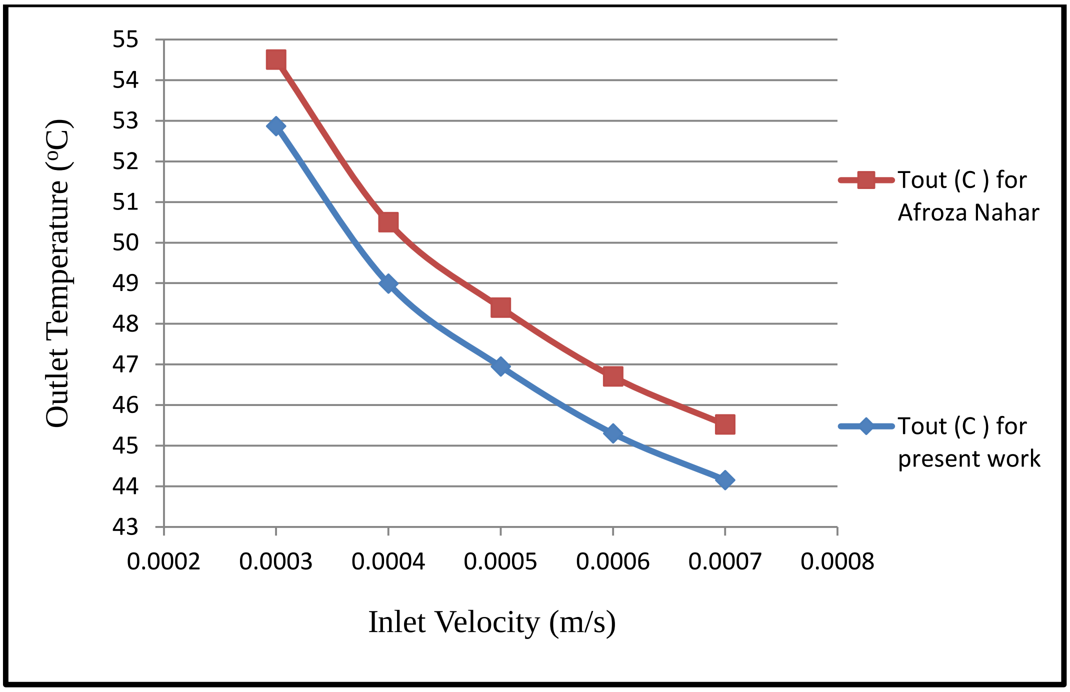


Figure3-4 Outlet water temperatures according to variable mass flow rates for the CFD validation results compared with results regenerated from [53]

3.7 Electrical Analysis of Photovoltaic Cell

The voltage will be equal zero in case of the short circuit, while the current generated from light will be equal to the short circuit current or called the maximum current. The current generated from the sunlight depends mainly on an intensity of the solar radiation and a surface temperature of the PV panel [54].

However, in an open circuit case, the current is equal to zero, while the voltage must equal the open circuit voltage [55], which is the maximum value. Figure 3-5 shows the typical (current-voltage) curve which indicates the electrical characteristics of the PV panel.

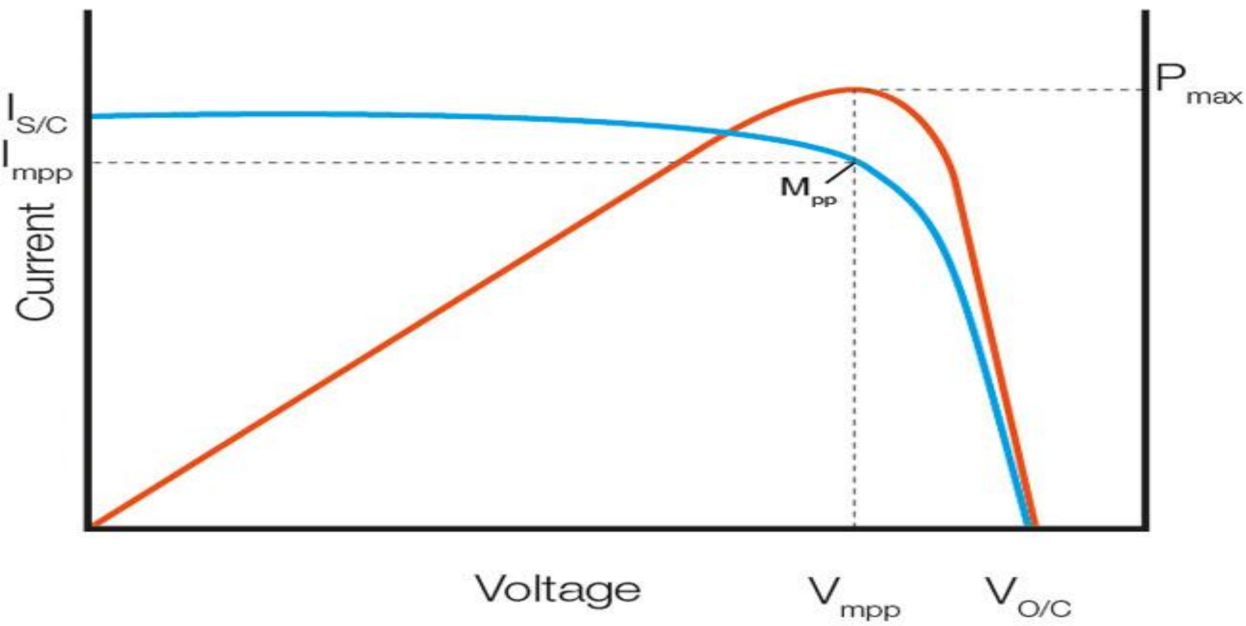


Figure3-5Current-voltage curve of the PV cell [56]

Efficiency of Cells (η_{cell}) indicates the maximum power of the photovoltaic panel. The amount of absorbed solar irradiance by the (PV) panels, cell efficiency can be expressed as shown in [57].

$$\eta_{cell} = (\frac{P_{max}}{G \times A_c}) \tag{3-4}$$

Fill factor (FF) is the maximum ratio of power to the short-circuit current and the open-circuit voltage ,which can be expressed as [58]:

$$(FF) = \frac{P_{max}}{V_{oc} \times I_{sc}} \tag{3-5}$$

The packing factor (PF), which is defined as the ratio of the single cell area multiplied by the number of cells divided by the area of the Photovoltaic panel (Am) as shown in equation (3-6), is one of the most important factors impacting the performance and efficiency of Photovoltaic panels. The value of (PF) is frequently less than one [59] as:

$$(PF) = \frac{A_c \times N_c}{A_m} \tag{3-6}$$

Equation (3-7) indicates the mathematical formula of the module efficiency (η_m), which is the product of cell efficiency (ηc) multiplied by the packing factor (PF).

$$\eta_m = \eta_c \times PF \tag{3-7}$$

The expression of electrical efficiency (η_{el}) according the temperature for (PV/T) panel, is given by [60]:

$$\eta_{el} = \eta_r\left(1-\beta\left(T_c - T_r\right)\right) \tag{3-8}$$

Where η_{el} is the (electric efficiency) of PV module, β is the [temperature coefficient (β=0.0045(1/^oC)], TC (^oC) is the (cell temperature) and Tr (^oC) is the (reference temperature) Tr= 25 ^oC .

3.8 Thermal Loses of (PV/T) system

The heat transferred from the solar radiation falling on the PV module to the water or any fluid flowing below the base of the PV module, is obtained by calculation the rate of convection which transferred from the base of the PV module to the water or any fluid which passed the under the PV module as well as the rate of convection transferred from the water to the surrounding air or vice versa.

As a result of the flow of water into the photovoltaic cells, we will have the largest amount of water vortices that move directly towards the base of the photovoltaic cells to absorb heat from it. Since the PV base is completely isolated from the outside environment, it can neglect the convection heat transfer between surrounding air and the base of the thermal collector channel. So the thermal energy transmitted of to water or any fluid can be calculated by the following equation [61]:

Hottel-Whillier equations describe the difference between the absorber solar radiation and the thermal losses

$$S = \left(\tau\alpha\right)G_T \tag{3- 9}$$

Chapter Four

Experimental Work

CHAPTER FOUR

EXPERIMENTAL STUDY

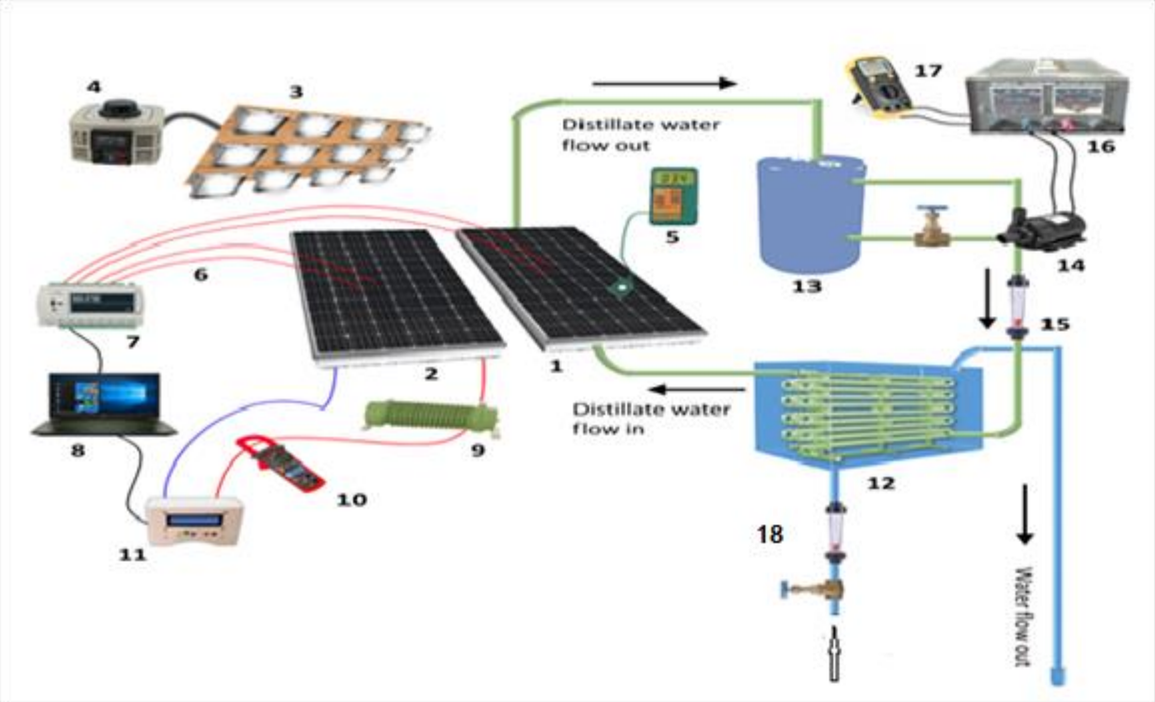
4.1 Introduction

This chapter provides an overview of the experimental work carried out as part of this study, with all components of the rig used for testing produced and installed at the Technical Institute of Najaf, Al-Furat Al-Awsat Technical University in Iraq. Indoor characterization of a photovoltaic thermal collector system with the use of a sun simulator is installed at the Rig location

4.2 Photovoltaic Thermal PV/T Collector Systems

The PV/T water cooling system which uses the distilled water as operating fluid consists of required and appropriate equipment to reduce the PV panel temperature. The first main part in the system is the PV module, installed and cooled at the system startup. The second main part is the channel fluid flow collector, which is installed on the upper and lower sides of the PV panel. The third part is the pump, using the circulating cooling liquid flowing through the thermal collector channel, and the final fourth part is the sun simulator that consists of the halogen light, installed on the steel structure where it is placed above the PV/T panels of the system. The entire system was mounted on a steel structure that can be moved and changed to any height and any orientation angle. The photograph of the experimental setup is show in Figure 4-1. The schematic diagram of the complete experimental setup is shown in Figure 4-2.

Figure 4-1 Experimental Rig setup of the PV and PV/T water cooling system.



Name of parts	
1- PV/T system. 2- PV module. 3- Halogen lamps. 4- Voltage regulator. 5- Solar power meter. 6- Thermocouples wires. 7- Data logger. 8- PC. 9- Variable resistance load.	11- Uno Arduino measurement device. 12- Heat Exchanger. 13- Storage tank. 14- DC- solar pump Circulation. 15- Flow meter for closed loop. 16- DC Power supply. 17- Voltmeter. 18- Flow meter for open loop.

Figure 4-2 Schematic diagram of the PV module and PV/Tsystem.

4.2.1 Photovoltaic (PV) Module

The PV module is the most important component of the system. The PV module (mono-crystalline) is made up of three major components (Glass, EVA and Tedler). The Rig was installed (Indoor Test Conditions) with the photovoltaic(PV) system utilizing the sun simulator as illustrated in Figure 4-1 and the specifications provided in Table 4-1.

Table 4-1 Photovoltaic specifications.

Details	Specifications
Type of Solar Cell	(Mono-crystalline) silicon
Cell Dimension	(62.5*125) mm
(PV) Module Dimension	(800*500) mm
Count of Cells	(36)
Maximum Power	60 Watt
Open Circuit Voltage	20.8 V
Short Circuit Current	3.68 A
Maximum Power Voltage	17.9 V
Maximum Operating Current	3.35 A
Cell efficiency (QUOTE %)	15
Tempered Glass Thickness	3 mm
Effective area	0.4 m^2
STC	G=1000 w/m^2, T_C = 25 °C, AM= 1.5

4.2.2 Thermal Collector Channel of the (PV/T) System

One of the most crucial components of the PV/T system is the water flow channel which is fixed on above and below sides of the PV module. According to the dimensions of the PV panel, the dimensions of the water flow channel are selected precisely. The optimal temperature distribution for the photovoltaic panel was achieved by using the thermal camera to acquire the best heat exchange process with the help of water, as shown in Figure 4-3.

The channel box has a suitable depth for the flow of water and also contains eight thermal sensors for both of the two photoelectric (PV) panels placed on the back side of them to measure the temperature as shown in Figure 4-4. Thermal collector channel has a length of 900mm, width of 600mm, and thickness of 25mm. The distance between the above and below parts of the PV module to route the water is 5mm. The channel material made of the foam is very light with having good heat insulation. To prevent the leaks from impacting the environment, the entire channel surface is coated with a thermal insulation material (Epoxy wax). At terminals of the channel, a hole is cutout to outlet and inlet the water flow by using the water pump.

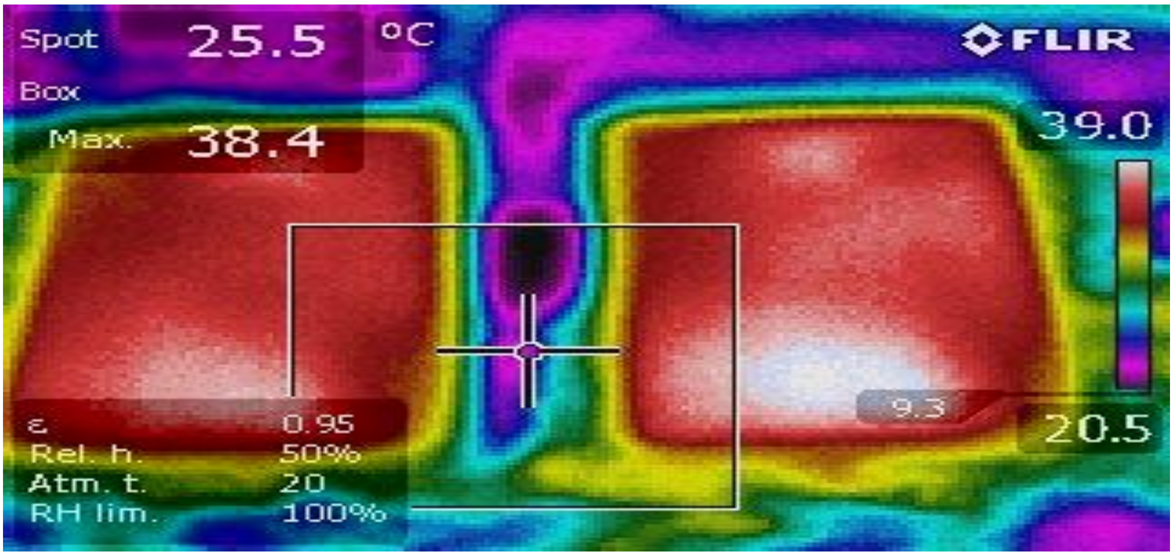


Figure 4-3 Real thermal image of Mono-crystalline PV panel [62].

Figure 4-4 Fluid collector channel with PV module (PV/T system).

4.2.3 Water Pump

The pump also considers one of the most important components of the (PV/T) system. It aims to pump water to above and below of the PV module through thermal collector channel. The pump is a variable-speed DC- type which consumes a maximum power about 8W, and it is connected to a variable DC power supply. The water flow rate is controlled by altering the pump's power capacity via a power supply control unit, and it can be measured using a flow meter. The various speeds of water flow rate can be obtained. The pump kind and specifications are introduced in Figure 4-5 and Table 4-2, respectively.

