

# Effect of Changing Several Factors and Variables on the Thermal Performance of a Photovoltaic/Thermal Collector

Mohammed Ahmed\* , Ahmed Khalid Ibrahim 

Mechanical Engineering Department, College of Engineering, Mosul University, Mosul, Iraq.

\*Email: [mohammed.20enp38@student.uomosul.edu.iq](mailto:mohammed.20enp38@student.uomosul.edu.iq)

Article Info	Abstract
Received 02/03/2024	<p>In this paper, we conducted a theoretical study using the TRNSYS program to simulate and analyze the impact of various parameters on the thermal performance of a hybrid photovoltaic/thermal solar collector in Mosul, Iraq, during November. A complete theoretical model of the hybrid photovoltaic/thermal solar collector was developed, including all components, setting all constants, and performing all necessary simulations to obtain the results. The results of the study indicate that a 2 m<sup>2</sup>-8 m<sup>2</sup> increase in surface area resulted in a 16 percent increase in thermal efficiency and an 18 percent increase in solar fraction. In addition to these two results, the increase also yielded a 6 percent increase in the efficiency of the solar panels. When the packing factor ratio increased from 0 percent to 100 percent, thermal efficiency decreased by 24 percent and solar fraction by 16 percent. The increase in solar panel efficiency resulted from variations in slope angles. The slope angle of solar panels increased from 0 to 90 degrees, resulting in a variable influence on thermal performance, with a maximum value of 50 degrees at 52 degrees. The maximum solar energy produced by solar panels was achieved at slope angles of 29 degrees and 27 degrees, respectively.</p>
Revised 26/04/2026	
Accepted 05/05/2026	

**Keywords:** Hybrid Collector, Photovoltaic Panel, Serpentine Tube, TRNSYS.

## 1. Introduction

In the last few years, countries have been turning to alternative energy sources and eliminating them wherever possible [1]. Solar PV panels generate electricity by converting solar energy. However, scientists are developing systems to track the sun's position throughout its path so they can optimize their solar panels for maximum energy collection, resulting in greater energy production. By providing clean, renewable energy, solar PV panels are transforming the world for the better and increasing the energy available to meet our energy demand. Because of this, solar PV panels are also helping to mitigate climate change and promote sustainable development, thereby reducing our dependence on fossil fuels and lowering the harmful emissions we release into the environment. Solar PV panels offer numerous environmental benefits, and they also have positive economic impacts [2].

Electricity demand has risen dramatically, and many countries now consider solar energy one of the fastest-growing renewable sources for producing electricity while addressing the significant issues of climate change. Solar energy, being renewable, is free, has no negative impact on the planet or environment, and can be produced anywhere in the world [3].

In this paper, a photovoltaic thermal collector (PVT) will be used, a technology that combines the benefits of solar thermal and photovoltaic systems to produce electricity and heat simultaneously [4]. In the next few years, solar energy will prove to be one of the most successful and worthwhile investments due to its widely used applications, such as solar cell systems [5]. The PVT collector consists of a solar panel that generates electricity and a thermal collector that absorbs solar heat. The thermal collector is usually placed behind the solar panel and consists of a series of pipes that carry a heat-transfer fluid. The heat-transfer fluid absorbs heat from the sun and transfers it to a heat exchanger, which then heats water for domestic or industrial use.

In recent years, studies have been conducted that achieved efficiency improvements in two-axis solar tracking using an algorithm to mitigate solar dispersion [6].

One advantage of PVT collectors is their versatility. They can be installed on rooftops, walls, or even as standalone units in open spaces. They can also be integrated into existing heating systems to provide additional hot water or space heating. In terms of maintenance, PVT collectors require less upkeep than traditional solar thermal systems. The absence of moving parts

reduces the risk of breakdowns, and the panels are designed to withstand harsh weather conditions.

