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IMPROVING THERMAL EFFICIENCY OF PHOTOVOLTAIC THERMAL SYSTEMS

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Abstract

The research presents the daily and monthly global solar radiation on a horizontal surface in Iraq and applies it to the PVT water system. The research contributes in two ways: first, it models a novel copper pipe system that improves thermal efficiency in an actual environment, and second, it investigates the hourly and daily intensity of solar radiation in Iraq using collected irradiation at mass flow rates ranging from 0.01 to 0.02 kg per second, the surface temp of the PVT model was calculated. The surface temp was also computed using the experimental data in the PVT model. The findings were consistent with those of prior investigations. A PVT system with a constant input temp is employed to raise the surface temp throughout simulated testing with an optimal mass flow rate of 0.02 kg/s and a constant low input temp, the findings demonstrate the thermal efficiency of the PVT. February records the highest thermal efficiency and 12 pm records the highest radiation comparison with other selected months.

Keywords: PVT, Water flow, Thermal efficiency

FOTOVOLTAİK TERMAL SİSTEMLERİN ISIL VERİMLİLİĞİNİN ARTIRILMASI

Özet

Araştırma, Irak'ta yatay bir yüzey üzerinde günlük ve aylık küresel güneş radyasyonunu sunuyor ve bunu PVT su sistemine uyguluyor. Araştırma iki şekilde katkıda bulunuyor: birincisi, gerçek bir ortamda ısıl verimi artıran yeni bir bakır boru sistemini modelliyor ve ikincisi, 0,01 ile 0,01 arasında değişen kütlesel akış hızlarında toplanan ışınımı kullanarak Irak'taki güneş ışınımının saatlik ve günlük yoğunluğunu araştırıyor. saniyede 0,02 kg'a, PVT modelinin yüzey sıcaklığı hesaplandı. Yüzey sıcaklığı da PVT modelindeki deneysel veriler kullanılarak hesaplanmıştır. Bulgular önceki soruşturmaların bulgularıyla tutarlıydı. 0,02 kg/s optimum kütle akış hızı ve sabit düşük giriş sıcaklığı ile simüle edilmiş testler boyunca yüzey sıcaklığını yükseltmek için sabit giriş sıcaklığına sahip bir PVT sistemi kullanılır, bulgular PVT'nin termal verimliliğini gösterir. Şubat, en yüksek termal verimliliği kaydeder ve 12:00, seçilen diğer aylarla karşılaştırıldığında en yüksek radyasyonu kaydeder.

Anahtar Kelimeler: PVT, Su akışı, Termal verimlilik.

1. Introduction

Due to issues such as a lack of mineral sources of fuel, global warming, and other relevant issues (Hasanuzzaman et al., 2015; Radhi et al., 2022), there is a growing concern across the globe for the development of energy technologies that are sustainable, environmentally friendly, and practical for use in both residential and commercial applications. This concern is growing at a rate that is increasing day by day. Solar energy has the most significant potential and promises to be the most promising type of renewable energy. It may be gathered in two forms: solar thermal energy and solar electricity. Nevertheless, the photovoltaic (PV) technology used to generate power could be more efficient in energy conversion. Just 15% of solar irradiation is said to be converted into electricity, with the other 85% being reflected and transformed into heat. Only 60% may be collected by a solar collector using a PV/T collector (Teo et al., 2012). In addition, the efficiency of conventional silicon solar cells decreases as the cell temp rises, which is a significant drawback. Removing the surplus heat produced by the module and its subsequent use in thermal processes represents an optimal option. This problem may be solved using a technology known as photovoltaic thermal (PV/T), which generates energy and heat using the same physical profile. A substantial number of numerical and experimental investigations on PV/T may be found in the published research (Ibrahim et al., 2011).

Nevertheless, the challenge presented by this combined technology is to enhance the efficiency of both the electrical and the thermal systems. Researchers have identified two primary strategies to improve performance: lowering the PV cell's operating temp and raising the packing factor (Dubey & Tiwari, 2008). Both of these methods have been demonstrated to have a positive impact. Nevertheless, the primary challenge presented by PV/T systems is the efficient removal of heat from the module and the subsequent transport of that heat to the user end to ensure its practical application. The skillful design of the thermal collector and its seamless integration with the photovoltaic module is required for the removal and transport of heat in an efficient manner.

Excessive utilization of conventional fossil-based energies at an alarming rate led to an energy crisis. It was responsible for accompanying environmental problems, including global warming, greenhouse gas emissions, and ozone depletion, that threaten the safety of humans and the world's future. These issues risk the planet's present and future (Abdulmunem et al., 2020). As a result, there has been an increase in the need for technologies that are both clean and renewable to lessen our reliance on energies that are based on fossil fuels and to mitigate the following adverse effects that these energies have on the environment. Solar energy is the most widely used and recognized kind of renewable energy due to its low environmental impact, ease of accessibility, long-term viability, and almost limitless potential (Xu et al., 2021). Since natural sunshine can heat and light homes and other structures, the sun seems the most effective and efficient renewable energy source. In furtherance of that, solar energy may be employed in producing electricity, heating water, and several other activities used in industrial settings. Solar energy is collected in various ways, including water-heating tubes installed on roofs, solar cells, and mirrors. These techniques, along with others like them, are constantly improving their overall effectiveness (Sharaf et al., 2022; Yousef et al., 2016). Solar radiation and other secondary energy sources, including wind, wave, hydropower, and biomass, are responsible for most of the renewable energy generated on Earth (Abo-Elfadl et al., 2021; Hassan & Yousef, 2021). It is important to remember that only a tiny percentage of the solar energy that strikes the planet can be converted into usable forms. Only humans can influence how solar energy is used once it has been transformed into electrical energy. The use of daylight, water heating, solar cooking, and high temps for industrial purposes are all examples of applications for solar energy. Other solar energy applications include heating and cooling systems in architectural designs dependent on exploiting solar energy, producing potable water from distillation and disinfection processes, and utilizing solar energy.