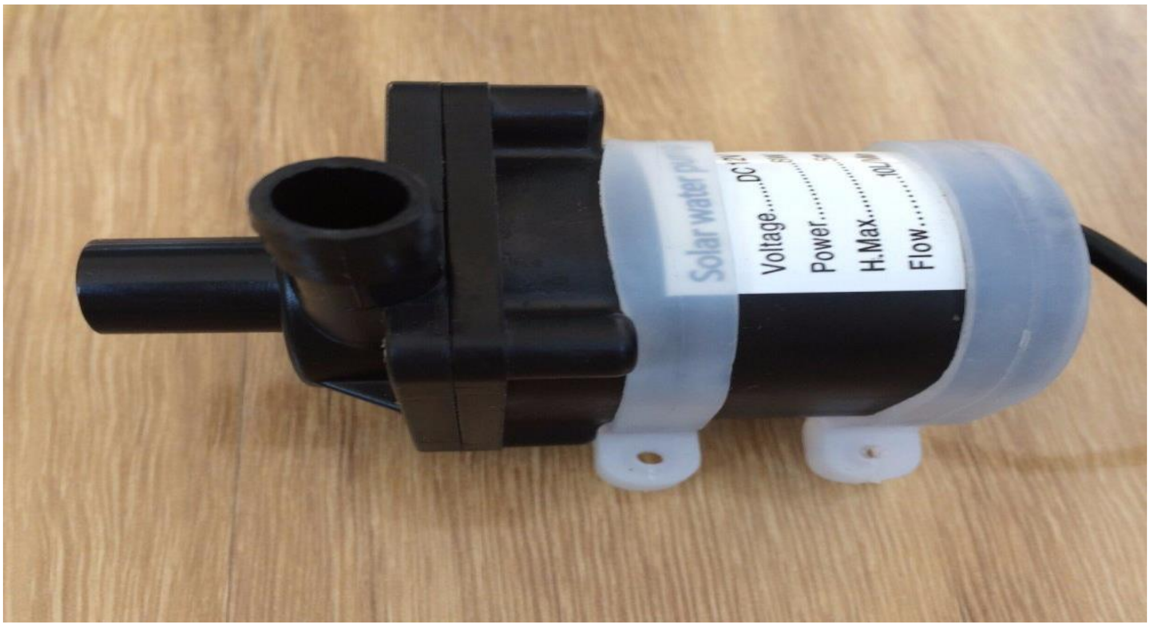


Figure 4-5 Solar pump.

Table 4-2 Pump Specifications.

Parameter	Specifications
Power Max	(8) W
Voltage	(12) V
Head Max	(5) m
Flow Rate-Max	10 (Litter/min)

4.2.4 System Structure

The final part of the system is the steel structure, in which a solar simulator consisting of twelve 500-watt halogen lamps is installed on this steel structure. It is designed to be movable at any required height and angle. The frame structure contains of two parts, where one is movable, and the other is fixed. The fixed structure is the outside structure, and it contains the sun simulation, whereas the moveable structure is the inside structure, and it contains a (PV/T) solar panel system, as illustrated in Figure 4-6.

Figure 4-6 The structure of sun simulator .

4.3 Measuring Devices and Sensors

A set of measuring devices and sensors is used to record the results that will be attained through the experimental work to suit the system conditions. Each device has been calibrated. All their s functions and specification in detail will be provided the subsequent sections.

4.3.1 Solar Power Meter Device

This device is used to measure an intensity of the falling solar radiation on the PV panels, where effects of the intensity on the efficiency and performance can be obtained. It is also known as (Pyrometer).

The pyrometer contains an adjustment button that may be used to calibrate the device by reading it in the dark, where the reading amount is (0) W/m^2. Because halogen light is stable at constant voltage and current, the intensity of solar radiation is constant throughout time in this experiment, and numerous readings of solar radiation intensity were recorded at various heights between the source of industrial radiation and the PV panel.

The pyrometer device contains an LCD screen and sensor as shown in Figure 4-7. Its specification and device range are listed below as shown in Table 4-3 and given Appendix (A).

Figure 4-7 Solar power meter device (Pyrometer).

Table 4-3 Specifications areas listed of solar power meter device.

Specifications	Details
maximum reading	2000 W/m^2
Accuracy	Typically, within±10W/m^2.
Angular accuracy	cosine corrected <5% for angle <60º
Sampling time	0.25 sec
Operating Temperature	(0 -50)ºC, Humidity: below (80%)RH

4.3.2 Data Logger Device

A Data logger is a device that measures temperatures and has many channels, as shown in Figure 4-8. After the cooling process, It is very important to measure the surface temperature of the photovoltaic panel, as well as the temperature of the inlet water to the channel and the temperature of the outflow water from the channel. A specific kind of the Data logger selected is Anpat (AT4532) with (32) channels. This device permits the use of Type K and Type T thermocouples with read accuracy of (0.2 % ± 1^{o}C).

Figure 4-8 Data logger thermometer device Anpat (AT-4532).

4.3.4 Clamp meter Device

The clamp meter device as shown in Figure 4-10 is (UNI-T) UT 203 type. It is used to measure the current and voltage caused by the PV panel at the variable load ranging from zero ohm to the highest possible value of the resistance to know the maximum electrical power for the PV panel performance in the case of without and by cooling for the (PV) module and (PV/T) system together. Photovoltaic panel load is connected in the parallel situation for voltage measurement at open-circuit state; while the Photovoltaic panel load is connected in the series situation for current measurement at short-circuit state.

Figure 4 - 10 Clamp meter .

4.3.5 Uno Arduino Device

The Arduino device is used to collect solar panel performance data and change it with time under testing, as the device contains sensors for temperatures, humidity ratio, time, electric current, electric voltage, and electric power as shown in Figure 4-11.

Figure 4-11 Arduino Uno Type.

4.3.6 Variable Resistance Load Device

By charting the relationship between voltage and current at the variable load of resistance starting from zero ohm, the variable resistance is utilized to attain the maximum electrical output of the PV panels that can be known without voltage drop. Figure 4-12 shows the kind of variable resistance used for (PV) panel without the cooling state and (PV/T) panel by the cooling state**.**

Figure 4-12 Variable resistance load.

4.3.7 Power Supply Device

The device is used to give the necessary power to the pump while also controlling the electrical consumption as illustrated in Figure 4 -13. The Power Supply has two analog screens to display the current and voltage to know the quantity of power that the pump can consume.

Furthermore, the pump speed can be controlled through the power supply device. An alternating current power can be used to drive other devices.

Figure 4 - 13 D.C. power supply device.

4.3.8 Thermocouples Sensor

K-type thermocouples are used in different places in the system to measure the temperatures as shown in Figure 4-14. Different lengths of thermocouples are attached to the digital data logger. Temperatures are measured using thermocouples. The heat sink squeezer and Aluminum conductive heat bar are used to improve the thermal conductivity of thermocouples, as shown in Figures 4-15 and 4-16, respectively.

The thermocouples sensors can be carefully placed at different locations as follows:

1- Four thermocouples are distributed at different locations with equal distances on the base of the (PV) module to measure the base temperatures of photovoltaic cells.
2- Four thermocouples are distributed at different locations with equal distances on the base of the (PV/T) system to measure the base temperatures of photovoltaic cells.
3- Two thermocouples are distributed at inlet and outlet flow water of the (PV/T) system to measure the temperatures of the inlet and outlet of distilled water which is utilized as a working fluid.
4- To measure the temperatures of the inlet and outlet of coolant water two thermocouples are distributed at inlet and outlet flow water of the heat exchanger
5- Six thermocouples are distributed at different locations with equal distances at the indoor room conditions to measure the average ambient temperatures.

Figure 4-14 Thermocouples K-type.

Figure 4-15 heat sink squeezer.

Figure 4-16 Aluminum conductive heat bar.

Calibration should be attained by recording separate readings of temperature to obtain the best reading of the temperature from sensors of thermocouples. First, comparing the recorded results with mercury thermometer reading at the freezing temperature of (0°C) is carried out. The second comparison is done with the boiling water at a temperature of (100°C). The calibration results of thermocouples are introduced in Appendix A.

4.3.9 Anemometer Device

An anemometer is used to measure the air velocity and temperature the surrounding air. The AM-4206 M type of anemometer is made up of two parts. The first part has a reading digital monitor and control buttons for controlling and selecting the measurement unit. A temperature sensor and a fan determine the air velocity in the second part. The device is shown in Figure 4-17 and it has a calibration shown in Appendix (A).

Figure 4-17 Anemometer AM-4206M device.

4.4 Operation Procedure

The steps for cooling the (PV/T) thermal collector which is submersed in water with forced circulation (closed loop) to make the system operating in appropriate way are given as in the following:

1. For the sun simulator utilizing the solar meter device, the intensity of incident solar radiation is fixed to the Photovoltaic panel by a voltage converter and the variable (50-80) cm distance between the photovoltaic panels and the light source.
2. Measuring the air speed and an ambient temperature of the system
3. Using the Arduino device and connecting the variable resistance device (loads) to the PV/T system and (PV) panel, then taking the reading of the maximum current and voltage every (5 seconds) to determine the maximum power.
4. Recording and analyzing the reading results by employing many devices to record data according to theoretical equations, then displaying the relationships and discussing the outcomes.

Chapter Five

Results and Discussion

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

After analyzing the performance of the photovoltaic panel and the proposed PV/T system, the governing equations were chosen as mentioned in the third chapter, and these equations were solved by simulation using COMSOL software to obtain the results from the previously constructed hypothetical design, where the theoretical and practical results were obtained as follows:

5.2 Modelling PV/T water collector according to the height of water channel.

To extract a lot of heat generated in the PV module, the most important methods must be applied in which the best final design can be obtained. Now, the depth of the channel thermal collector channel is manipulated to get the best heat exchange, so as the depth of the water flowing inside the channel changes, giving a change in the amount of heat exchange.

Figure 5 – 1 shows the change between the water channel height and the amount of change in the base temperature of PV panel. Channel thermal collector with the height of (5mm) illustrates the best final design that was suitable base temperature of PV panel, where it gave the lowest temperature of the solar cells approximately (T_b = 35.5). Then, mesh face generation work is conducted on the base temperature Tb of cells to becomes (T_b =33.55°C) as shown in Figure 3-2 in chapter Three.

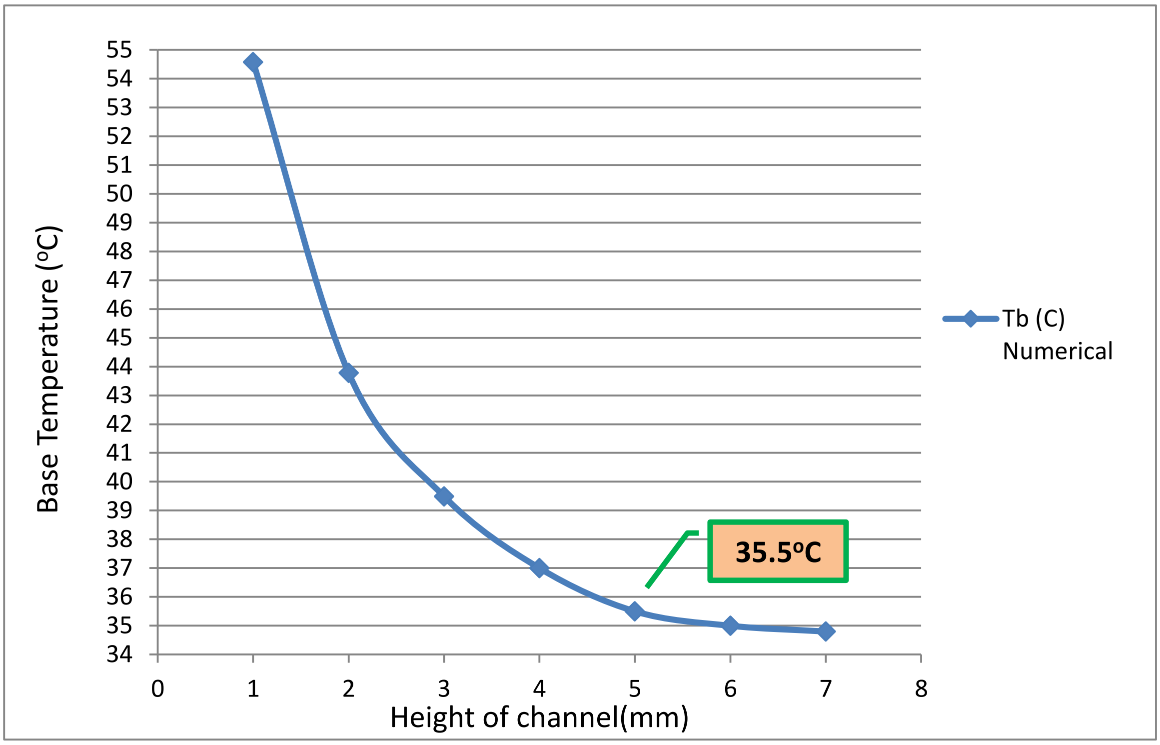


Figure 5-1 Relationship between water channel height and base temperature of PV/T system at 1000 W/m^2 and 1LPM.

5.3 Numerical Analysis

While the virtual system is running after setting the boundary and initial conditions, it is run on the PV panel and at the same time on the PV/T system, meanwhile the physical and electrical properties of the whole system are simulated. Then the results of thermal properties are obtained by achieving the best simulation design by using the COMSOL program to increase the efficiency and performance of the photovoltaic as shown in Figure 5.2a and Figure 5.2b respectively.

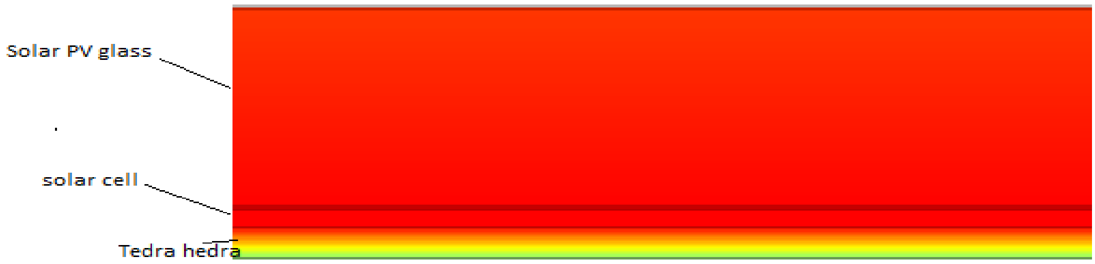


Figure 5.2a Side view of the Simulation PV panel Virtual model Surface Temperature distribution

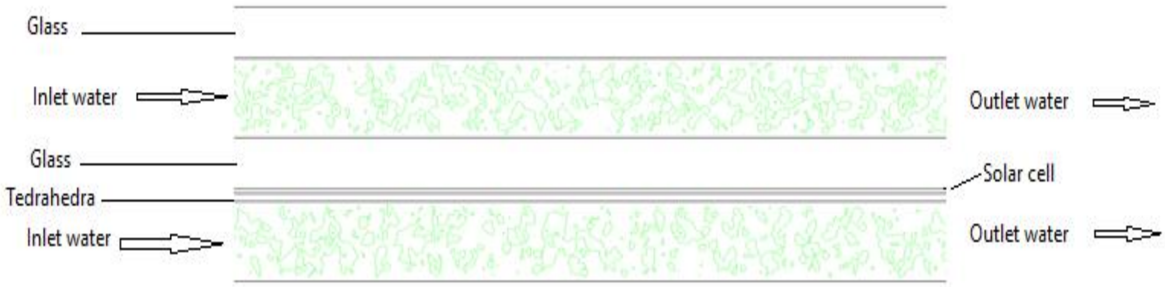


Figure 5.2b Side view of the Simulation PV/T system Virtual Model Streamline Velocity Field.

5.3.1 Electrical efficiency and performance of the virtual design PV panel

In this section, the temperature of the cell increases with increase of solar radiation, therefore the electrical efficiency η_e is affected by the temperature increase of the PV panel, as shown in Figure 5-3 and Figure 5-4 respectively. In this test of the PV panel, the T_b increased from 63.595°C to 89.642°C at the solar radiation increased from (600-1000) W/m^2, while electrical efficiency varied from 12.349% to 10.636% at the same above conditions.