Fudholi et al. [7] used spiral tubes; a group of his colleagues studied an integrated photo/thermal solar hot water collector, which consists of a compact PV panel (photovoltaic) and one for storing heat. The amount of solar radiation from the sun was measured in between 400 and 800 watts per square meter; for this experiment the researcher found that when the solar collector was operational at 800 watts/square meter with a fluid flow of 0.041 kilograms/second, it achieved an overall efficiency of approximately 65 percent for the solar collector, 13 percent photovoltaic (pv) efficiency, 52 percent thermal efficiency and primary energy savings of approximately 79-91 percent (depending on mass flow rates between 0.01-to-0.041-kilogram/second). It also found that as the temperature of the PV module decreased, so did its efficiency, and that the decrease in efficiency was not linear with changes in the mass flow rate; thus, using a spiral solar collector offers a design method for developing sustainable energy systems. The temperature will decline more steeply than normal when the mass flow rate is above 0.024 kg/second. PVT Water Collectors were found to exhibit increased collector efficiency with increasing mass flow rate, regardless of solar irradiation level. This occurs because, as the mass flow rate increases, the cooling factor of the photovoltaic cell also increases. Therefore, through this indirect association, mass flow rates affect solar collector efficiency.

Lee et al. [8] presented an experimental study investigating the performance characteristics of a PVT hybrid solar collector across various water flow rates. The results indicated that the flow rate of the fluid affected the efficiency of the PVT collector, with the highest efficiency occurring at a flow rate of 3 liters per minute, compared with flow rates of 1, 2, and 4 liters per minute. Results indicated that the overall thermal efficiency of the collector was 23.59%, the overall electrical efficiency was 12.80%, and the energy-saving experience was 36.39% across all flow rates combined. Additionally, the use of Nanofluids (CuO/water, Al<sub>2</sub>O<sub>3</sub>/water) was analyzed for its impact on the thermal and electrical efficiencies of the PVT system. The research indicated that all differences in thermal and electrical efficiencies occurred due to the applications of Nano-fluids (CuO/water, Al<sub>2</sub>O<sub>3</sub>/water), as compared to plain water, for both thermal and electrical efficiencies; therefore, the use of (CuO/water) as a nano-fluid increased thermal and electrical efficiencies of the PVT collector by 21.30% and 0.07%, respectively, compared to that of the water-based system. Nonetheless, there was not a large, significant increase in the system's electrical efficiency, and it was suspected that the increase was due solely to measurement error. So, there was little difference in electrical efficiency when the PVT system used a nanofluid (i.e., water with added AL<sub>2</sub>O<sub>3</sub> nanometer-sized particles) compared to using only water in the system. The research article found that adding nanoparticles improves heat transfer characteristics. The research article also suggested that the use of nanofluids can improve overall system efficiency because nanoparticles enhance the fluid's heat-transfer capabilities. However, when the PVT system was oriented at a fixed position on the Earth, there was no difference in the cell surface temperature.

Gupta et al. [9] evaluated a solar collector as an example of an integrated system to determine how efficiently it uses solar energy compared with other solar technologies and photovoltaic systems. They perform this analysis based on two systems: a single zigzag, tube-shaped solar collector and an electricity-generating photovoltaic (PV) collector. By comparing both systems, they can determine how well-suited each system is for integration in an energy-harvesting environment, demonstrate the effectiveness of their model, and discuss the merits and disadvantages of each type of system., after that the performance was implemented and compared in terms of annual thermal energy subscribe the annual electricity to join the thermal energy completely, where the average improvement in the total electrical quality per hour of connection and energy gain per hour for the first version was measured by 5.72% and 31.34% respectively. For the second case, the paper states that the annual performance standards for the electrical energy you own. The company has many advantages over the first case by 8.4%, 14.8%, and 41.7%, respectively.

Ahmed and Mohammed [10] investigated the effect that accumulated layers of dust on the exterior of a hybrid solar facility have on its operational performance. Specifically, their results indicate that two forms of efficiency (thermal and electrical) were negatively affected by reduced solar radiation intensity due to dust accumulation. In particular, they found that the total thermal efficiency of a collector with accumulated dust was reduced by 13.4% from that of an unsoiled collector. In contrast, the maximum electrical efficiency of the collector that had accumulated dust was only 5.67%, compared with 10.24% for the unsoiled collector. Overall, the total collector efficiency was reduced by 17.5% when comparing a dirty collector to a clean collector.