The research aims to improve the solar cell's performance through the water cooling process. The process is carried out by passing the water through tubes of copper in a different way, as the shape of the tube path and the speed of the water are among the most critical factors that help improve the cooling process of solar cells by testing the effect of the intensity of solar radiation on the temp of the solar cell, and then cool the solar panel with water through a set of tubes using different speeds.

1.1. The working principle of solar cells and how temp affects the electricity that they produce

Photovoltaic, or PV for short, represents one of the most popular methods for converting solar energy into other forms of energy. It directly transforms solar energy into electricity with unbounded potential, noiseless operation, and low maintenance requirements. In its most basic form, a PV cell is a diode with a p-n junction. Photovoltaic (PV) solar cells are a kind of photoelectric cell, a device whose electrical properties (including voltage, current, or resistance) change when subjected to light. PV solar cells are used to generate electricity. Solar panels are composed of modules that are formed by the combination of individual solar cells. The most significant open-circuit voltage produced by the typical single-junction silicon solar cell is 0.5 to 0.6 V. In and of itself, this is not much; but, keep in mind that these solar cells are relatively small. Significant quantities of clean energy can be created by combining several solar cells onto a single big panel (Krishan & Suhag, 2019).

When light travels to a p–n junction, the photons of that light can readily enter the junction via a thin layer of p-type material. A significant amount of energy, in the form of photons, is supplied to the junction by the light energy to facilitate the formation of many electron–hole pairs. The situation of thermal balance in the junction is upset by the light that has just come into it. Free electrons are rapidly transferred from the depletion zone to the n-type side of the junction. In a similar vein, the holes that are present in the depletion may rapidly make their way to the p-type side of the junction (Jordehi, 2016), as could be demonstrated in Figure 1. The voltage is generated due to the movement of electrons from the p-type side to the n-type side and vice versa. If we attach a load to the junction, current will flow via the circuit.

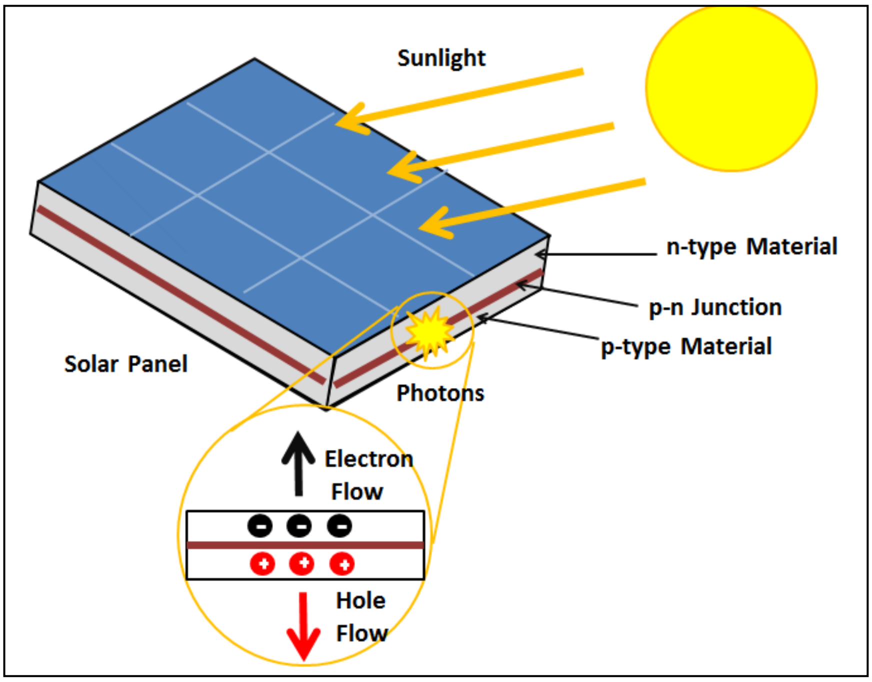

Figure 1. The working principle of (PV) (Mathur, 2020).

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2. Experimental Part

2.1. Study Srea

Iraq is situated in the southwestern section of the Asian continent and extends between 29.5∘ –37.22∘ north latitude coordinates and 38.45∘ –48.45∘ east longitude (Hashim et al., 2013). Iraq's climate falls between that of the continent and the subtropics. The winters are typically chilly to cold, with temps reaching an mean daily high of 16 degrees Celsius and falling to 2 degrees Celsius overnight. The summers are dry and very hot, reaching 43 degrees Celsius during July and August, although the temps only drop to 26 degrees Celsius at night (Zakaria et al., 2013). The climate of Iraq is classified as continental, with summers that are hot and dry and winters that are cold and damp. The predominant winds are from the northwest. Most of the precipitation that fell during the winter months was caused by the movement of stormy weather from the Mediterranean area towards the east and through northern Iraq (Al-Kataa, 1982). This stormy weather was caused by the fluctuation of stormy weather in the region. Therefore, the most significant quantity of precipitation is produced in the northern and northeast parts of Iraq due to the direction that this wind is blowing and the geography of those areas (Mukhopadhyay et al., 1996).

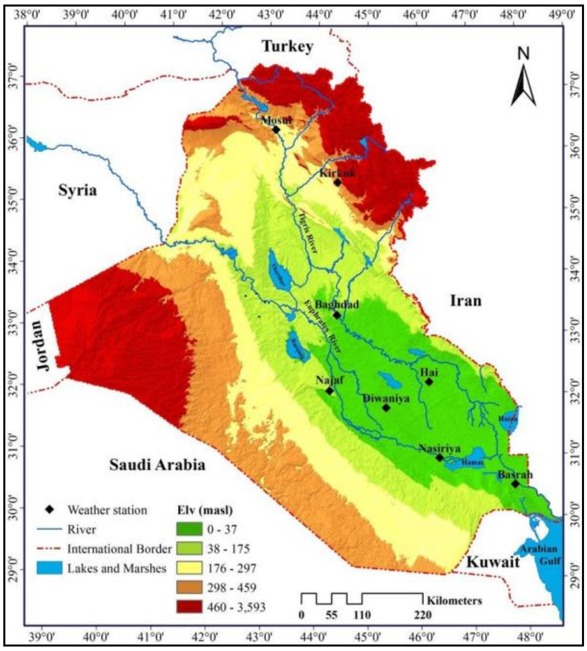


Figure 2. Map of the study area (Al-Qadi et al., 2021).