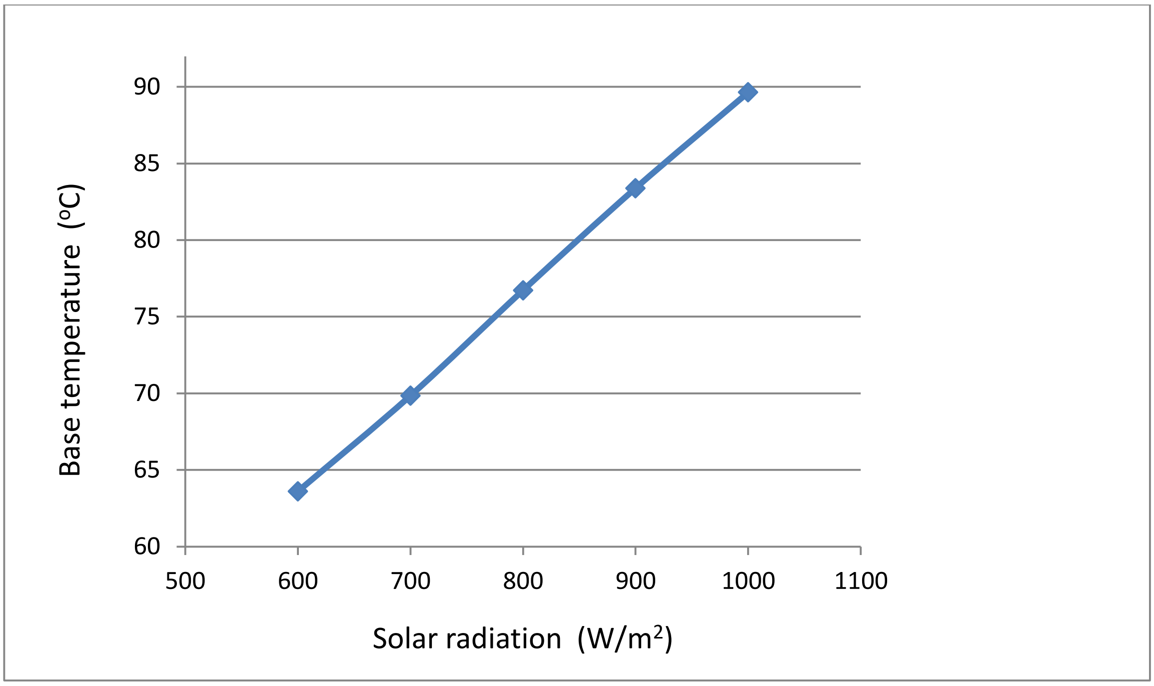


Figure 5.3 Base PV panel temperature T_b against solar radiation (600-1000) W/m^2.

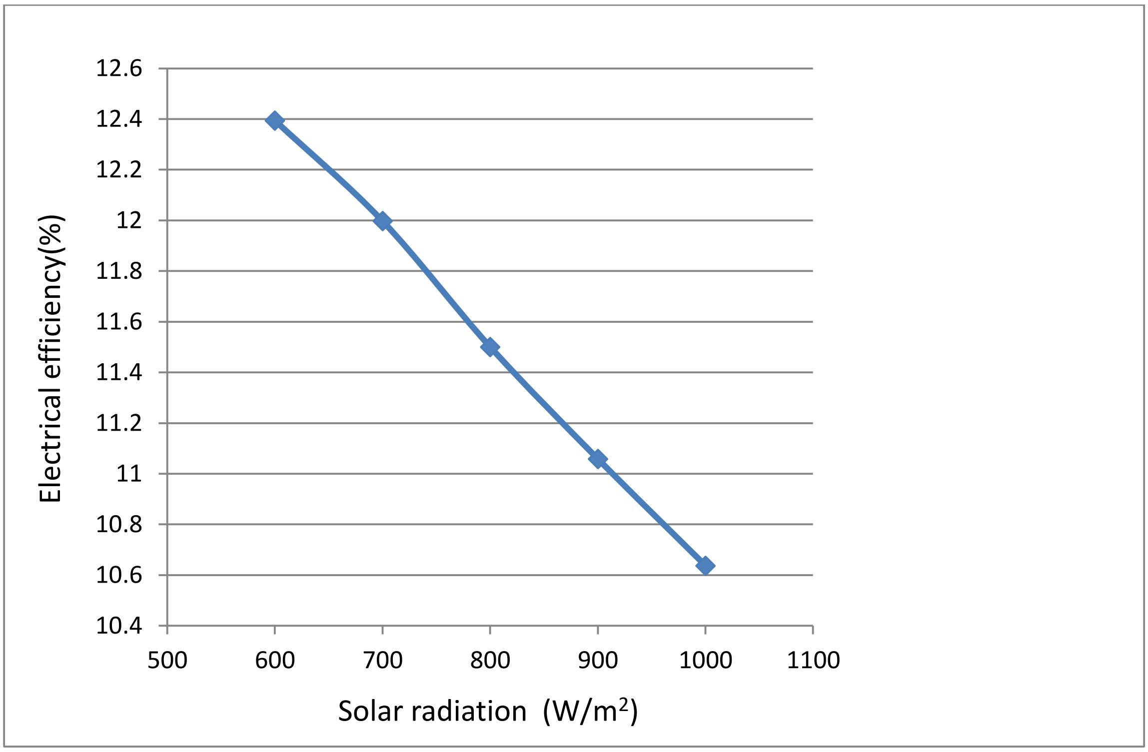


Figure 5.4 Electrical efficiency η_e against solar radiation (600-1000) W/m^2 for (PV) panel.

5.3.2 Electrical efficiency and performance of the virtual design PV/T system

During this numerical study of the PV/T system which was applied by comsol software. By changing the coolant pump flow rate inside the thermal collector, variable results were obtained for the temperature of the outside water and the temperature of the base of the PV panel, in addition to the change in electrical efficiency as shown in the Figures 5-7 respectively. The ambient temperature and the inlet flow water temperature were fixed at 27°C in this numerical study, then the data of the output water temperature and the temperature of the base of the PV panel were recorded, thus the electrical efficiency of the photovoltaic panel obtained with cooling at a variable flow rate of (1-5) LPM and constant solar radiation 1000 W/m^2.

Figures 5-5 and figure 5-6 showed a decrease in the outlet water temperature and base temperature of the PV panel by (35.5-28.37) °C and (33.5-29.2) °C respectively against the increase the water flow rate from 1 to 5 LPM at 1000 (W/m^2). Figure 5-7 showed the increase in the electrical efficiency η_e by (14.42-14.72) % at the same above conditions.

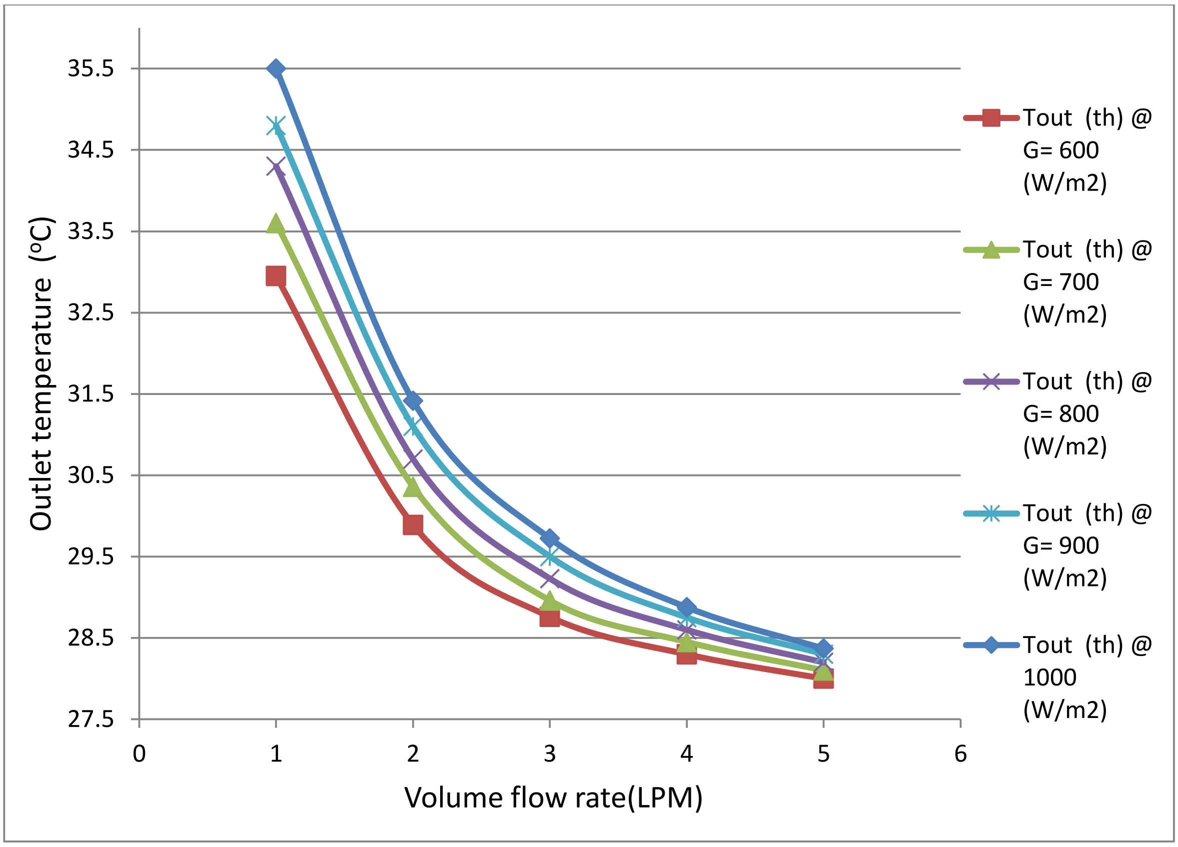


Figure 5.5 Outlet water temperature T_o against (solar radiation and flow rate) different

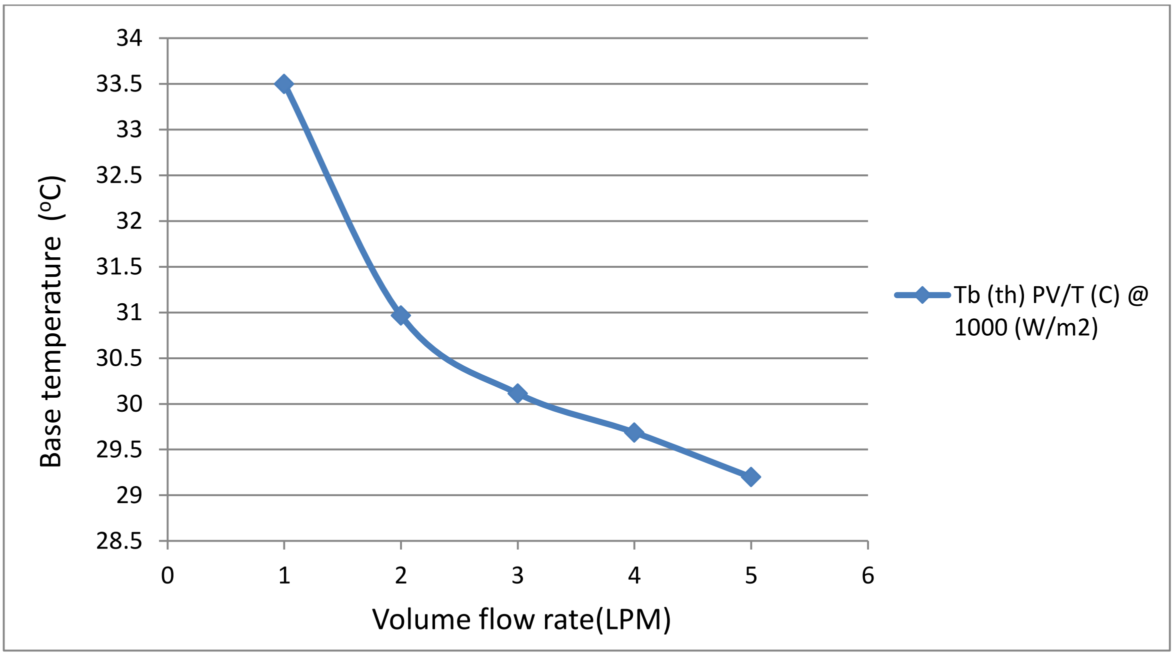


Figure 5.6 Base PV panel temperature T_b against water flow rate (1to5) LPM at 1000 (W/m^2).

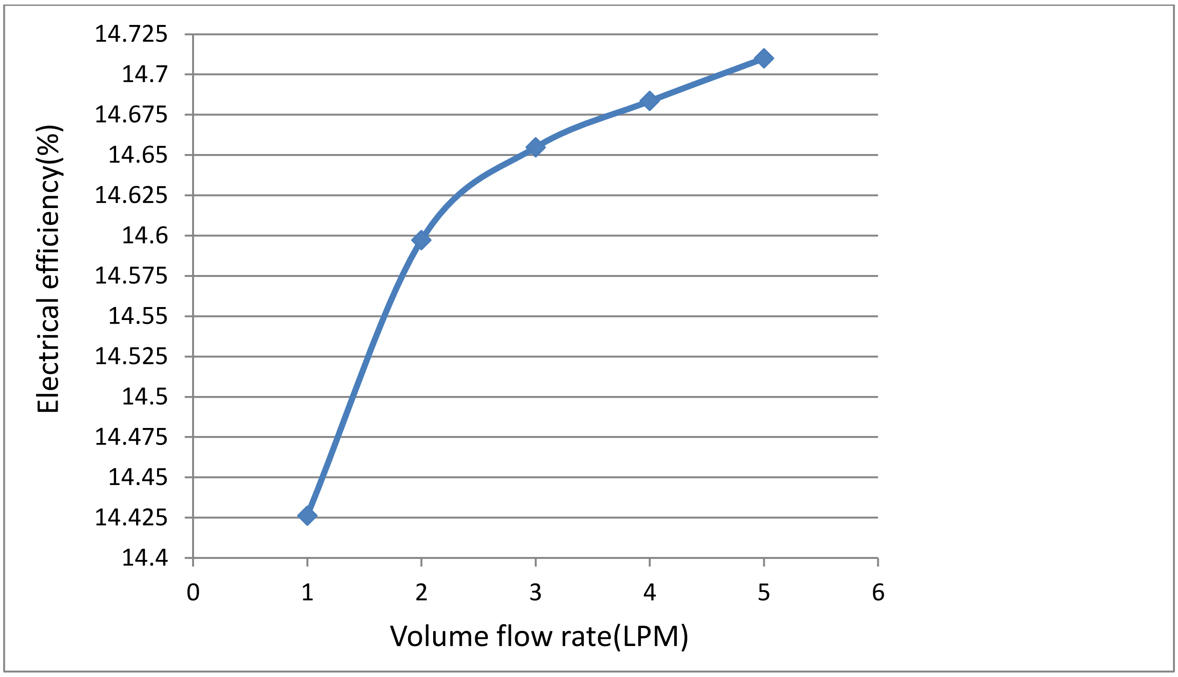


Figure 5.7 Electrical efficiency η_e against water flow rate (1to 5) LPM at 1000 (W/m^2).

5.4 Experimental Analysis

The general objective of this chapter is to present the actual result we can obtained from the performance PV/T system experimental and efficiency results applied on the absorber thermal collector design. In terms of the thermal aspect, variables such as base fluids, main PV module temperature at various locations, inlet and outlet base fluid temperature, ambient temperature, solar irradiance, electrical efficiency, and mass flow rate have all been thoroughly investigated in order to determine the potential of combining the PV module and thermal collector. This parameter would adequately indicate whether the cooling mechanism could improve the electrical performance of PV/T system or no.

5.4.1 Current-Voltage Characteristics of the PV panel at STC, PV panel and PV/T System

The DC load must be linked in parallel to the PV panel to measure the voltage value, while the DC current value is measure by serially connecting the DC load. To find out the maximum power extracted from the PV panel and through the graphical relationship between (voltage - current), the variable load is connected to the PV panel and start from zero ohms to the highest load. The most electrical important elements are shown in Figure5-8 and Figure 5-9 respectively, which indicated to the relationship between the voltage and current are: (open-circuit voltage and short-circuit current without load at same time, maximum voltage and maximum current with load at same time, and maximum power at the maximum voltage and current) and compared with standard test condition of PV module.