Hamdoon [11] tested nanofluids (Multi-Walled Carbon Nano Tubes in Water) to improve the thermal performance of the fluid used as a working fluid in Mosul, Iraq, instead of a traditional working fluid such as water. A dimensional dynamic simulation model was utilized and revealed that the temperature and thermal efficiency of the working fluid stream are affected by varying mass flow rates (kg/s, 0.004 to 0.030) and particle sizes (0% - 6%), as well as particle size ratios. The results yielded different results. The addition of MWCNT nanoparticles resulted in higher temperature differentials at both the inlets and outlets of the working fluid within the collectors, as well as higher collector thermal efficiencies. The temperature difference (28.1°C) between the serving fluid entering the collector (0.014 kg/sec) and exiting during April is an example, while the increase in thermal efficiency of the nanofluid solar collector compared to the standard solar collector is clearly demonstrated by an increase of 2.41 – 6.68 percent in the case of nanofluid versus water-based collectors, with these same temperature differences (25.0°C) for both fluid types falling within a range. Thus, the increased thermal efficiency of the nanofluid and/or the enhanced temperature differences (across different months) of both the inlet & outlet together result in better performance than either the nanofluid or the standard fluid.

To investigate improvements to solar water heaters, researchers Rashid et al. [12] studied how various factors affect solar water heater performance, including mass flow rate, angle of incidence with the sun, total available solar radiation, size of collector tubes, and number of glass plates used as covers. They conducted experimental research on a solar water heater during September and October, measuring overall system efficiency. Dynamic modeling and optimization were performed on the test data in MATLAB to generate practical data for assessing the operation of the flat-panel solar water heater. The overall efficiency of the water heater was improved by 9.09%, from 62.17% to 71.26%, by reducing the length of each solar collector tube. The distance between the solar collectors has decreased from 186 mm to 86 mm. The new collector efficiency has increased by approximately 2.00% when using 20 mm-diameter collectors instead of the previously determined standard 10 mm-diameter collectors. The maximum collector efficiency of approximately 83% was achieved with three glass covers on a flat-plate solar collector. The flow rate of fluid through the flat-plate solar collector increased significantly, as evidenced by the fluid volume flowing through the collector varying between 1 and 5 liters per minute, and the corresponding energy collected increasing from 64% to 83%. An optimum inclination angle for a flat plate solar collector has been determined to be 30 degrees based upon the highest total energy collected (and delivered) to the water (or other liquid). Due to an increase in wind speed, the coefficient of heat loss increased approximately 50% as wind speed increased from a slow velocity of 1 m/s to a rapid velocity of 5 m/s.

According to a survey conducted by Wael, Mahmoud, and Hamdon et al. [13], three electrical energy users were identified in the city of Mosul (northern Iraq). These users differ from one another in the amount of electricity they use (high, medium, or low consumption). Electricity prices for the domestic sector of the economy (Iraq) vary by level of consumption. The survey used for these three electrical energy users was based on an earlier survey, including data about their hot water requirements; the total value (financially) of the solar water heating equipment used and the savings generated (reduction in electricity consumption) from these consumers' use of the solar water heaters will be presented. The payback period (in years) for each consumer's solar water heater will be documented. As a result of the three consumers using this equipment, the gap between generation and load (from the point of view of this equipment) will decrease, thereby reducing the time consumers must wait to receive programmed discharges from the electricity network.

According to the results, the three consumers' total annual energy use is 40441, 24755, and 14695 kWh, respectively, without a solar water heater. Once a solar water heater was added to their system, the consumers' annual energy utilization decreased to 32,040,20659 kWh and 11,610 kWh, respectively.

The savings associated with solar water heaters are based on the difference between the energy consumed without a solar water heater and the energy consumed with one.

## 2. Photovoltaic Thermal Solar Collector (PV/T)

### 2.1. Working Principle of the (PV/T) Collector

A combined flat-plate PV/T system uses different frames to collect sunlight (PV) and a heat-absorbing plate (thermal collector) to extract heat from within a glass plate and transfer that energy to produce electricity; therefore, it will be covered with photovoltaic cells [14].

This technology can produce hot water and electrical energy simultaneously.