2.2. System Setting up

The prototype was created with a separate solar thermal collector connected to a storage tank. Cold water is provided from a source to the PVT systems via flexible plastic piping, and hot water is fed from the PVT system to the tank via flexible plastic piping. Water is circulated throughout the system using a water pump. Separate PV panels and PV panels combined in PVT collectors are connected to a voltmeter, an ammeter, and a separate thermometer to measure voltage and current, as well as the temps of the water and PV panels as demonstrated Figure 3.

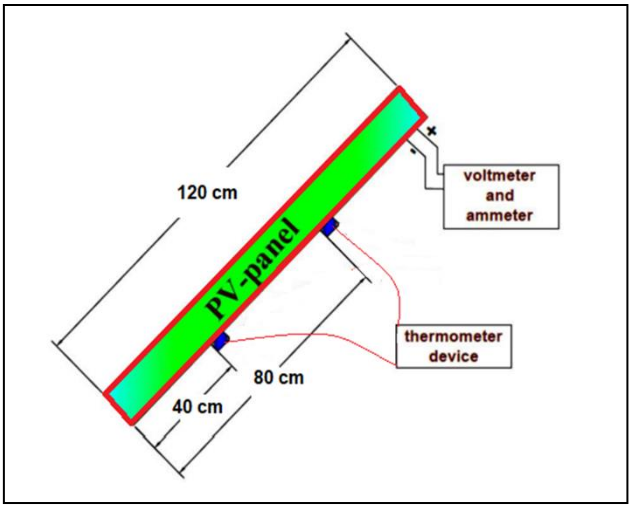


Figure 3. Schematic of PV testing.

PV-panel dimensions are 120 cm for the length of the panel, and the thermometers subjected in the back of the panel at 40 cm and 80 cm height. The current wires are connected at the back of the panel, allowing the user to connect a voltmeter device. This system can be used to measure the generated current and the generated heat on the panel's surface. The components are the principal heat transmission modes (between all solid layers) each component of a PVT glazed door as demonstrated in Figure 4.

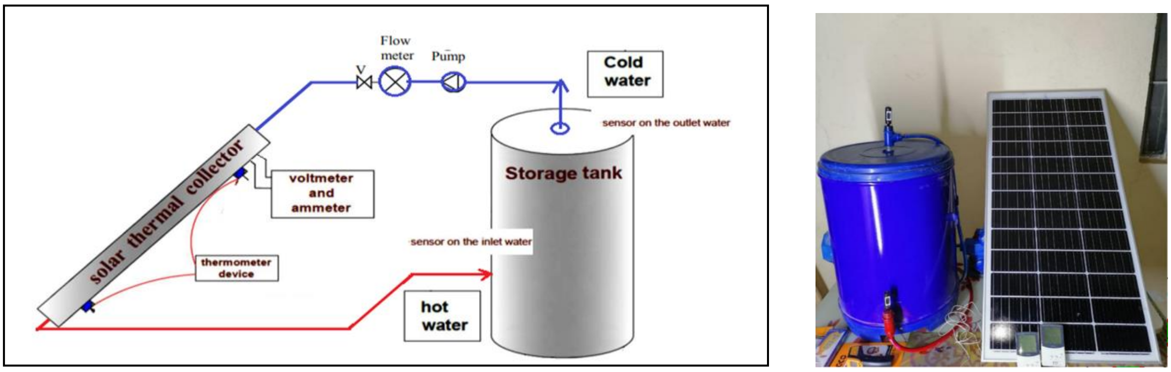


Figure 4. Experimental prototype of all systems: PVT collector.

2.2.1. PVT Collector Panel

The photovoltaic panel type employed for the experiment is depicted in Figure 5. Table 1 shows the panel's properties as measured under standard test conditions.

Figure 5. PV panel used in experiments

Table 1. Data specification of the PV panel.

Maximum Power	100 Watt
Power Tolerance Ranger	+/- 3%
Open Circuit Voltage	21.5 V+/- 3%
Short Circuit Current	6.46 A+/- 4%
Maximum series fuse	12 A
Maximum power Volt	17.5 V
Maximum power current	5.7 A
Weight	7 kg
Operating temp	-40 oC to + 85 oC
Dimensions	1200x540x30
Application class	A+

2.2.2. The Present System Component

Experiments include two types of copper tube design, the first type and the second type is demonstrated in Figure 6. The main reason for using two types of tube shapes is to know the effect of the tube shape on the cooling efficiency of the solar panel, as changing the shape is related to the length of the tube path and the nature of the heat transfer from the panel to the water. As for the selection of copper pipes, it is known that copper is a good conductor of electricity, so it was adopted in the experiments devoted to this work. The soft copper tubing with a ½ inch (12.7 mm) diameter and 0.8 mm thickness produces the coils. This tube type can be bent easily to travel around the PV panel in the tubing path.