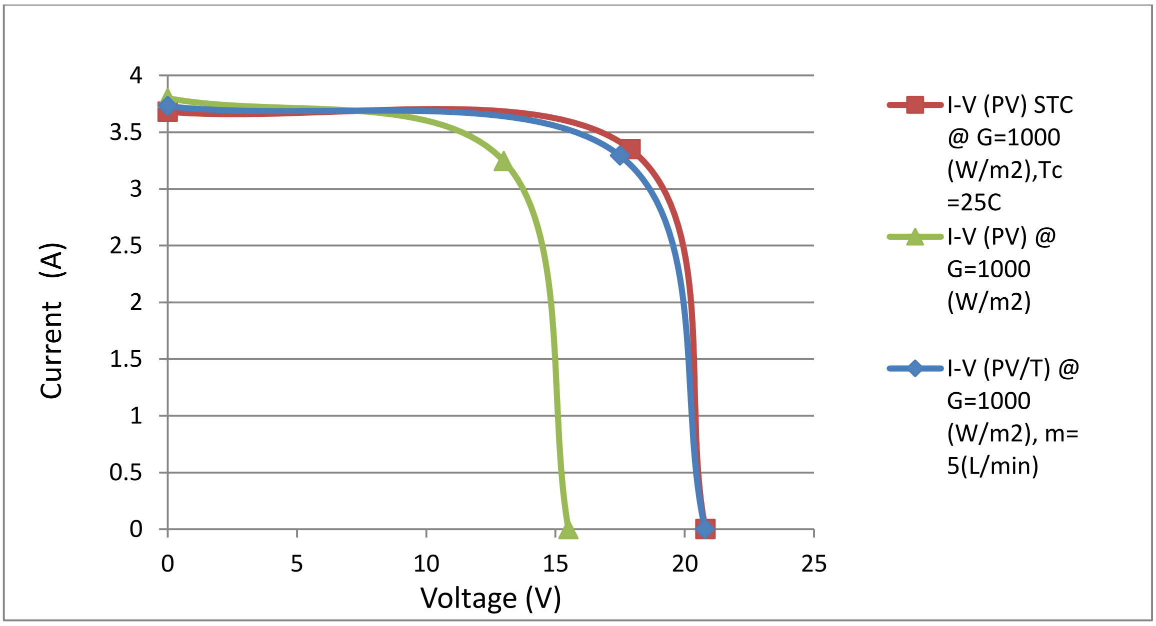


Figure5-8 I-V curve of the PV-STC module, PV module and PV/T water System

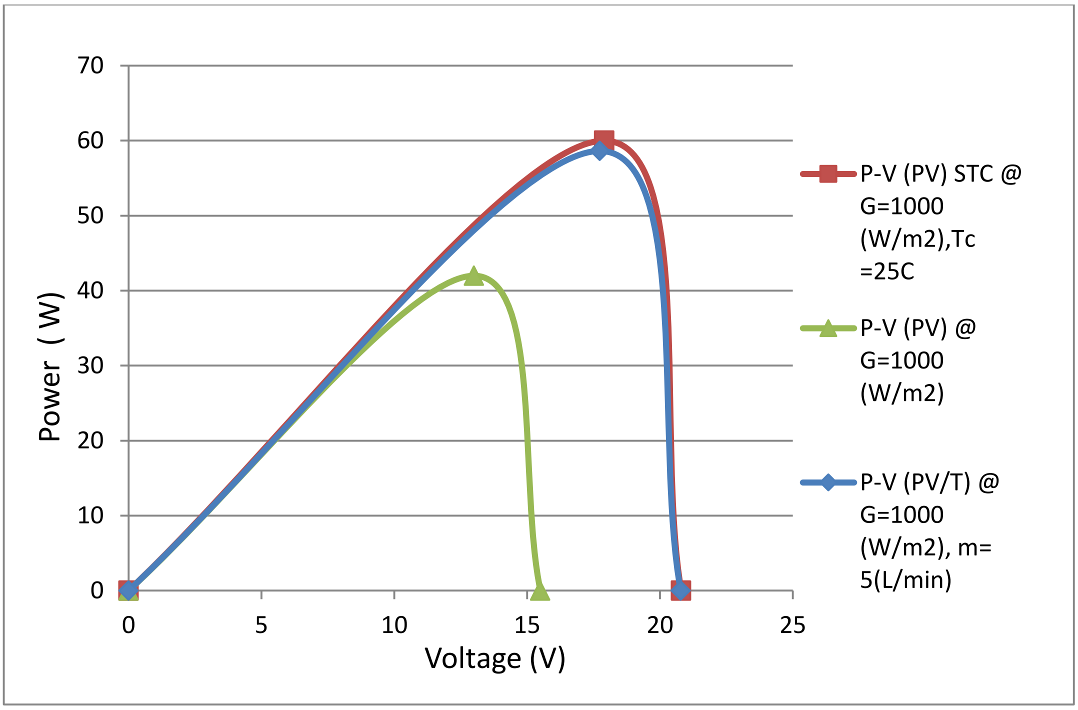


Figure 5-9 PV curve of the PV-STC module, PV module and PV/T water System

5.4.2 Photovoltaic (PV) panel (without absorber collector)

As seen in Figure 5-10, increasing cell temperature produces a rise in self-concentration, which increases the amount of reverse saturation current, thus it decreases the value of the circuit voltage as shown in Figure 5-11 and leads to a decrease in the maximum value of energy produced by the PV panel, as shown in Figure 5-12. Because the electrical power produced by the cell depends on two factors, the current and voltage.

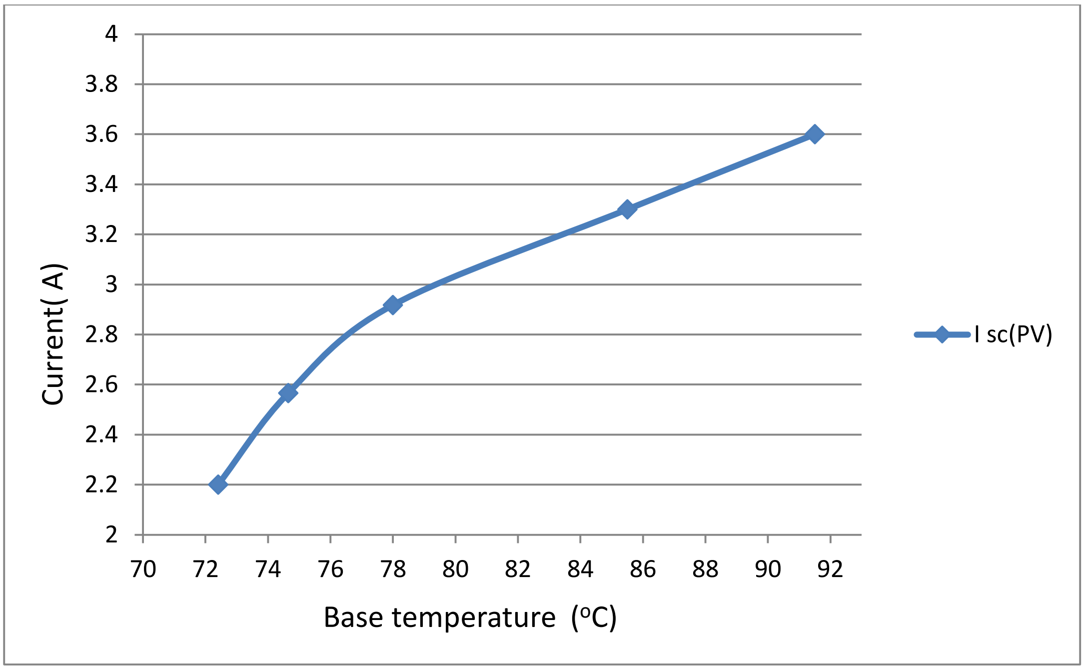


Figure 5-10 Short circuit current I_{sc} at the various of the base temperature T_b of PV module under solar radiation (600 - 1000) W/m^2

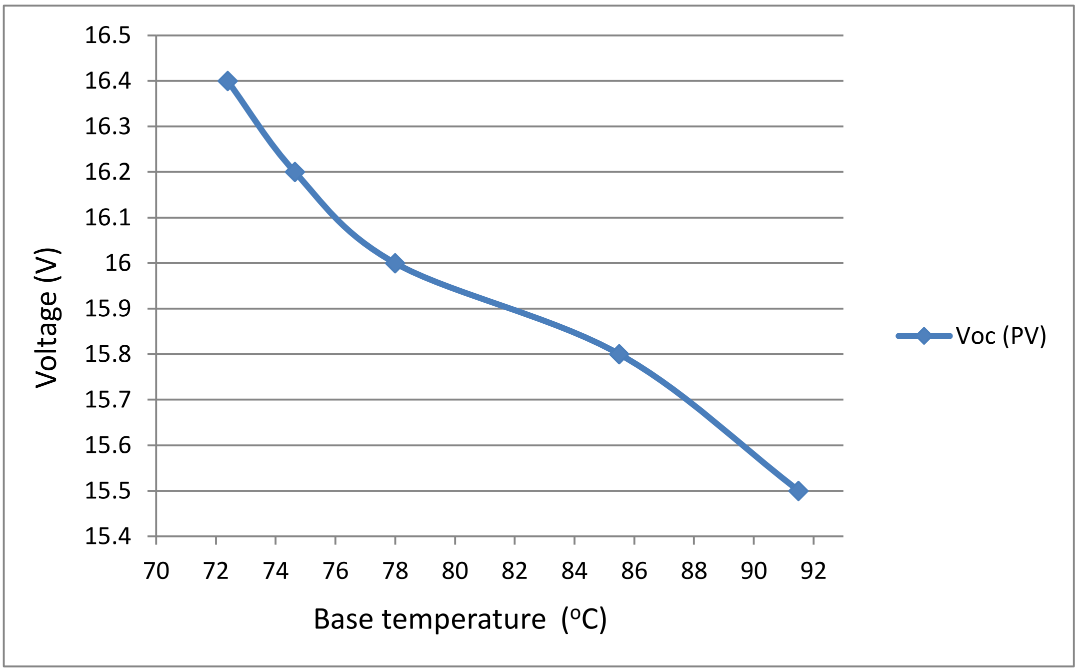


Figure 5-11 Open circuit voltage V_{oc} at the various of the base temperature T_b of PV module under solar radiation (600 - 1000) W/m^2

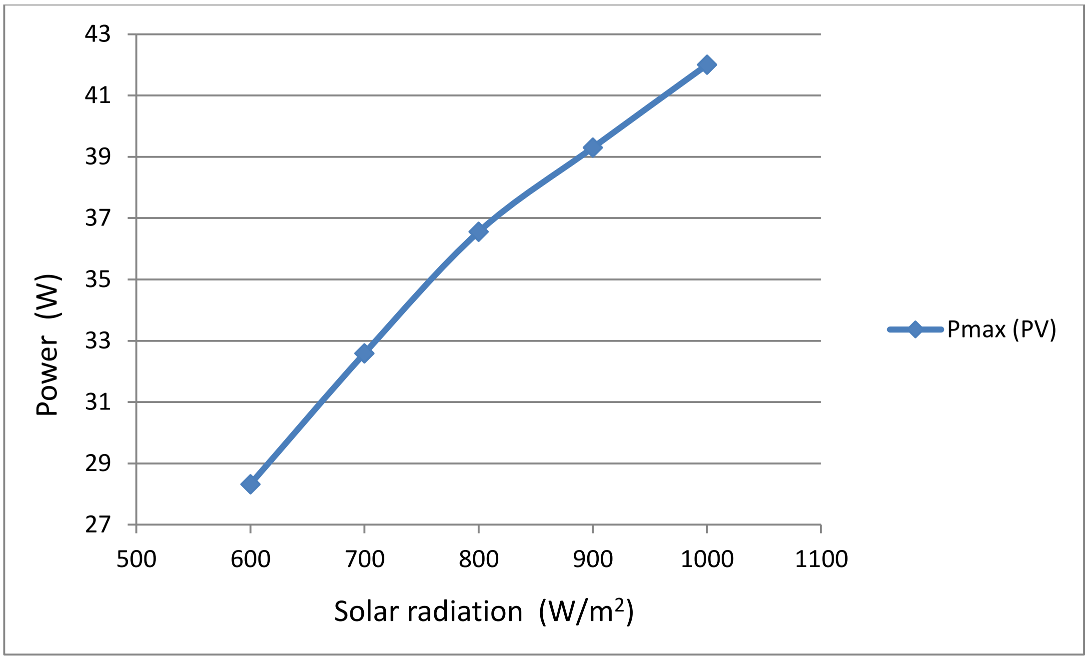


Figure 5-12 Electrical power *P* at the various of the solar radiation *G* of PV module.

Moreover, the change of maximum power has been identified clearly as in Figure 5-13 and Figure 5-14 respectively and the results of the increase in the productivity of electrical power indicated from 28.32 W to 42 W. Fill factor (FF) in this testing has been decreased from 0.785 at solar irradiance of 600 W/m^2 to 0.7526 at 1000 W/m^2. They are good range bounds for (FF), because they are within the limits of the fill factor based on Standard Test Conditions (S.T.C), which should be between 0.7 to 0.8, respectively. The electrical PV module efficiency indicates 11.8% at 600 W/m^2 and decreases to 10.511% at 1000 W/m^2.

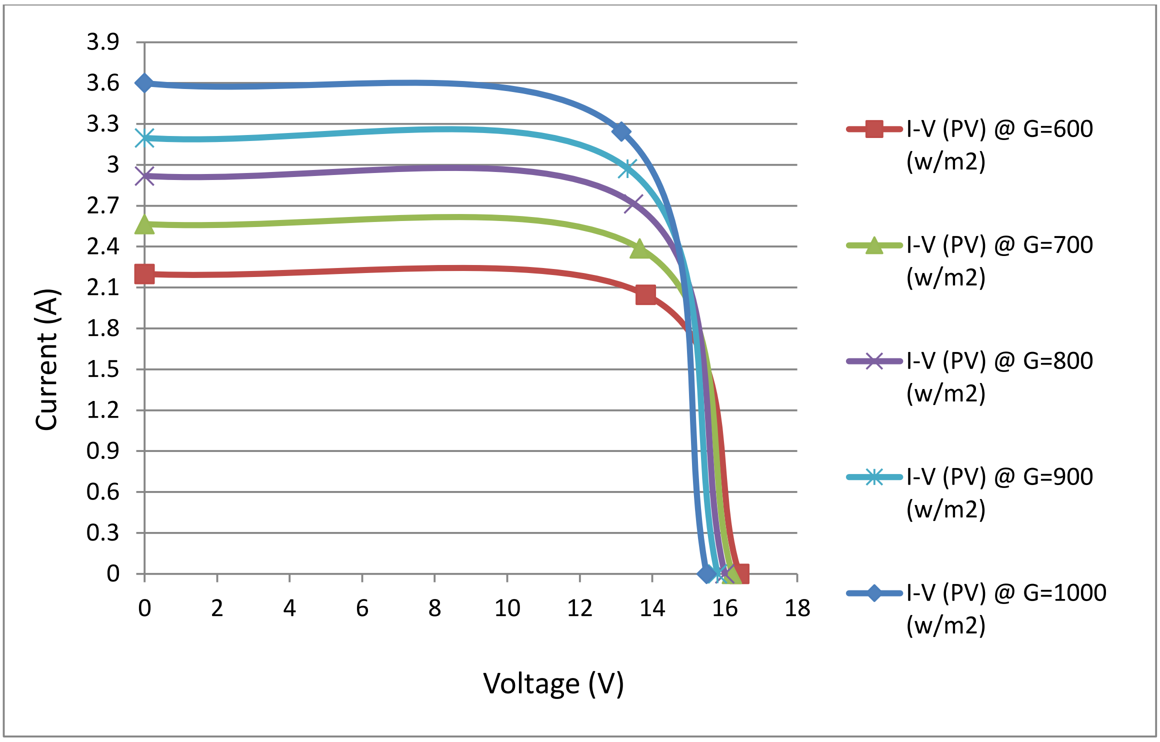


Figure 5-13 I-V curve for PV module for different solar radiation.

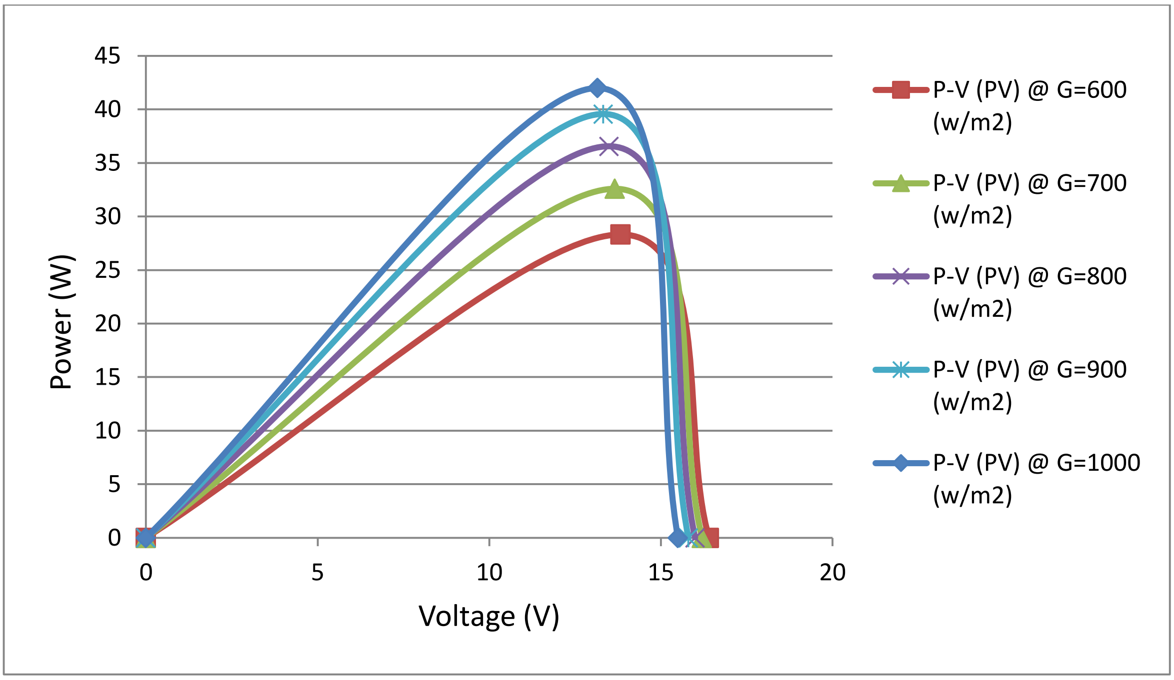


Figure 5-14 P-V curve for PV module for different solar radiation.