When sunlight hits the collector's surface, the hybrid solar collector converts photovoltaic (PV), or solar, energy into thermal energy stored in the working fluid. The amount of radiation that falls on the surface of the collector and the amount of thermal energy that can be obtained (captured) from the surface of the collector depends on two variables: how much radiation falls on the surface at a given time, and how much thermal energy can be obtained (captured) at that same point in time during the day and month. The photovoltaic part of the hybrid solar collector converts the solar energy that is spilled over (applied) to the PV side of the hybrid solar collector; when the solar radiation strikes the PV panels, the result is a flow of electrons created by the potential energy difference, creating an electrical field in the PV panels and producing an electrical current generated by the solar energy.

### 2.2. TRNSYS Program Overview

It is a simulation program called Transient System Simulation, abbreviated as TRNSYS, which handles data and outputs over time, simplifies the process of building projects, saves effort, time, and money, and provides outputs in graphical and digital formats. The paper examines this program as a pioneer in the field of renewable energy; it will be approved in this paper, tested, and the results analyzed and compared with practical results. Work will be done on version (V.18) in this paper.

### 2.3. The Parameters in the Simulation

The devices used in the simulation inside the program include the elements shown in Table 1, which shows each name of the Type used in the simulation with the symbol that symbolizes it; otherwise, there are some parameters fixed in the collector Properties shown in Table 2, while there are many factors fixed during the simulation shown in Table 3.

**Table 1.** The components used in the program.

Component Name	Symbol
Weather Data Processor	Type15
PV-Thermal Collector	Type 50a
Cylindrical Storage Tank	Type534-NoHX
Auxiliary Fluid Heater	Type138
Single Speed Pump	Type114
Time Dependent Forcing Function	Type14h
Quantity Integrator	Type24
Printer	Type25c
Online graphical plotter with output file	Type65c

The solar panel length is the length of the surface solar cell, and the solar collector length is the length of the collector surface, which contains the collector tubes; it has the same meaning as the solar panel width and the solar collector width.

**Table 2.** Fixed parameters in the design of the solar collector for all components.

Parameters	Value	Units
The length of the solar collector	1.5	m
The solar collector width	1	m
The number of solar collectors	1	----
The number of layers of the board: Clear plastic	1	----
The distance between the collector tubes	0.05	m
Solar collector tube diameter	0.007	m
The distance between the tubes and the transparent sheet	0.04	m
Insulator thickness	0.04	m
The length of the serpentine pipe in the collector	10	m
Tank diameter	0.4	m
Tank length	0.8	m
Tank volume	100	L
Water flow rate	1	L /min
Specific heat of water	4.19	KJ/kg.K
Viscosity of water	3.12	kg/m.hr
Water thermal conductivity	2.14	kJ/hr.m.K
Solar panel length	0.32	m
Solar panel width	0.75	m

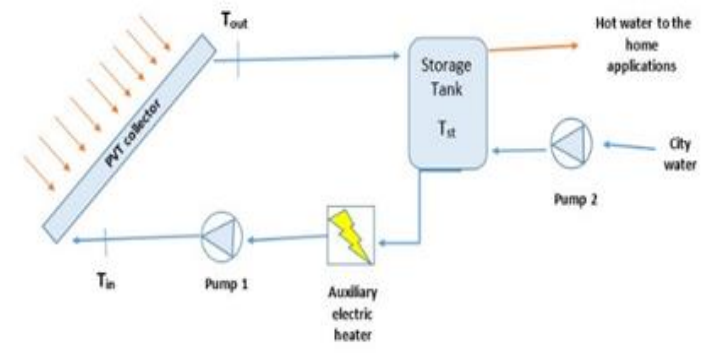
**Table 3.** Constants and factors used in TRNSYS software.