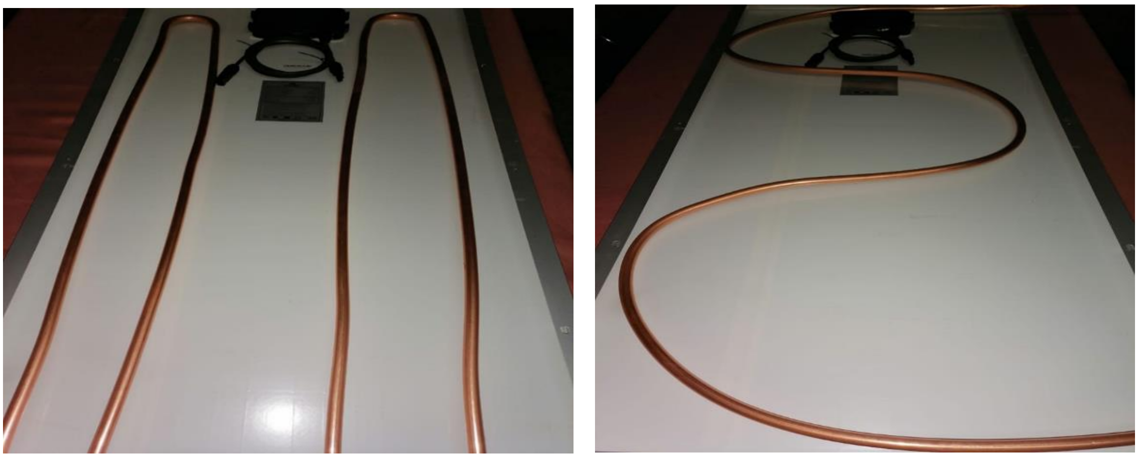


Figure 6. U-shape and S-shape copper pipe model.

2.2.3. The Storage Tank

A water tank was connected to the cooling system to achieve optimal heat exchange between the water and the surface of the solar panel and to ensure the cooling process and heat transfer in a regular manner. The main work of the water tank is to control the transfer of temps and to control the process of measuring the temp of the water entering and leaving the panel dynamically. To ensure the water circulation process, a small water pump is attached to circulate the water, in addition to a lock position to control the flow. It is produced for household usage in an Iraqi facility and has a capacity of 60 L. Table 2 outlines the tank's specifications.

Table 2. The tank dimensions.

Outer diameter tank (cm)	43
The inner diameter of the tank (cm)	35
The volume of the tank in the letter	60
Outer thickness (mm)	0.4
The thickness of insulation material (cm)	4
Inner tank thickness (mm)	2

2.3. Solar Radiation Measurement and Calculations

The system uses a series of equations to find efficiency, which is one of the essential steps in this research. The current research is based on several essential factors, the most important of which are the temp of the plate, the ambient temp, and the intensity of the solar's brightness on the plate. These factors are included in a series of equations that combine with the temp of the water used to cool the solar panel. The equations below show the type of mathematical relationships that be used to find the results (Misha et al., 2020):

$$E_{th} = M_w \times C_p \times \Delta T \quad (1)$$

$$\Delta T = T_3 - T_4 \quad (2)$$

$$M_w = V_w \times \rho \times (T) \quad (3)$$

$$\eta_{th} = \frac{100 \times E_{th}}{A_m \times G_p} \quad (4)$$

Where E_{th}: $thermal\ energy$, M_w: mass flowrate of water, T3:inlet water temp, C_p: $specific\ of\ gravity\ of\ water$,$\Delta T$: $water\ differences$, T4:outlet water temp,

V_w: $water\ velocity$, ρ: water density, η_{th}: $thermal\ efficiency$, A_m: $pipe\ area$, Gp: Solar irradiance (w/m2).

The following formula may be used to determine the intensity of alien solar radiation that strikes the Earth's surface and is directed at a right angle to the direction of solar energy (Temps & Coulson, 1977):

$$I_{on} = I_{sc} \frac{r}{R^2} \quad (5)$$

Where the Earth's intermediate distance from the Sun is r, the Earth's immediate distance from the Sun is R, solar constant ISC=(1353±21) (Matuszko, 2012).

3. Results and discussion

3.1. Solar Radiation İntensity

The intensity of solar radiation determines the amount of energy the sun delivers in a given amount of time. The information is used to create and assemble solar energy systems in various sectors. The researcher measures the amount of solar light falling on specific areas at various times within the year. The solar light amount falling on places with similar climates at the same latitude is calculated (Shubbar et al., 2017). The most common methods for measuring solar energy are total radiation on a horizontal or solar-tracking surface. The daily solar radiation intensity and total solar radiation intensity during three months in Baghdad's city is depicted in Figure 7 and 8, respectively.

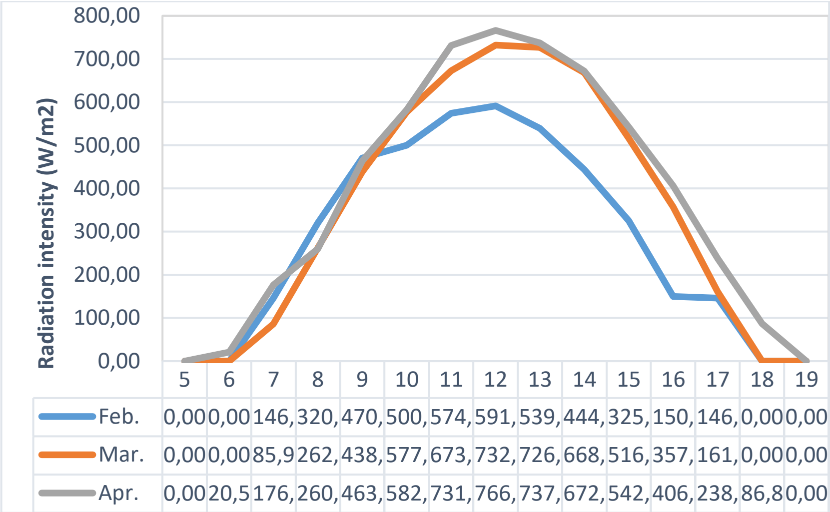


Figure 7. Solar radiation intensity in Iraq, Baghdad.