The PV panel efficiency which has been indicated is much lower compared specifications of PV panel at STC, as in Table 5-1, where the PV panel to produce V_{oc}= 20.8 V, I_{sc}= 3.68 A, and electrical efficiency by manufacturer was 15%. As a result, the dissimilarity of the power and efficacy values under experimental testing decreases compared to the provided by the manufacturer because electrical efficiency of PV module has been decreased as its temperature increases, the base temperature of the PV module increased while working and reached about 91.5 ° C and this will lead to more energy and efficiency loss.

Table 5-1 typical electrical characteristic of solar PV panel.

Details	Specifications
Solar cell type	Mono-crystalline silicon
Maximum power (W)	60
Open circuit voltage (V)	20.8
Short-circuit current (A)	3.68
Maximum power voltage (V)	17.9
Maximum operating current (A)	3.35
Cell efficiency (QUOTE %)	15
Standard Test Condition	G=1000(w/m^2), T_C = 25 (°C), AM= 1.5

5.4.3 Testing on Optimum design of PV/T Absorber Collector Using Water as Base Fluid

Performed Indoor Test Conditions of PV/T absorber collector experimentally in ambient temperatures and solar radiation, side to side traditional PV panel. During these tests, the PV panel and PV/T system are put together and then data is collected from the PV module and PV/T system at the same time. Changing the intensity of the solar radiation and the coolant flow rate of the photovoltaic thermal collector, variable results for V_{oc} and I_{sc} were obtained. Temperatures were measured for every (ambient, inlet flow, outlet flow, back surface of PV panel and PV/T collector) of Rig, then this data was recorded to determine the electrical power and electrical efficiency of the PV panel with cooling and without cooling. The PV panel and PV/T system has been exposed to the constant simulator of solar radiation for every test. Select ranges of solar radiation from 600 W/m^2 to 1000 W/m^2 to compare between PV traditional panel and PV/T system.

When the load has been applied to the PV panel and PV/T system at same time and same load, the changes of current and voltage have been recorded for every intensity value of solar radiation. Arduino is a DC programmable electronic load for measuring and plotting the I-V curve. In addition, the thermal data from the test was collected using a data logger and then applied in the mathematical relationship to arrive at the results. For this testing supplied the volume flow rate from 1 to 5 LPM and setting any varies on the collector channel due to these flow rates have been recorded.

a. I-V and P-V curves for PV/T system at different solar radiation

Figure 5-15 and Figure show the results obtained from the PV/T absorber thermal collector under the influence of different solar radiation. The solar radiation for this test was selected as (600, 700, 800, 900, 1000) W/m^2 use to measure and draw the *I-V* curves, mass flow rates ranging (1-5) LPM. From the *I-V* and *P-V* curves results of PV/T system, it can be simplified that the I_{sc} *and* V_{oc} increased linearly with the increases of solar radiation received to the PV panel.

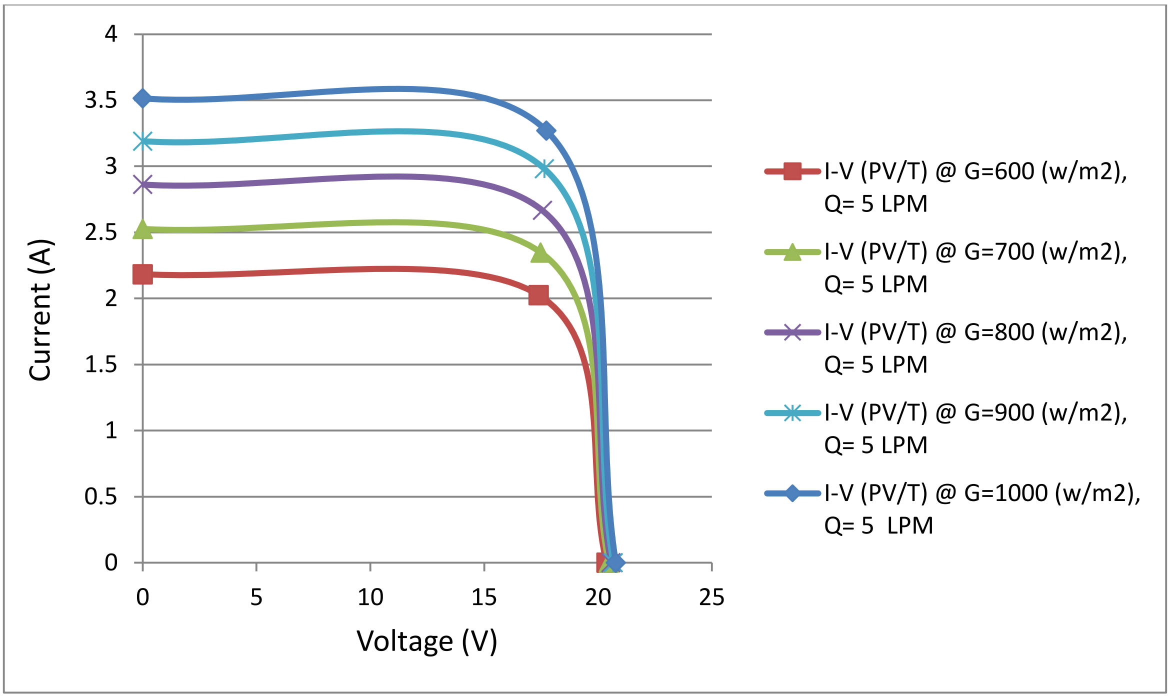


Figure 5-15 I-V curve for PV/T module for different solar radiation at m = 5 LPM.

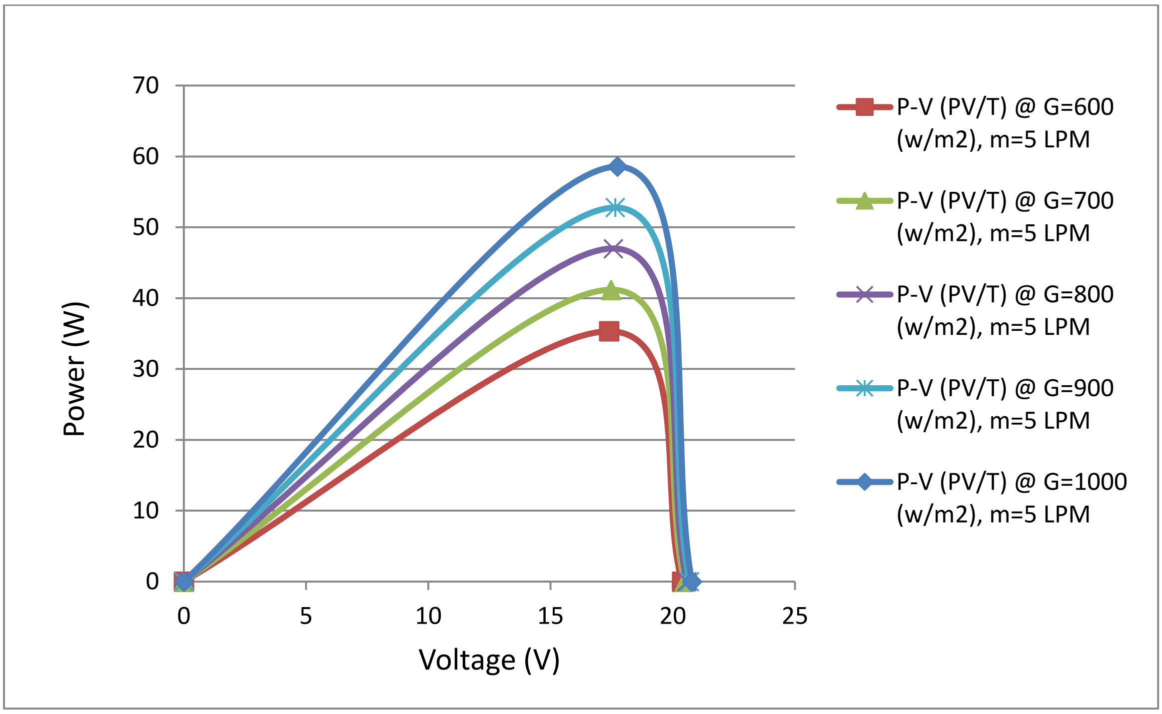


Figure 5-16 Characteristic of PV/T system for different solar radiation at flow rate 5 LPM.

b. I-V and P-V for PV/T absorber collectors at different volume flow rates

Heat effects are the results of an inherent characteristic of the PV/T system, i.e. the photovoltaic cells, where the voltage of PV panel decreases with increasing temperature. Thus, temperature will play an important role in the characteristics of the PV panel *I-V* and *P-V* curves. As the temperature of the PV panel increases due to exposure to sunlight, the Isc will increase slightly and at the same time the Voc will decrease compared to a STC for the PV panel.

The results on the effect of temperature over electrical characteristic of the PV/T collectors were shown clearly in Figure 5-17 and Figure 5-18. In this temperature effect testing, the ambient indoor condition temperature was set constantly at 34 ^oC with solar radiation of 1000 W/m^2 and volume flow rate varied (1-5) LPM. It can be seen that when the volume flow rate is increased, the average PV/T unit temperature decreases. The collector of the base PV/T panel temperature deceased from 35.5^{o}C to 30.3^{o}C, while it increased the volume flow rate (1-5) LPM. Because of the temperature decreased, the V_{oc} for the collectors also have been increased form 20.65V to 20.77V for PV/T system, meanwhile, the I_{sc} for PV/T system has been shown to decrease from 3.56A to 3.515A.

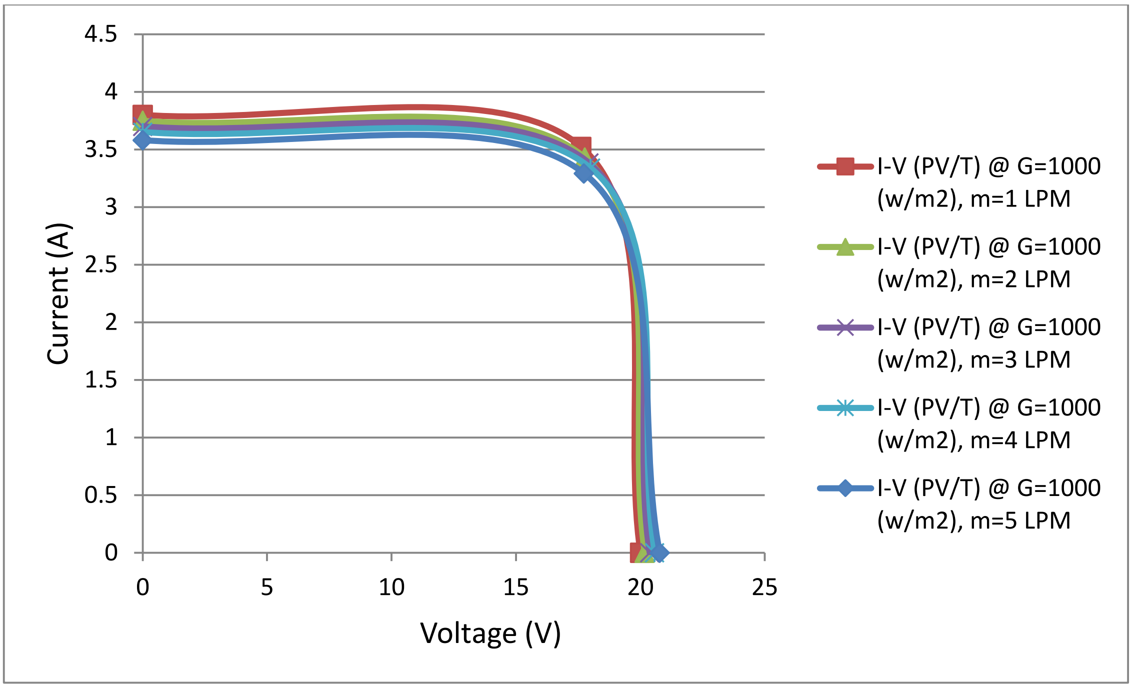


Figure 5-17 *I-V* curve of the PV/T module for various volume flow rate at 1000 (w/ m^2).

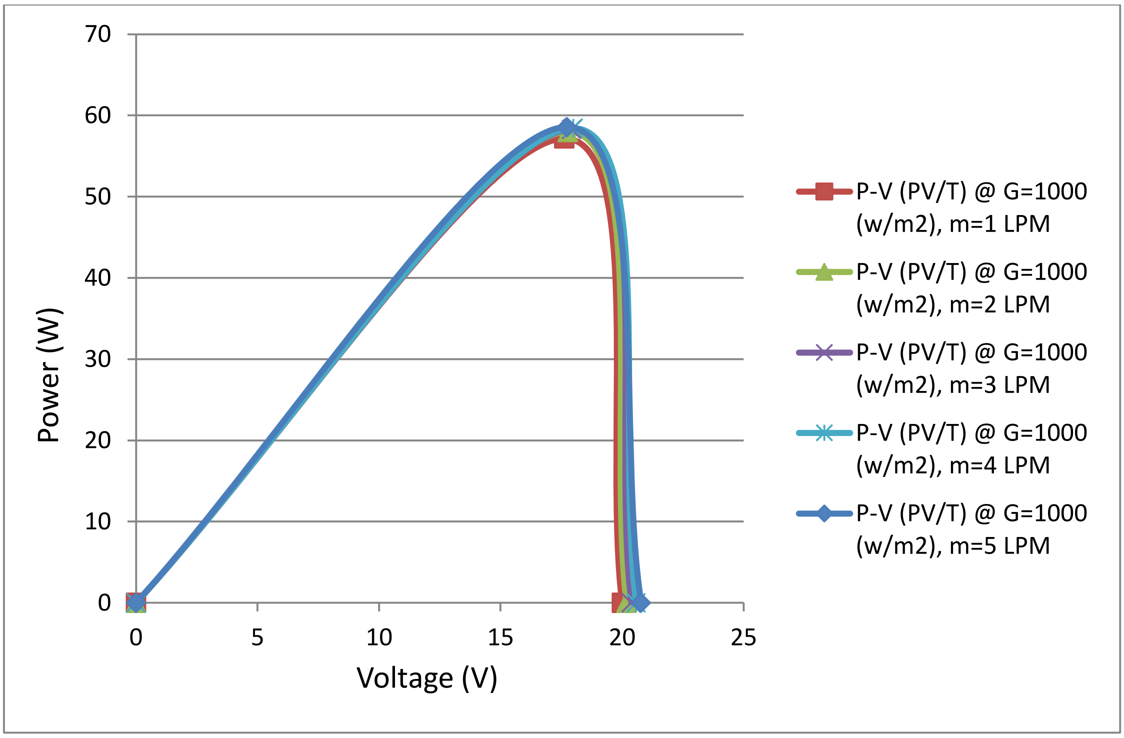


Figure 5-18 *P-V* curve of the PV/T module for various volume flow rate at 1000 (w/ m^2).

c. Maximum power (P_{max}) for PV/T absorber collectors using water as base fluid at different solar radiation

Figure 5-19 shows the maximum power value P_{max} of the PV/T system, where an increase in the maximum electrical power of a PV/T system can be observed with the increase in solar radiation as compared to the traditional PV panel.

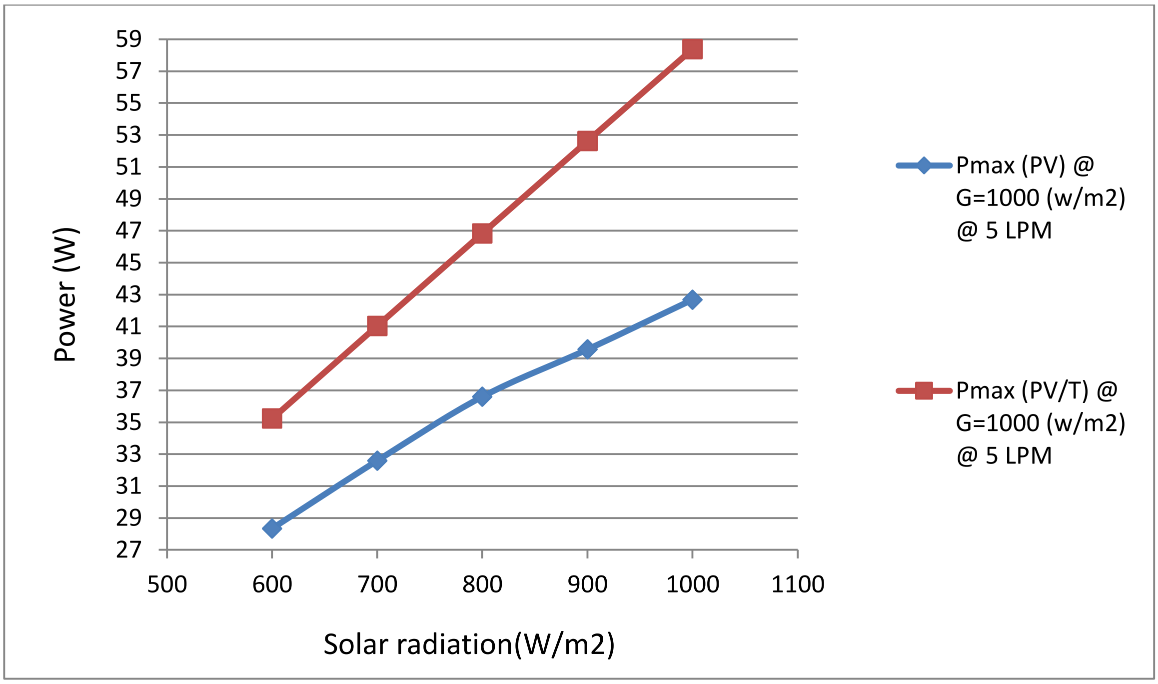


Figure 5-19 The comparison of PV/T water system with traditional PV module on the P_{max} with various solar radiation at flow rate of 5 LPM.

d. Maximum power (P_{max}) of the various base PV, PV/T module temperature (T_b) for PV/T absorber collector using water as base fluid

The total maximum power P_{max} is affected by increasing the temperature of the PV panel, as illustrated in Figure 5-20. In this testing of the PV/T system, the P_{max} decreased from 58.568W to 57.164W at volume flow rate (1-5) LPM.