Parameters	value	units
Collector Fin Efficiency Factor	0.96	----
Fluid Thermal Capacitance	4.19	kJ/kg.K
Collector plate Absorbency	0.92	----
Collector loss coefficient	14	kJ/hr.m <sup>2</sup> .K
Cover transmittance	0.89	----
Reference temperature for cell efficiency	25	C
Packing factor	0.16	----
Tank Volume	0.1	m <sup>3</sup>
Tank Height	0.8	m
Fluid Specific Heat	4.19	kJ/kg.K
Fluid Density	1000	kg/m <sup>3</sup>
Fluid Thermal Conductivity	2.14	kJ/hr.m.K
Fluid Viscosity	3.12	kg/m.hr
Maximum heating rate	5000	kJ/hr
Efficiency of auxiliary heater	0.8	----
Set point temperature	60	C°
Slope of the surface	55	Degrees
Azimuth of surface	0	Degrees
Reference efficiency of photovoltaic	0.25	C°

### 3. The Methodology of The System

This study was done in the region of Iraq, specifically in Mosul city, at the location (36°N,43°E), and the instantaneous weather conditions were taken from the weather component in the library of TRNSYS software, which contains all weather data, like the temperature of the atmospheric environment and the intensity of the radiation.

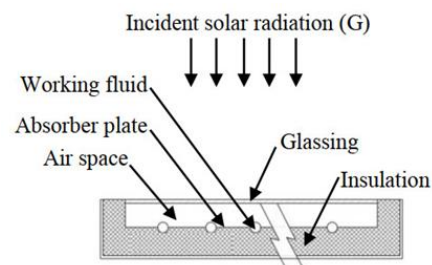
There are some input data, such as the solar collector surface being oriented towards the south at an inclination angle of 55 degrees, and the system was connected in open-loop mode, as shown in Fig. 1.



**Figure 1.** Connecting components in open-loop mode.

#### 3.1. Physical Model of the (PV/T) Collector

The solar collector consists of a serpentine tube through which water is circulated, with holes for water entry and exit, and is painted black. It is placed inside a black box. Under the tubes is a black metal plate that absorbs solar radiation, with Heat-insulating materials placed below it to store as much heat as possible [15]. A transparent polyethylene sheet is placed above the tubes to allow entry of solar radiation and to provide an atmosphere similar to that of a greenhouse, as shown in Fig. 2.



**Figure 2.** Physical representation of a (PV/T) collector.

#### 3.2. Mathematical Model

##### 3.2.1. The Amount of Useful Heat Gained in the Process

The heat absorbed by a solar collector when using solar energy is measured in watts (W) and is denoted by the symbol ( $Q_{u\_theo}$ ). There is a mathematical equation for how much heat the sun produces to warm water using a solar collector. The quantity of heat produced from the sun and delivered to a solar collector ( $Q_{u\_theo}$ ) depends on the temperature difference

between the interior and exterior water of the solar collector and can be represented by the following equation: [16]-[17]

$$Qu_{theo} = \dot{m}c_{p_w}(T_{in,theo} - T_{out,theo}) \quad (1)$$

Where:

$\dot{m}$  : the water mass flow rate

$c_{p_w}$  : The specific heat of water

$T_{in,theo}$  : inlet water temperature

$T_{out,theo}$  : outlet water temperature

### 3.2.2. Thermal efficiency of the solar collector

The theoretical thermal efficiency is calculated by entering the theoretical variables into the equation, and the thermal efficiency is symbolized by ( $\eta_{theo}$ ), and the theoretical thermal efficiency is represented as follows [18]-[19],

$$\eta_{theo} = \frac{Qu_{theo}}{Rad_{theo} * A_{coll}} \quad (2)$$

Where:

$Qu_{theo}$  : useful heat gain

$Rad_{theo}$  : intensity of radiation

$A_{coll}$  : collector area

### 3.2.3. Solar fraction

The solar contribution is denoted by the symbol (SF) for short (Solar Fraction), and it denotes the amount provided by the solar radiation of the value of the useful heat gained in the solar collector to the auxiliary heater energy, and the following satisfactory representation represents it,

$$SF = \frac{Qu}{(Qu + Q_{aux})} \quad (3)$$

Where:

$Qu$  : useful heat gain

$Q_{aux}$ : auxiliary heat energy

### 3.2.4. Solar panel efficiency

It is the solar efficiency of solar panels related to different temperatures, where its value indicates how much the temperature of the solar panel affects the efficiency of the solar panel, and it is symbolized by the symbol (Pveff), and it is mathematically represented as follows [20],

$$PV_{eff} = Ref_{eff} (1 - \beta(T_{pv} - T_{ref})) \quad (4)$$

Where:

$Ref_{eff}$  : reference panel efficiency

$\beta$ : temperature coefficient  $\beta = 1/T_{pv}$

$T_{pv}$  : photovoltaic solar panel temperature

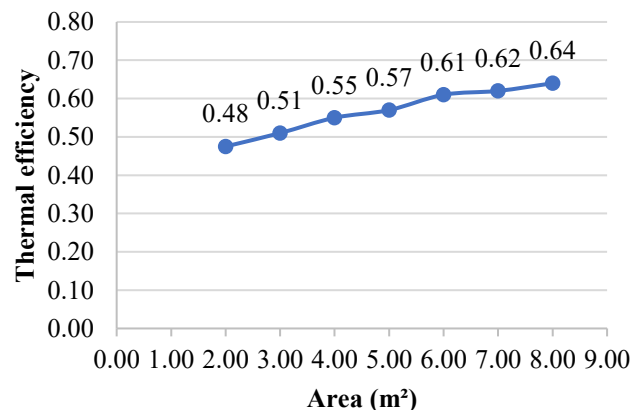
$T_{ref}$ : Solar panel reference temperature

## 4. Results and Discussions

Several papers indicated that simulation software (TRNSYS) was validated against empirical results, and this led to the construction of a solar thermal energy collection system along with all associated equipment. The interconnection of these items using the program involved testing and simulation to see how adjusting different parameters would affect the system's performance. These parameters included but were not limited to: the surface area of the solar collector; the coverage factor of the solar collector; the solar collector's tilt angle from horizontal; the volumetric flowrate of the water inside the solar collector; the capacity of the storage tank; and finally the thermal efficiency; solar fraction (SF); and efficiency of the photovoltaic panel (PVeFF) performance. Over November, a 24 hr/day simulation was run, with one representative sample taken each day for averaging. The system was designed as an open-loop system in which all components were sequenced together (see Fig. 1). Cold water (19 degrees Celsius) is added to the tank at a flow rate of 18 L/h. Hot water is withdrawn from the tank according to its temperature. (18 L/h).

### 4.1. The Effect of Changing Collector Surface Area

The impact of varying the solar collector surface area was investigated while maintaining all other variables constant. As the surface area of the solar collector increased from 2 square meters to 8 square meters, the thermal efficiency of the solar collector improved from 48% to 64% (see Fig. 3). Based on modeling of multiple runs in the software, the thermal efficiency of a solar collector improves in direct proportion to the amount of surface area of the solar collector and is influenced by how long and how far the water flows through the piping inside the solar collector as it absorbs solar energy.



**Figure 3.** Effect of collector surface area on the thermal efficiency.

Through investigating how surface area changes affect the solar fraction (SF) to energy absorbed from a water source at a solar collector and conducting the necessary simulations, it was discovered that when the surface area of the solar collector was 2 m<sup>2</sup>, the SF equals 31% and increased along with continued increases in surface area up until an SF value of 49% was reached when the surface area was increased to 8 m<sup>2</sup>. It was also concluded that as the surface area of the solar collector increased, the contribution from solar energy (SF) absorbed by

the solar collector increased; However, in conducting simulations on the impact of a changing surface area on solar panel efficiency (PVeff), only a modest increase occurred except for minor increases (refer to Fig. 4).

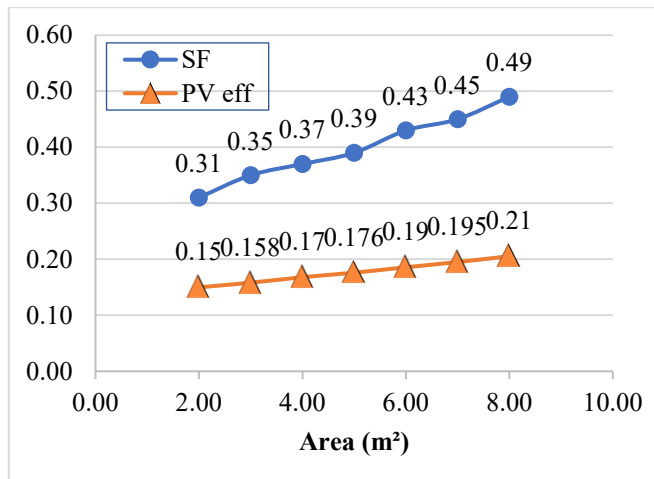


Figure 4. Effect of collector surface area on the solar fraction and solar panel efficiency.