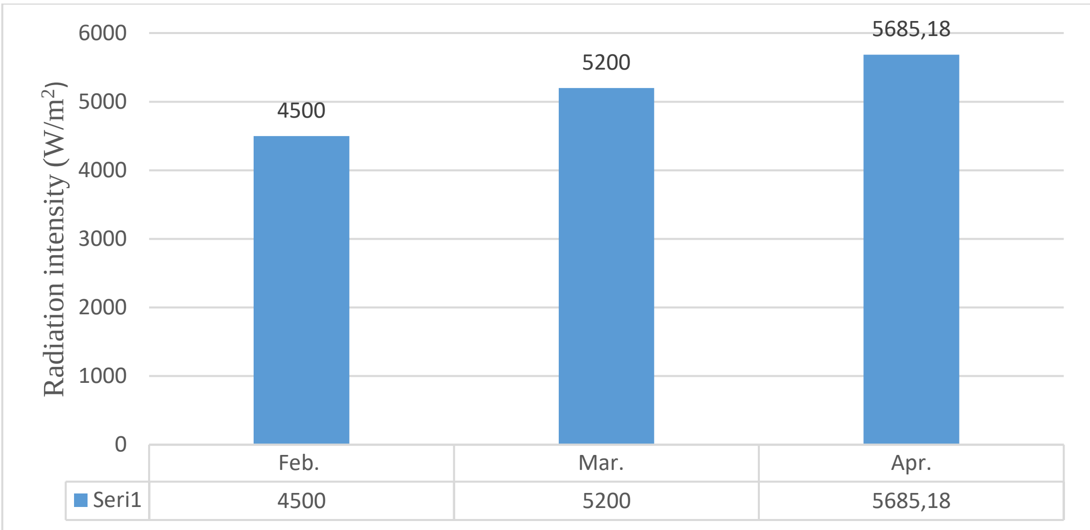


Figure 8. Total solar radiation intensity in Iraq, Baghdad.

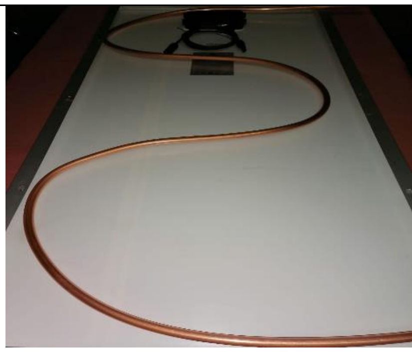
3.2. Mass Flow Rate Effect

The PVT water collector is designed and built with a flow channel absorber design as a PVT water system. At varied mass flow rates and based on the compared data of mass flow rate and temp differences from the previous studies, as demonstrated in the previous section, the researcher selected the water flow rate values for experiments. In this research, the researcher measured Baghdad's daily solar radiation intensity using a solar radiation detection instrument and compared it with (Hamad et al., 2022) and the dimensions and shapes selected from (Rosli et al., 2018).

Based on the measured data was applied in the formulas (1 to 5). The water flow (0.0.1 and 0.02 kg/s) has been determined. It has been found that 0.01 kg/s is more suitable for the cooling pipe diameter (Misha et al., 2020). The radiation levels vary based on the boundary circumstances during design and selection, as demonstrated in Figure

9. All the other data, such as the PV panel and pipe dimensions, are taken from the system component's accurate measurement. The examination of the dynamic properties of the thermal effect in the absorption domain is known as PVT model analysis. It aids in the selection of a PV cooling system. It is demonstrated in Table 3 below.

Table 3. The cases of the present study.

	Temp (°C)	Water flow (kg\s)	Case Figure
First case	18 to 26	0.01, 0.02	
Second case	18 to 26	0.01, 0.02	

The experiments are carried out as described in chapter three, and the results demonstrate that solar radiation, ambient temp, and mass flow rate had an impact on the performance of the PVT cell temp. These effects ranged from 0.01 to 0.02 depending on the mean cell temp of the PV panel, the PVT water collector, and the ambient temp. The thermal absorber and water flow both works to lower the temp of the PVT water-collecting cell. According to Figure 9 a, the thermal absorber and water flow lower the temp of the PVT water collecting cell.

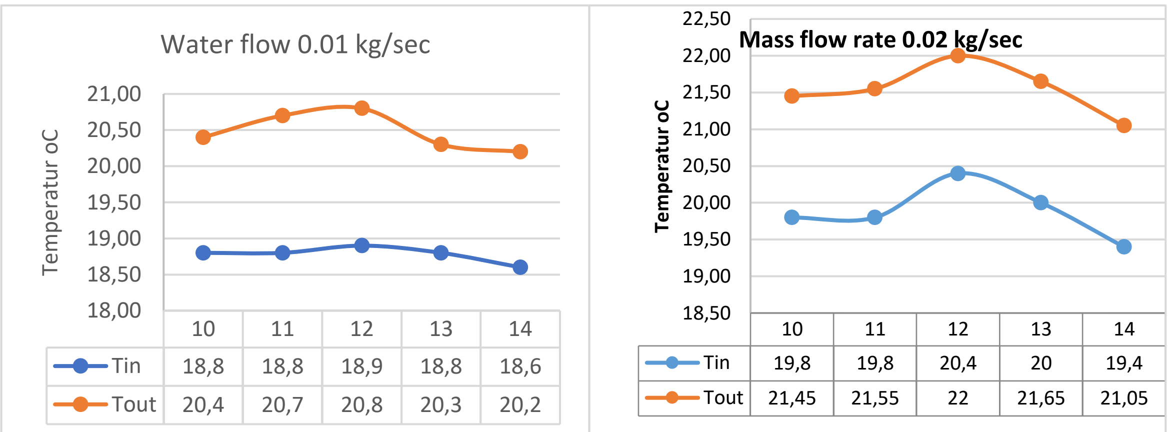
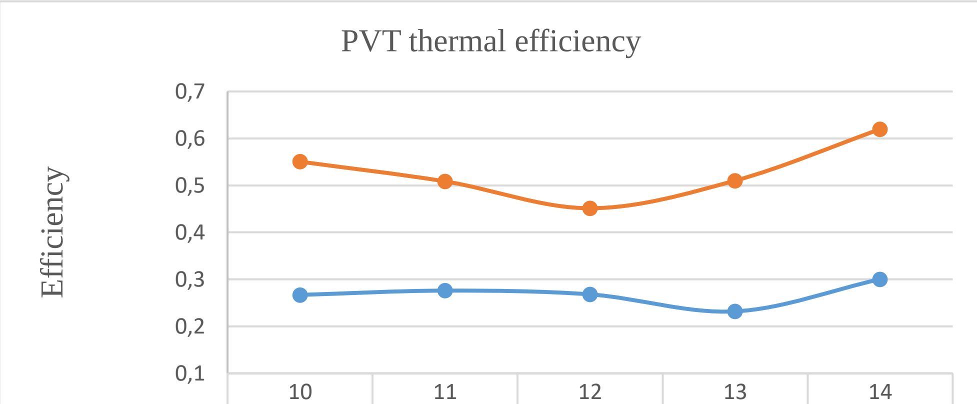