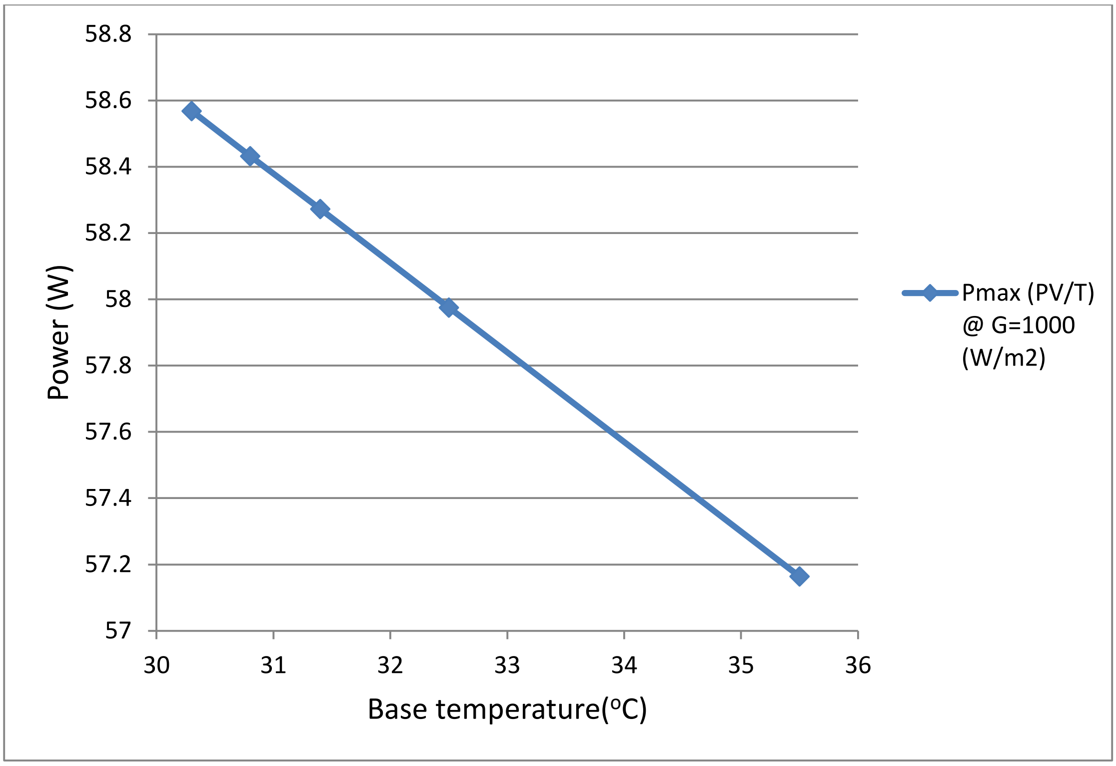


Figure 5-20 Changes of P_{max} over T_b of PV/T water system under solar radiation of 1000 w/m^2 and volume flow rate of (1 to 5) LPM.

e. Effect on the base PV/T module temperature (Tb) over open circuit voltage (Voc)

The open circuit voltage V_{oc} will decrease linearly as the temperature of the PV module rises. At 1000 W/m2 of solar radiation, this behavior is readily visible as shown in Figure 5-21. After applying solar radiation to the basic design, a change in the amount of V_{oc} and I_{sc} occurred according to the change in the amount of T_b. At (1-5) LPM and 1000 W/m^2, the experimental V_{oc} decreased from 20.7V to 20.5V when the base temperature Tb of the PV/T system was increased from 30.3°C to 35.5°C.

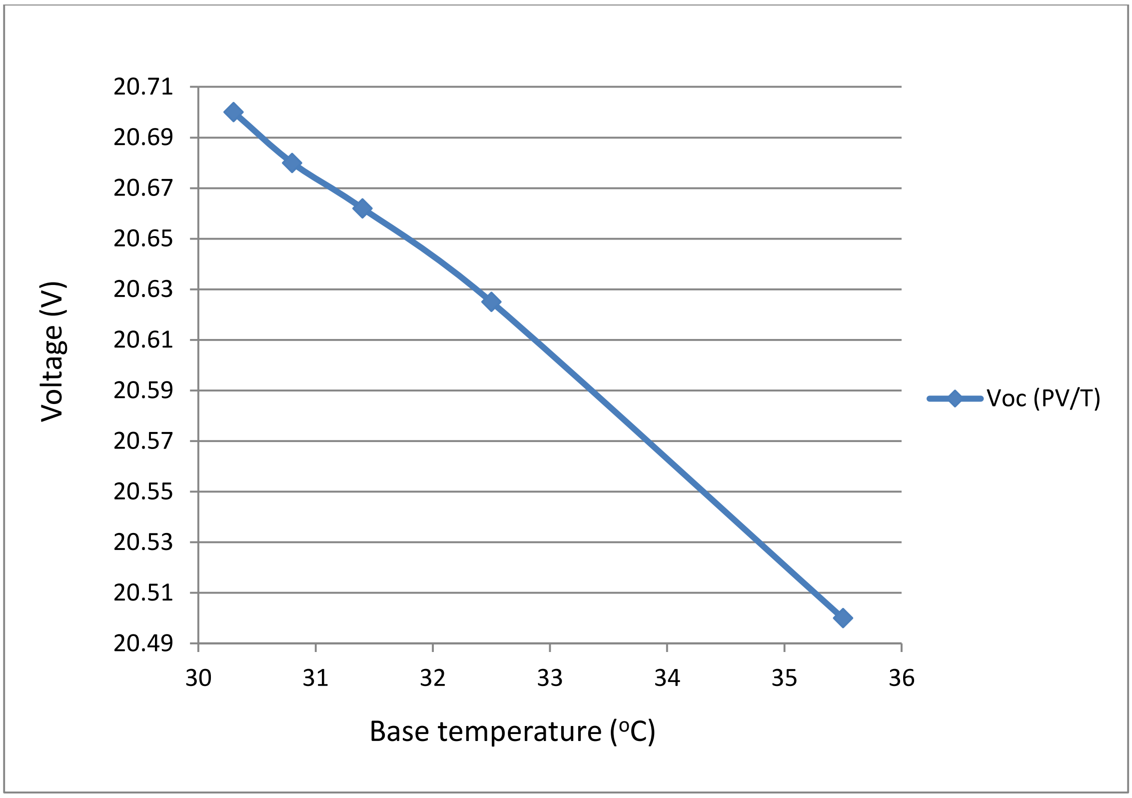


Figure 5-21 Effect of T_b over V_{oc} for PV/T system under solar radiation of 1000 w/m^2 and volume flow rate of (1 to 5) LPM.

f. Effect on the base PV/T module temperature (T_b) over short circuit current (I_{sc})

Under particular solar radiation, the Isc rose proportionally with the decrease in mass flow rate due to temperature fluctuations in the PV module as shown in Figure 5-22. When the volumetric flow rate decreased and the solar radiation was 1000 W/m^2, the I_{sc} began to rise, as this occurred due to the rise in the temperature of the photovoltaic panel. The rise in the creation of electron-hole pairs by heat generation in P-N junction in the PV cell.

The I_{sc} increase was considered small when compared to V_{oc} decrease due to an increase in the temperature of the PV module. It clearly shows slight increase of I_{sc}, at solar radiation of 1000 W/m^2 with volume flow rate of (1-5) LPM, in the PV/T system the I_{sc} increased from 3.515 A to 3.56 A.

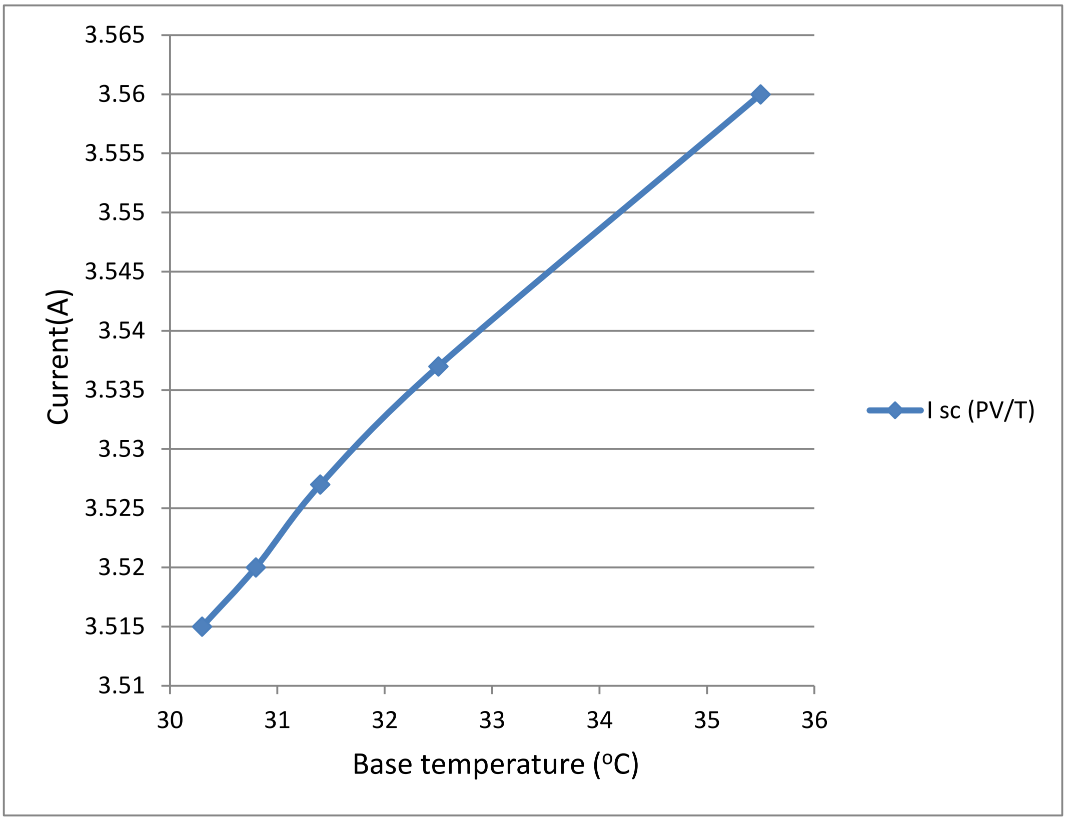


Figure 5-22 Effect of T_b over I_{oc} for PV/T system under solar radiation of 1000 w/m^2 and volume flow rate of (1to 5) LPM.

5.4.4 Performance and Efficiency of the PV/T System at used the Water as Base Fluid

Electrical and thermal parameters affect the performance and effectiveness of PV/T systems. The mathematical relationships were applied to the virtual and experimental design of the PV/T system and we get the electrical efficiency of the both design. The testing has been performed in Al-Najaf Technical College-Iraq (indoor test condition) for the PV panel and PV/T system under a constant of (solar radiation and ambient temperature) respectively with different mass flow rates to predict in the temperatures of (PV panel, PV/T system and water inlet and outlet) at the testing, for PV panel, PV/T system can be calculated the electrical efficiency.

a. The influenced of base PV/T module temperature and electrical PV/T efficiency over volume flow rate on PV/T system

The heat from the PV panel is absorbed by the water passing from above and below of PV panel through the thermal collector channel which is pre-designed and engineered by CNC machine, thus it will affect the cooling of the PV panel. This effect is caused by the change in the flow rate inside the thermal channel collector of the PV/T system and can be seen in the Figure 5-23 and Figure 5-24. Pumping supplied from 1 to 5 LPM has been used in this testing which later applied with a solar radiation for indoor test condition, where (600-1000) were selected W/m^2. The results showed that by increasing the flow rate simultaneously the temperature of the PV/T system decreased, in addition to the decreased temperature of the outlet water T_{out} at any solar radiation levels at the same mass flow rate.

At lower mass flow rates, this behavior is readily visible. As shown in Figure 5-23 of PV/T system at flow rate (1- 5), LPM with solar radiation of 600 W/m^2 indicated decreased temperature from 32.1^{o}C to 29.2^{o}C, simultaneously the electrical PV/T efficiency increased from 14.52% to 14.72% as shown in Figure 5-24. When the solar radiation increased up to 1000 W/m^2, the temperature decreased from 35.5 ^{o}C to 30.3 ^{o}C as shown in Figure 5-23 and the electrical PV/T efficiency increased from 14.291% to 14.642% as shown in Figure 5-24.

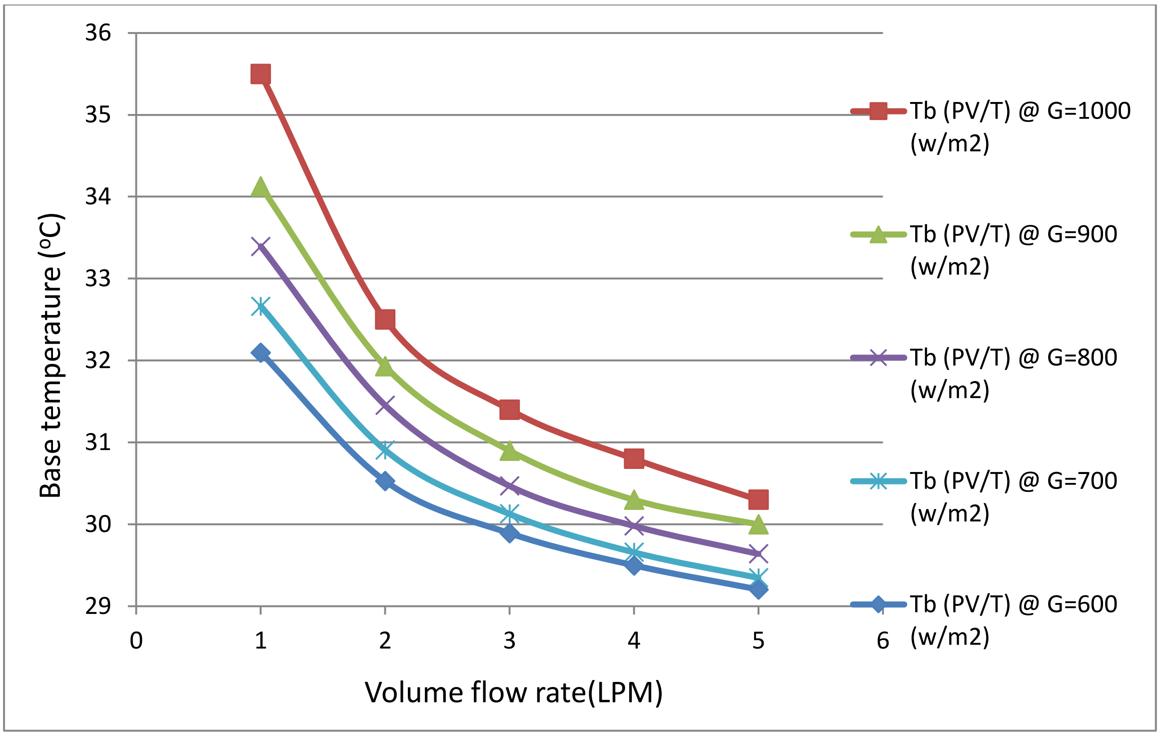


Figure 5-23 Changes of base temperature (T_b) of water PV/T system over volume flow rates under various solar irradiance

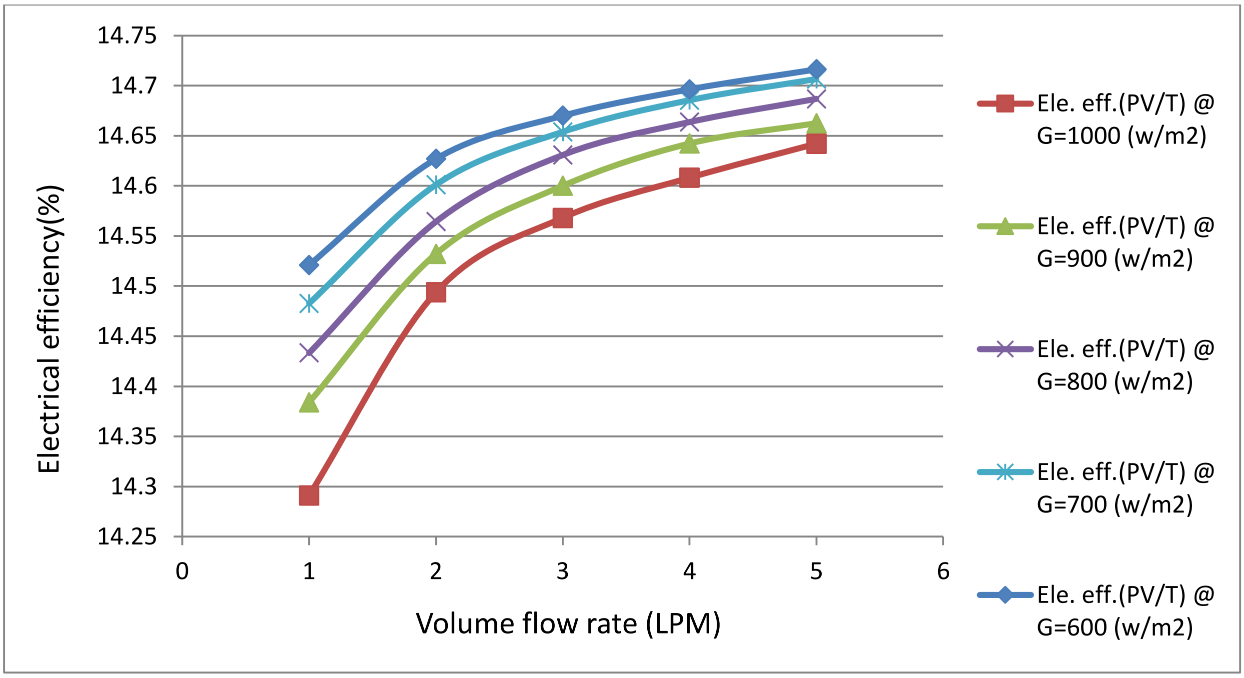


Figure 5-24 Changes of electrical efficiency (η_{el}) of PV/T system over volume flow rates under various solar irradiance.

b. The performance of PV/T system

The performance of the PV/T system can be depicted by the effectiveness of the thermal collector channel. This is measured in the amount of increase in the electrical efficiency of the photovoltaic panel to evaluate the overall performance of the system. Based on the tests performed on the PV/T thermal collector, it has been shown that the electrical efficiency increases when the mass flow rate increases at the same intensity of solar radiation. Figure 5 – 25 illustrates the electrical efficiency variation in the traditional PV panel and PV/T system at different solar radiation when the flow rate was 5 LPM. The results have shown that the electrical efficiency of traditional PV panel without cooling variation between (10.5-11.6) %, while the electrical efficiency of PV/T system varied between (14.6-14.7) %.

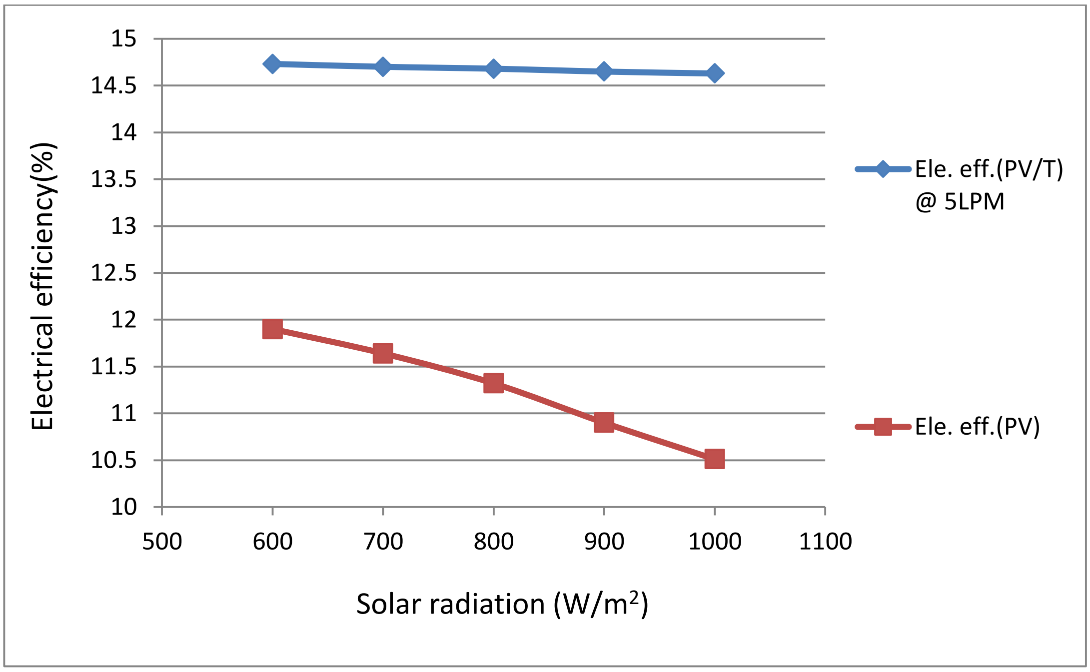


Figure 5-25 Electrical efficiency of PV/T water system and PV panel variation with different solar irradiances at volumetric flow rate of 5 LPM.

5.5 Numerical, Experimental Validation and Comparison Results

In this section, a comparison was done between the numerical and experimental results, as well as a comparison with earlier studies. During the analysis, the following factors are taken into account:

1. Effect of the base temperature T_b on the PV panel at the various solar radiation.
2. Effect of the base temperature T_b on the PV/T system at the various flow rate and constant solar radiation.
3. Effect of the outlet temperature T_o on the PV/T system at the various flow rate and constant solar radiation.
4. Electrical efficiency of the PV panel and PV/T system.

5.5.1 Numerical and experimental Comparison of Tb and To for the PV panel and PV/T system respectively.

a. Comparison base temperature T_b of the PV panel at deferent solar radiation.

Figure 5-26 showed the affected of base temperature T_b towards the various solar radiation. In general, the results obtained from the numerical and experimental study showed that for PV panel, the base temperature T_b of the PV panel at solar radiation of (600-1000) W/m^2 in the numerical result was (63.595, 69.8544, 76.723, 89.642) oC and (68, 74.65, 81, 87, 92.5) oC for the experimental results.

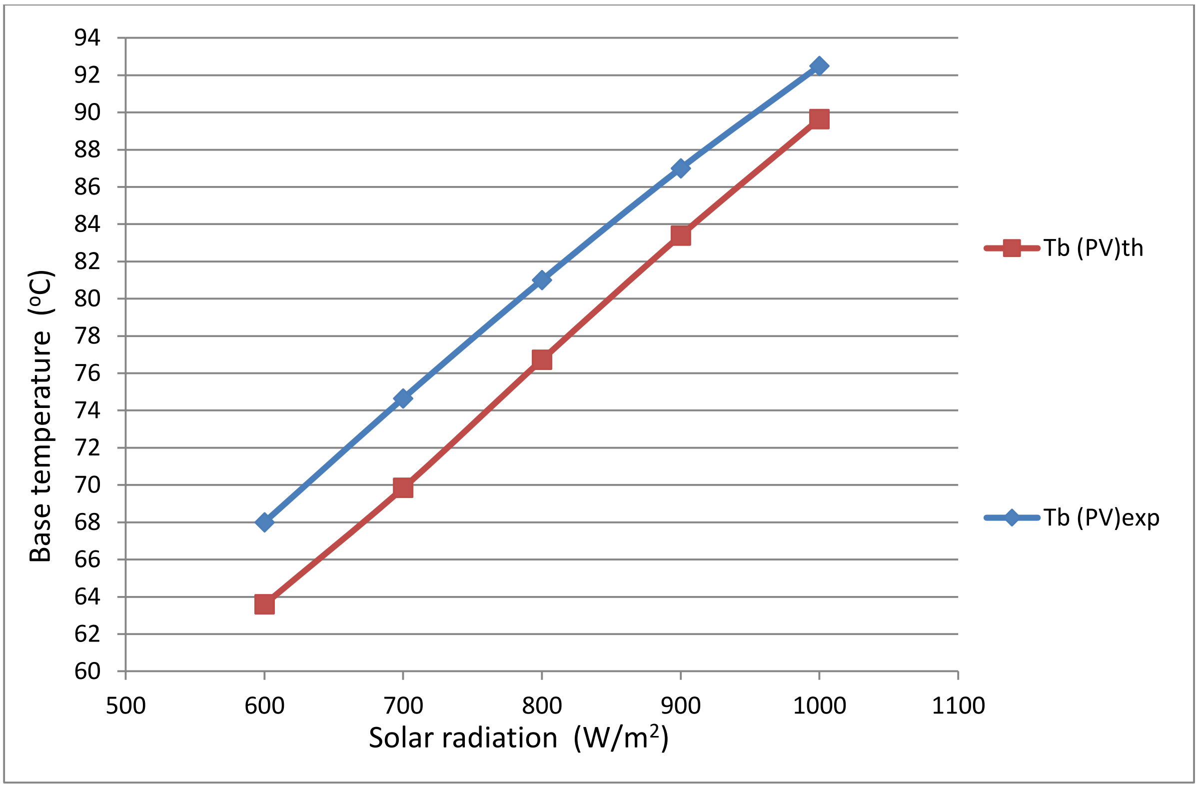


Figure 5-26 Base temperature T_b over solar radiation in comparison on numerical and experimental results for PV panel.

b. Comparison outlet temperature T_o of the PV/T system at deferent mass flow rates.

Figure 5-27 showed the effect of outlet temperature T_o towards the various flow rate at flow rate. In general, the results obtained from the numerical and experimental study showed that for PV/T water system under flow rate (1-5) LPM and 1000 W/m^2 of solar radiation, the outlet water temperature T_o of the PV/T system in the numerical result was (35.5, 31.418, 29.725, 28.878, 28.38)^{o}C, while the outlet water temperature T_o of the PV/T system in the experimental result was (34, 30.6, 29.2, 28.4, 27.9)^{o}C.

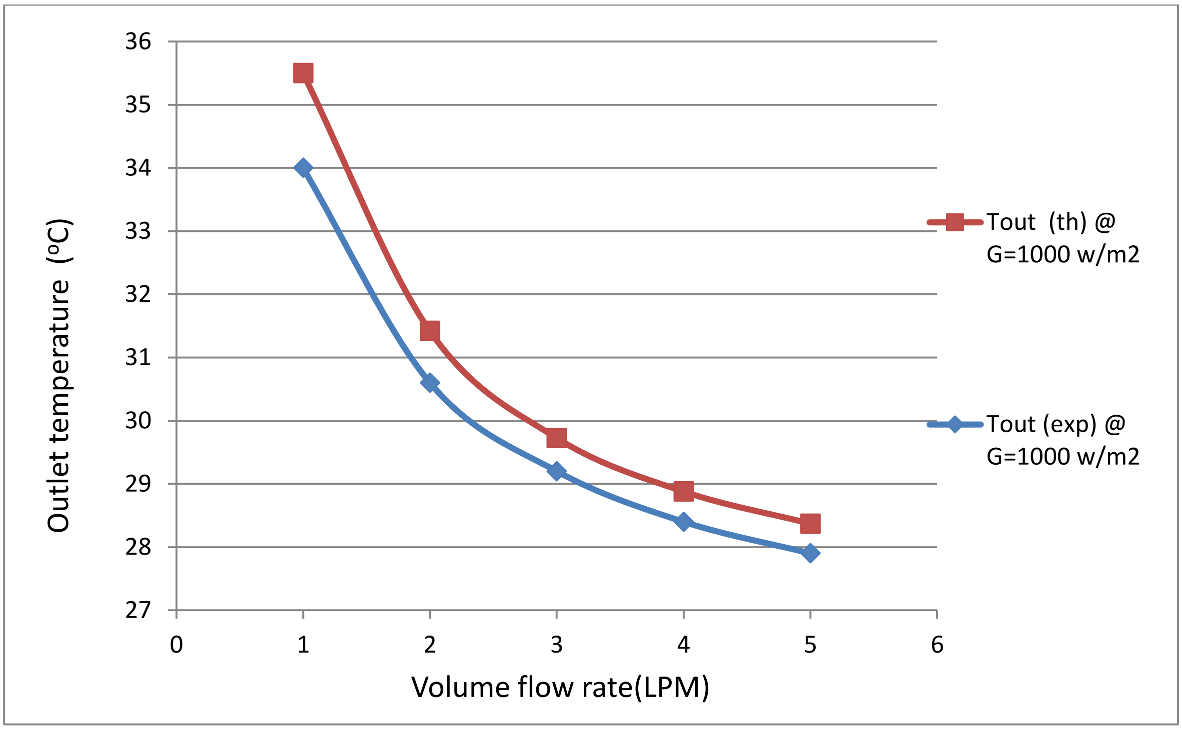


Figure 5-27 Outlet temperature T_o over volume flow rate in comparison on numerical and experimental results for PV/T water system.

5.5.2 Comparison electrical efficiency *η*e of the PV/T system at deferent mass flow rates.

The change in the electrical efficiency of the PV/T system can be observed, for both numerical and experimentally with the increase of the flow rate. It is observed that the both numerical and experimental electrical efficiency of the PV/T system changed under of testing with volume flow rate 1 to 5 LPM and solar radiation of 1000 w/m^2.

Figure 5-28 shows the results of the PV/T water system increased for numerical and experimental electrical efficiencies from 14.42% to 14.72% and 14.29% to 14.649% respectively. From the results, it can be concluded that the experimental results show an acceptable agreement compared to the numerical results.

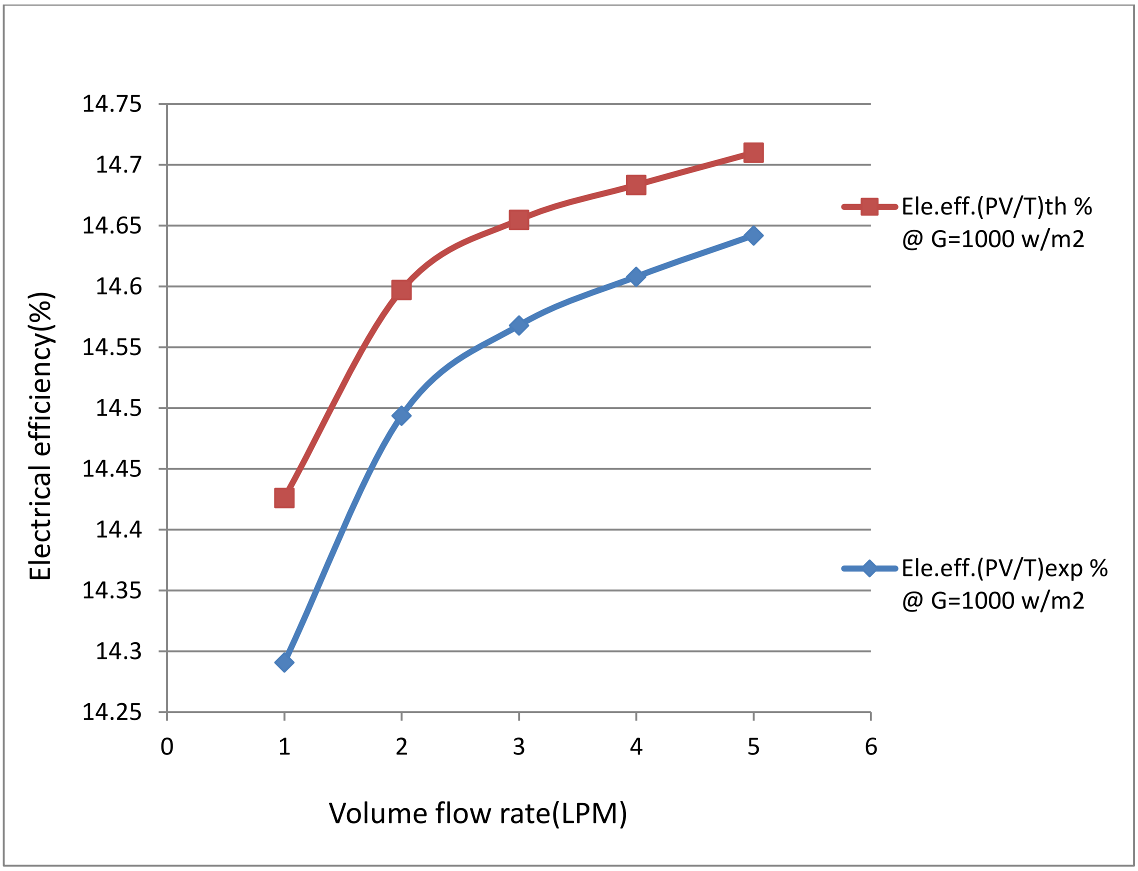


Figure 5-28 Electrical efficiency η_e over volume flow rate in comparison on numerical and experimental results for PV/T water system.

Chapter Six

Conclusions

and

Recommendations

CHAPTER SIX

6.1 Conclusions

The final conclusion can be summarized based on the theoretical and experimental results as follows:

1. Cooling photovoltaic cells by immersion in pure water is an effective technology and at a lower cost to increase their performance and electrical efficiency.
2. The pure water immersion cooling system helps clean the photovoltaic panels from dust and dirt that negatively affect the performance and efficiency of the photovoltaic panels.
3. Through different researches, there are several methods of cooling that were used. The current study reached a previously unused model, according to the best knowledge of the researcher, which is immersed PV panel a forced flow water from the top and bottom of the panel. It proved successful in improving the performance.
4. The theoretical or numerical validation with experimental results of the research gives high reliability to the researcher during the study.
5. The use of modern and developed devices and equipment with high reliability increases the speed of completion of the test.
6. The control of the mass flow rate is necessary to increase the electrical energy and efficiency of the photovoltaic panels. The highest numerical and practical electrical energy and efficiency are (58.5, 58.8) W and (14.72, 14.64) % respectively.