Figure 9. Differences in temp of inlet-outlet cooling pipe system using water flow (0.01 and 0.02) kg/s during February

It can be noticed in the figure the results of the mass flow rate tests in the copper cooling tubes at a speed of 0.01 kg/s. The results observed that the maximum differences in the temp are at 12 o'clock, representing the highest thermal load. The water flow temp reached 20.8 °C, and the temp difference in the cooling system was 1.9 °C. Accordingly, all the calculations mentioned in the laws presented in the third chapter were completed, and then the water flow in the copper tubes was increased to 0.02 kg/s. The results appear in Figure 9b.

In this case, the results observed the maximum differences in the temp. Are at 12 o'clock also, which means that the thermal load must be calculated in Iraq. The water flow temp reached 22°C, and the temp difference in the cooling system was 1.6 °C. When comparing the results demonstrated in Figure 9 (a and b), observe differences in temp in the 1.66 °C between the input and output of the cooling pipe system. These differences will be used in the calculation of equation 3.2. Also, the range of temp differences between the water mass-flow of 0.01 and 0.02 kg/s was 1.06 °C, which shows the differences in heat transfer based on flow speed. The next step is calculating the thermal efficiency, as demonstrated in Figure 10.



	10	11	12	13	14
0.01 kg/sec	0,266949911	0,276117471	0,268066018	0,231919007	0,300471018
0.02 kg/sec	0,550584191	0,508637446	0,451479609	0,510221816	0,619721475

Figure 10. PVT thermal efficiency differences in February.

Figure 10 demonstrates that the minimum efficiency difference was at 12 o'clock. The efficiency difference reaches 18% and 32% at 14 o'clock. The weakness in thermal efficiency at 12 o'clock is due to the high differences in the panel temp. The counters demonstrate a direct relationship between the change in mass flow and the drop in cell temp in the PVT water system. The effect of varying water velocities is a crucial factor influencing the overall heat transfer process. Results demonstrate the findings of studies undertaken to assess how the speed of the water influenced the collecting pipes, which suggests that the water's speed absorbs some heat delivered from the PV down the pipe.

The PVT water collector may create both heat and power. As a result, the temp of the output water after heat gain and the device's thermal efficiency are the measurements used as indications of thermal performance within the scope of this study. According to the data, there is a negative relationship between the change in mass flow rate and the temp of the exit water. To generate warm water with higher thermal efficiency, the flow rate must be kept constant between 0.01 and 0.02 kg/s. The mean thermal efficiency is proportional to the temp differential between the water being pumped in and the water being pumped out. The ratio varies with the mass flow rate values. The temp difference between the water's entry and exit points decreases as the mass flow rate increases. The temp difference between the water's entry and exit points can be decreased by raising the mass flow rate and boosting thermal efficiency. The same procedure was repeated in March and April. The results are presented in Figure 11.

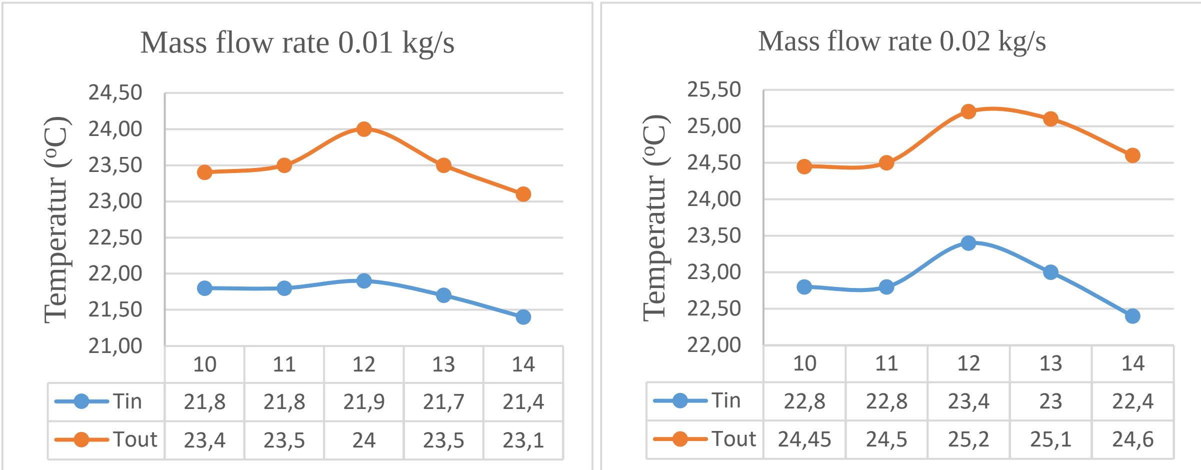


Figure 11. Differences in temp of inlet-outlet cooling pipe system using water flow (0.01 and 0.02) kg/s in March.

Figure 11 observe that the maximum differences in the temp are at 12 o'clock in March same as indicated results in February, which also represents the highest thermal load. The water flow temp reached 24 °C at 0.01 kg/s water flow rate and 25.2 at 0.02 kg/s water flow rate. The temp differences in the cooling system are 2.8 °C.and 1.8 °C in both cases.

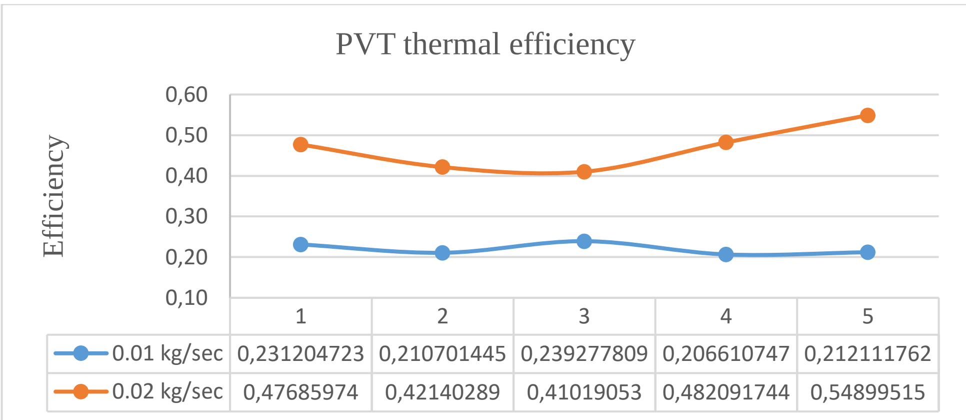


Figure 12. PVT thermal efficiency differences in March.

Figure 12 displays the hourly fluctuations in electrical efficiency from mass flow rate throughout the course of the months. The electrical efficiency for both systems varied in direct relation to the outside temp. However, compared to the 0.01 kg/sec mass flow rate, electrical efficiency for 0.02 kg/sec is much greater. It is clear from Figure 12 that the minimum efficiency difference also was at 12 o'clock. The efficiency difference reaches 17% and 34% at 14 o'clock. The weakness in thermal efficiency at 12 o'clock is due to the high differences in the panel temp.

Figure 13 observe that the maximum differences in the temp also at 12 o'clock as in April, which also represents the highest thermal load. The water flow temp reached 28.85 °C at 0.01 kg/s water flow rate and 29.1 at 0.02 kg/s water flow rate. The temp differences in the cooling system are 2.18 °C.and 1.7 °C in both cases.

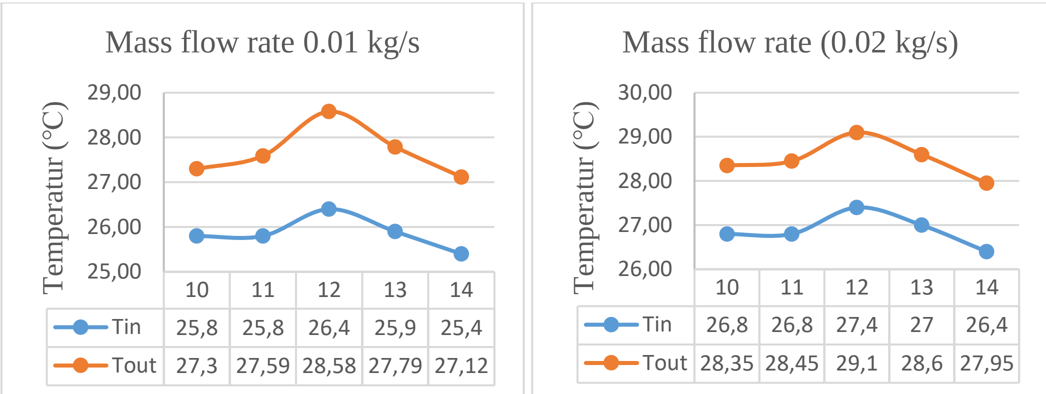


Figure 13. Differences in temp of inlet-outlet cooling pipe system using water flow (0.01 and 0.02) kg/s in April

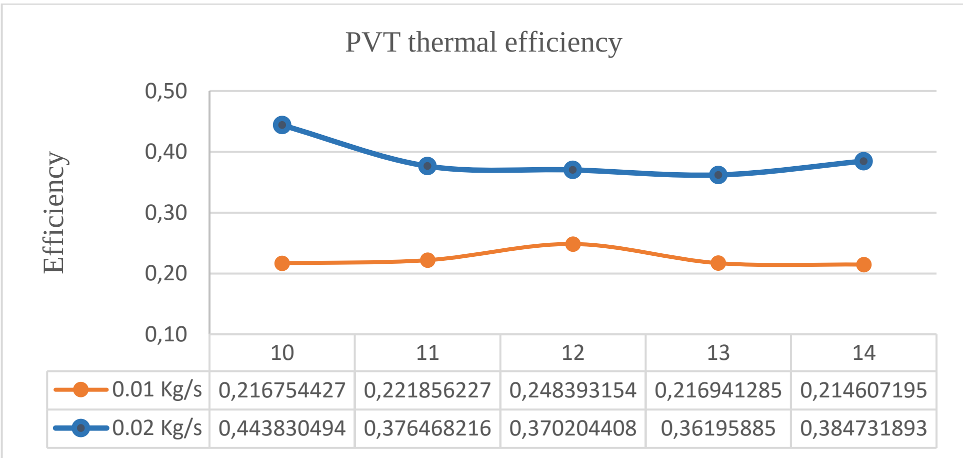


Figure 14. PVT thermal efficiency differences in April.

The thermal efficiency calculations demonstrated in Figure 14 observed that the minimum efficiency difference was also at 12 o'clock. The efficiency difference reaches 12% and 17% at 14 o'clock. The weakness in thermal efficiency at 12 o'clock is due to the high differences in the panel temp. The figures show that the increase in water flow rates is directly proportional to the rate of heat absorption. That is, the increased flow of water in the copper tubes has increased the heat absorption in the solar panel. In turn, this positively affected the efficiency of the solar panel. Figure 15 shows thermal efficiency of all cases of the present study.