7. At the best mass water flow rate, the temperature decreased to about (30.3°C) at 1000 W/m^2 and 5 LPM, which led to an increase in the energy and electrical efficiency of the photovoltaic panels.
8. After the cooling process with forced flow water immersion technology of photovoltaic panels with pure water, the percentage increased in the maximum electrical efficiency of the panels is (38.6) %.
9. The net electrical power gain of the photovoltaic panel after cooling technology is (12) W.

6.3 Recommendations for Future Work

It is possible to suggest some recommendations for future work:

1. A thermal study of the collector can be made to take advantage of the hot water.
2. Nano can be used to increase heat exchange and improve the electrical performance of the panels.
3. The free-circulation fluid load can be applied to gain or utilize the energy expended on the pump.
4. The use of underground cooling technology, the use of a water tank buried underground and a pump to cool the water in the heat exchanger

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LIST OF APPENDICES

Appendices

Appendix A

Table A.1: Specifications of the solar power meter (model TENMARS TM 207).

Property	Value
Range	From 0 to ~2000 W/m2
Temperature Error	±0.38 ºC
Drift	< ± 2% per year
Accuracy	±10 W/m2 or ± 5 %
Sampling Time	0.25 Second
Operating Temperature	From 0 ºC to 50 ºC
Spectral response	400 nm - 1100 nm
Humidity	< 80 % RH
Weight	0.5 kg
Dimensions W/D/H	22.5 cm / 15.75 cm / 4.75 cm
Battery	1pcs 9 V

Table A-2: Specifications of the (Data Logger)

Value	Property
Resolution	(0.1) °C
Thermocouple compatibility	(S,J,B, K,N, T, E)
Accuracy	(0.3)% + (1)°C
Range	(-200 to 1300)°C (this varies based on the type of thermocouple)
Interface	U-Disc interface RS233C interface Mini USB (virtual serial port)
Speed	Fast: 100 ms /channel, Medium: 500 ms /channel Low: 1ms /channel
Comparator	High and low beep High and low value setting individually for each channel
Correction	Error correction for each channel

Table A-3: Specifications of the Anemometer (model AM-4826)

Property	Value
of velocity	From 0.4 m/s to ~30 m/s
Range of temperature	From 0 ºC to 50 ºC
Accuracy	±2 %
Display	10mm(0.4") 4-digits LCD
Operating temperature	From 0 ºC to 50 ºC
Humidity	< 85 % RH
Weight	0.3 kg
Resolution	0.1 (m/s, km/h and ft/min)
Device screen	Large LCD display for easy viewing (4 digits of 10 mm).
Dimensions W/D/H	14.1 / 7.1 / 3.2 cm
Power Supply	1 x 9 V 6 F22
Sensor head	7.2 cm Diameter

Appendix B

Table B: Calibration of K-type thermocouples provided from the test with Hg-thermometer

Sensor type	Freezing water temperature 0^oC	Boiling water temperature 100^oC
Mercury thermometer	0.11	99.7
Sensor 1	0.16	99.31
Sensor 2	0.1	99.60
Sensor 3	0.12	99.25
Sensor 4	0.17	99.66
Sensor 5	0.13	99.81
Sensor 6	0.09	99.82
Sensor 7	0.1	99.36
Sensor 8	0.14	99.65
Sensor 9	0.17	99.55

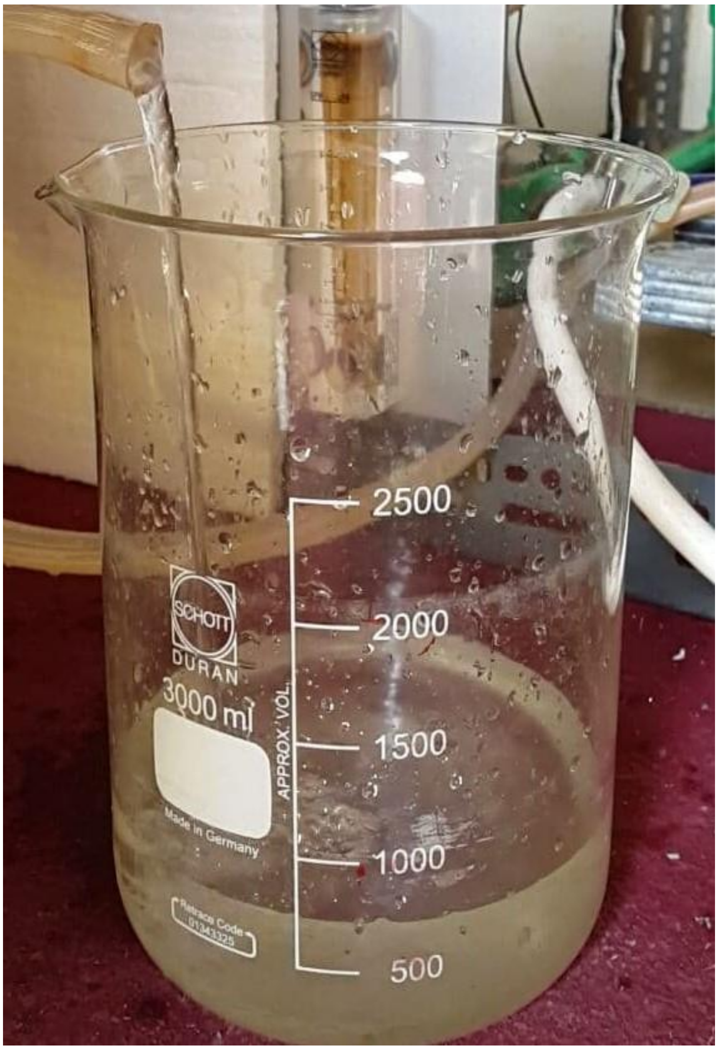
Sensor 10	0.13	99.88
Sensor 11	0.15	99.64
Sensor 12	0.17	99.74
Sensor 13	0.18	99.63
Sensor 14	0.13	99.49
Sensor 15	0.14	99.52
Sensor 16	0.13	99.36
Sensor 17	0.14	99.85
Sensor 18	0.11	99.66
Sensor 19	0.16	99.51
Sensor 20	0.18	99.85
Sensor 21	0.13	99.24
Sensor 22	0.13	99.55

Calibrated Flow meter Device

A flow meter is a device that measures the rate at which water flows. Then, a flow velocity of the water can be obtained. A type of the flow meter is AM-4206M as shown in

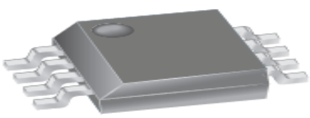
Figure(4- a. The flow-meter was calibrated by a known size vessel with stop watch, as shown in the

Figure(4-b.



Figure(4- a) Flow meter. (b) Calibrated the Flow meter by a known size vessel with stopwatch.

Datasheet of the Arduino Device (Uno Type).

<table>
<tr><th>Sensor</th><th colspan="5">Specifications</th></tr>
<tr><td rowspan="2">DHT11–Temperature and Humidity Sensor
</td><td colspan="5">Relative Humidity
Resolution：16Bit
Repeatability：±1%RH
Accuracy：25℃ ±5%RH
Interchangeability: Fully interchangeable
Response time：1/e (63%)25℃ 6s
1m/sAir6s
Hysteresis：<±0.3%RH
Long-term stability：<±0.5%RH/yr</td></tr>
<tr><td colspan="5">Temperature
Resolution：16Bit
Repeatability：±1℃
Accuracy：25℃ ±2℃
Response time：1/e (63%) 10S
Electrical Characteristics
Power supply: DC 3.3～5.5V</td></tr>
<tr><td rowspan="4">ACS712-Fully Integrated, Hall-Effect-Based Linear Current Sensor IC with 2.1 KVRMS Isolation and a Low-Resistance Current Conductor
</td><td>Part Number</td><td>Packing*</td><td>TA (°C)</td><td>Optimized Range, IP (A)</td><td>Sensitivity, Sens (Type) (mV/A)</td></tr>
<tr><td>ACS712ELCTR-05B-T</td><td>Tape and reel, 3000 pieces/reel</td><td>–40 to 85</td><td>±5</td><td>185</td></tr>
<tr><td>ACS712ELCTR-20A-T</td><td>Tape and reel, 3000 pieces/reel</td><td>–40 to 85</td><td>±20</td><td>100</td></tr>
<tr><td>ACS712ELCTR-30A-T</td><td>Tape and reel, 3000 pieces/reel</td><td>–40 to 85</td><td>±30</td><td>66</td></tr>
<tr><td>Arduino 25V Voltage Sensor Module
</td><td colspan="5">• Input Voltage: 0 to 25V
• Voltage Detection Range: 0.02445 to 25
• Analog Voltage Resolution: 0.00489V
• Needs no external components
• Easy to use with Microcontrollers
• Small, cheap and easily available
• Dimensions: 4 × 3 × 2 cm</td></tr>
</table>

Appendix C

LIST OF PUBLICATIONS

1. Published of the paper" The Impact of Surface Temperature on the Performance of Photovoltaic Cells: Review"

Al-Furat Journal of Innovations in Mechanical and Sustainable Energy Engineering (FJIMSE) Published by Al-Furat Al-Awsat Technical University (ATU) / Iraq
ISSN: 2710-3374

The Impact of Surface Temperature on the Performance of Photovoltaic Cells: Review

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https://dx.doi.org/10.52262/150821-03

Abstract: The sun is an incredible energy source at which point the sunlight radiates to the earth's surface is transformed to electrical power via photovoltaic cells. However, a small portion of absorbed sunlight will be utilized in an electrical grid, while the remaining is lost in the form of heat. The rise in temperature negatively affects the cell's efficiency and reduces the cell's life span. In order to get rid of this side effect, many different cooling techniques were used. This paper is reviewing the existed technologies that are used to reduce the impact of temperature on (PV) performance that aims to achieve the highest efficiency.

Keywords: Photovoltaic Cell, Efficiency, Cooling Methods, Solar Energy

1. INTRODUCTION

In any country in the world, the standard of people's lives depends on the economic growth in the country, and economic growth depends on the consumption and provision of energy. In countries with high financial capital, it may be more than the literacy rate in countries with less electricity consumption. In most countries, fossil fuels, including gas, oil, and coal, oil are the foundation for energy consumption. This energy produces damage and pollutants to the environment, as it is one of the main factors for air pollution and the cause of global warming [1]. The crisis of saving fuel and its low price, in addition to waste and damage affecting the environment increasingly, led to attempts to find alternatives [2]. Due to an increase in the usage of fossil energy to produce electric power, environmental problems have become

2. Published of the paper "Improvement of the PV Module Performance by Cooling Method Through Immersing in a Forced Water Circulation"

IICESAT Conference, College of Material Engineering, University of Babylon, Iraq IOP Publishing
Journal of Physics: Conference Series **1973** (2021) 012020 doi:10.1088/1742-6596/1973/1/012020

Improvement of the PV Module Performance by Cooling Method Through Immersing in a Forced Water Circulation

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Abstract. Just 15 to 20 percent of the PV modules solar radiation's turned to electrical energy while the rest's transformed into thermal energy, resulting in a decrease in the efficiency of the electrical energy. Thus, to useful from the each electrical and thermal energy generated by the PV module, a hybrid thermal photovoltaic system is the perfect choice. A hollow rectangular box was used as a water flow channel to absorb heat from the photovoltaic's. Then, this heat extracted from photovoltaic's will be used in secondary applications, which leads to improved performance of photovoltaic modules and increased electrical conversion. The hybrid PV/T system consists of two sides of a rectangular channel made of insulating material, which are built-up on the bottom and top side of the PV panel, where the upper material is glass to transmittance the solar radiation and lower material is insulation foam, with a depth 5 mm of each one and through which water flows along the channel. The front side of the thermal collector contains transparent glass that allows solar radiation to pass through it to reach the PV module.3D numerical simulation was performed by COMSOL Multiphysics® software, and is validated at different volume flow rates of 1LPM to 5LPM, by Boundary Conditions investigation to keeping the inlet water and ambient temperature at 27°C and solar irradiation at 1000 W/m^2.Hence, the benefit of this work is to evolve the electricity yield of photovoltaic (PV) module, thus increasing the electrical adequacy, also can be obtained the hot water by the heat absorption from the PV module by use heat exchanger. The results of the simulation had shown that the (PV) / T system produced 14.2% Maximum Electrical Efficiency (η_{el}), while

3. Accept of the research “Improving the Efficiency of photovoltaic cells by using the Distilled Water Immersion Method”

Scopus

Date: Sept 20, 2021
Paper ID: ICAUC_84

Letter of Acceptance

Dear Authors,

On behalf of the ICAUC_ES_21 Committee, and based on the reviewers' evaluation after double blind peer review Process and Guest Editors' approval we are pleased to inform you that your paper entitled:

" Improving the Efficiency of photovoltaic cells by using the Distilled Water Immersion Method "

Written By

Sarah Yahya Hattam And Mahdi Hatf Kadhum Aboaltabooq

Has been accepted and will be processed for possible publication in the IOP Conference Series: Earth and Environmental Science (Online ISSN: 1755-1315, Print ISSN: 1755-130). It is our pleasure to invite you to attend 2nd International Conference of Al-Esraa University College for Engineering Sciences (ICAUC_ES), Al-Esraa University College, Baghdad, Iraq in 3- 4 November, 2021 to present your paper. We congratulate you for your achievement, the technical details about the publication will be informed later. The publication of the accepted paper will be provided by the end of January 2022.

We Will encourage more quality submissions from you and your colleagues in future

Shubham Sharam

Regards,

Prof. Dr. Shubham S. Sharma
ICAUC_ES Guest Editor

Caution: This Acceptance Letter Made by ICAUC Conference Guest Editors, All Approval Inquiries Should Made to Editorial Board Members of ICAUC Conference, as all Accepted Papers will Process for publication in Conference Journals.

الخلاصة

تعد الألواح الكهروضوئية حلاً رائعًا لنقص الطاقة في جميع أنحاء العالم. تعاني كفاءة اللوحة الكهروضوئية من انخفاض ملحوظ مع زيادة درجة حرارة اللوحة الكهروضوئية. وبالتالي هناك حاجة إلى نظام تبريد بسبب خفض درجة حرارة اللوحة الكهروضوئية. درس هذا العمل تأثير تقليل درجة حرارة عمل الألواح من أجل زيادة كفاءة التحويل باستخدام تقنية التبريد بالغمر بالماء المقطر. تم إجراء الأجزاء النظرية والعملية للدراسة حول تأثير تبريد الألواح الكهروضوئية عن طريق غمر (PV) في دورة مغلقة بتدفق متوازي في الماء المقطر القسري من (أعلى وأسفل) اللوحة الكهروضوئية. النتائج العددية التي تم الحصول عليها باستخدام برنامج Comsol 5.5. أجريت النتائج التجريبية في كلية الهندسة التقنية بالنجف مع ظروف اختبار داخلية تم التحكم فيها. أجريت الدراسة العددية لتحديد أفضل عمق غمر للوح لإعطاء أدنى درجة حرارة أساسية للوحة الكهروضوئية ، وأظهرت نتائج المحاكاة أن أفضل عمق غمر هو (5 مم). تم استخدام لوحين شمسيين من السيليكون أحادي البلورة ، تم تبريد أحدهما للحصول على نظام PV / T وتم استخدام اللوحة الكهروضوئية الأخرى للمقارنة مع نتائج اللوحة المبردة. بناءً على النتائج التي تم الحصول عليها من المحاكاة ، تم تصنيع نظام PV \ T من مادة (رغوة صلبة) ذات عزل حراري عالي. تعد قناة تدفق المياه واحدة من أهم أجزاء نظام PV / T والتي يتم تثبيتها على الجزء العلوي والسفلي من الوحدة الكهروضوئية. طول نظام PV / T (900 مم) ، العرض (600 مم) ، السماكة (25 مم) ، كانت المسافة أعلى وأسفل الوحدة الكهروضوئية لمرور المياه 5 مم. في أطراف القناة ، تم تصميم فتحة لإدخال تدفق المياه وإخراجها باستخدام مضخة المياه. كانت كمية الإشعاع الشمسي المستقبلة بكميات مختلفة (600-1000) واط / م 2 ومعدل التدفق LPM (5-1). وأخيرًا ، تم الحصول على زيادة في الكهرباء (الكفاءة والتعزيز) من النتائج العددية والتجريبية (38.4)٪ ، (14.72)٪ ، (38)٪ ، (14.642)٪ على التوالي.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية

الكلية التقنية الهندسية – نجف

دراسة عددية وتجريبية لتحسين أداء الخلايا الشمسية باستخدام نظام التبريد المائي

ساره يحيى حاتم

ماجستير في هندسة تقنيات ميكانيك القوى

1443 هـ