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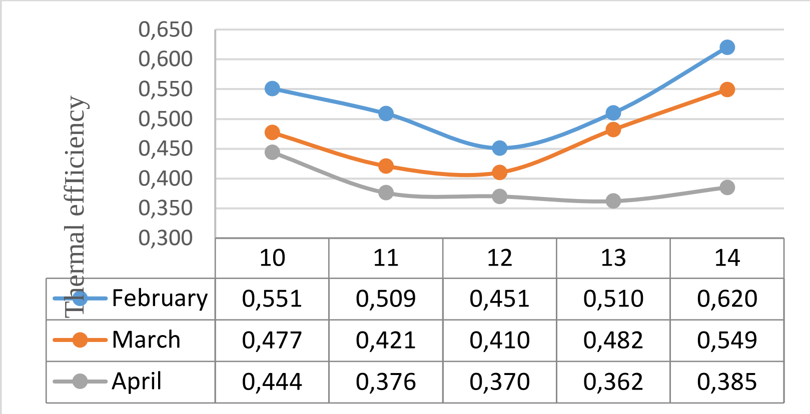
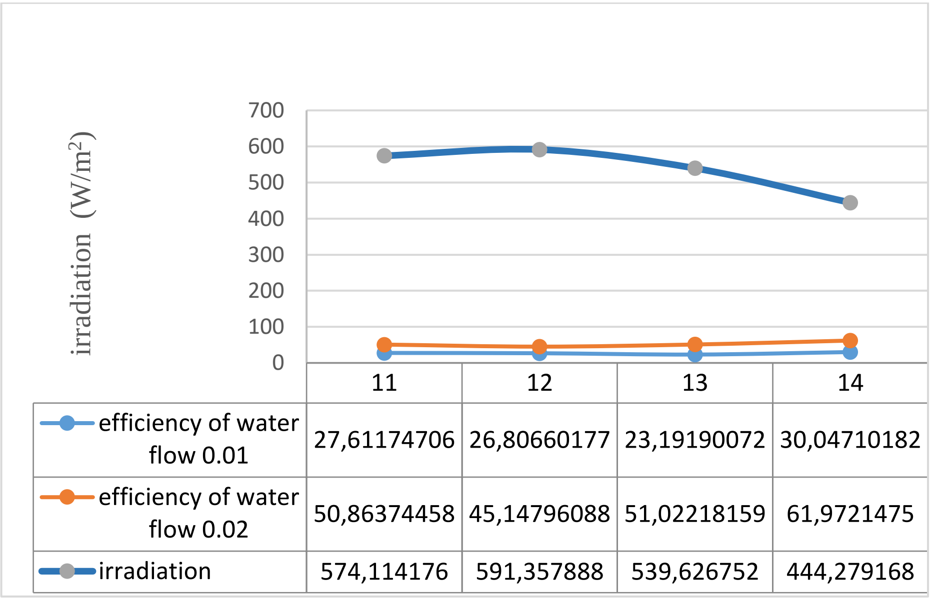


	10	11	12	13	14
February	0,551	0,509	0,451	0,510	0,620
March	0,477	0,421	0,410	0,482	0,549
April	0,444	0,376	0,370	0,362	0,385

Figure 15. A comparison of thermal efficiency of different months.

Solar cells operate under different weather conditions. The most important is the change in the intensity of solar radiation. Therefore, the intensity of solar radiation was compared with the efficiency of the solar panels in all of the below. PVT water collectors can produce both electrical and thermal energy. As a result, the output water temp and the thermal efficiency of the device are used to assess its effectiveness. The results reveal that when the mass flow rate increases, the temp of the outflowing waterfalls. The flow of 0.02 kg/s is observed to be more efficient heat absorption than 0.01 kg/s, and the increase in efficiency was about 0.3% of thermal efficiency.

When the mass flow rate changes, the mean thermal efficiency demonstrates how well the system handles the temp difference between the entering and exiting waters. The temp difference between entering and departing water may reduce as the water moving through a given area increases. Increases in mass flow rates enhance thermal efficiency, which is measured by how much warmer the incoming water is than the existing water. The PVT water collector, which also generates energy and heat, serves an important use in the home by supplying hot water.



	11	12	13	14
efficiency of water flow 0.01	27,61174706	26,80660177	23,19190072	30,04710182
efficiency of water flow 0.02	50,86374458	45,14796088	51,02218159	61,9721475
irradiation	574,114176	591,357888	539,626752	444,279168

Figure 16. compares different mass flow rates and irradiation thermal efficiency.

Figure 16 shows that irradiation has a direct thermal effect on thermal efficiency. Furthermore, the higher mass flow rate increases the thermal efficiency in all cases. As a result, the output water temp and the thermal efficiency of the device are used to assess its effectiveness. The mean water temp at the PVT system's output and input change when the intake water temp changes. The results reveal that the temp of the outflowing waterfalls when the mass flow rate increases. Because mean thermal efficiency is determined by the temp difference between the input and output, it varies with the mass flow rate. The thermal efficiency (as measured by the temp differential between the entering and departing streams) improves as the amount of water passing through the system increases.

4. Conclusion

The conclusion of the present work can be summarized below:

- The thermal efficiency calculations observed that the minimum efficiency difference also was at 12 o'clock. The efficiency difference reaches 12% and 17% at 14 o'clock. The weakness in thermal efficiency at 12 o'clock is due to the high differences in the panel temp.
- The results reveal that the temp of the outflowing waterfalls when the mass flow rate increases. The flow of 0.02 kg/s observed more efficient heat absorption than 0.01 kg/s, and the increase in efficiency was about 0.3% of thermal efficiency, and irradiation has a direct thermal effect on thermal efficiency.

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