4.2. The Effect of Changing the Value of the Packing Factor

The packing factor is defined as the packing ratio of the solar panels in the solar collector. When studying the effect of the packing factor on the thermal efficiency of the solar collector, it was found that at a packing factor of 0%, the thermal efficiency is 53%. The thermal efficiency continues to decline with the increase of the packing factor to reach the value of thermal efficiency 29% at a packing factor of 100%, as shown in Fig.5, which illustrates the relationship and proportionality between them, and the inverse proportion between thermal efficiency and packing factor (PF), that whenever the packing factor increase whenever the packing area increase of the collector by solar panels, which leads to blocking part of the solar radiation from the solar collector tubes inside which water flows, and thus reducing the energy absorbed from the incident solar radiation.

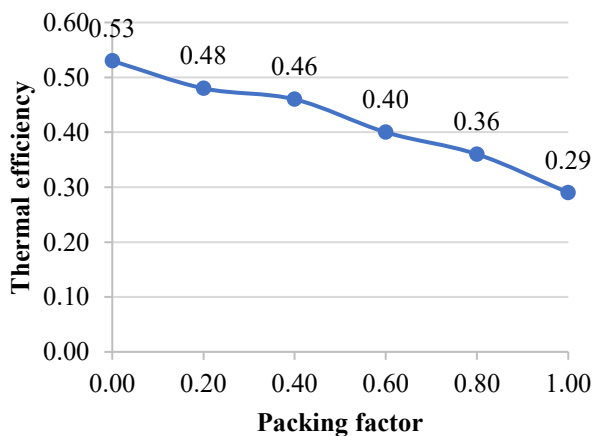


Figure 5. Effect of packing factor on the thermal efficiency of the solar collector.

Then When study the effect of the packing factor on the solar fraction (SF), it was found that the solar fraction is 35% when the packing factor is 0%, and decreases with the increase in the packing factor to reach the value of the solar fraction 19% when the packing factor is 100% as shown in Fig.6, the value of the packing factor due to the large area of the panels, as well as due to a secondary effect, which is the cooling process of the panels by the water that flows under them inside the tubes of the solar collector.

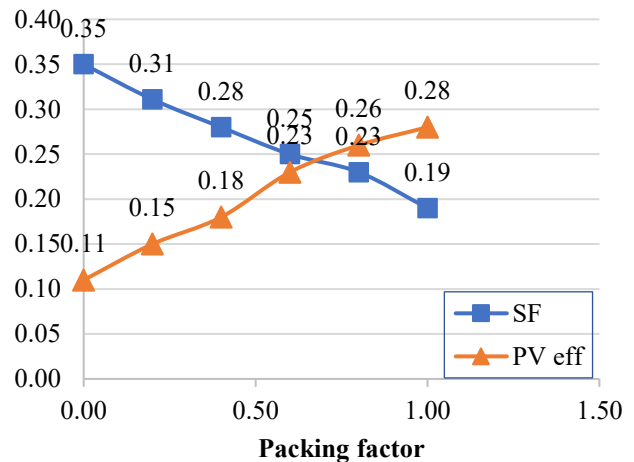


Figure 6. Effect of packing factor on the solar fraction and solar panel efficiency.

4.3. The Effect of Sloping Value

The angle of inclination of the solar collector is considered one of the important matters in determining the characteristics of many types of solar collectors. A simulation of a hybrid solar collector system was carried out, and the angle of inclination was varied; an efficiency of 32% was recorded at a horizontal inclination angle of 0°. It was observed that the thermal efficiency increased with increasing angle of inclination until it reached its maximum value of 50% at 52°, then gradually decreased to 38% at 90°. These increases and decreases are due to the non-perpendicularity of solar radiation to the solar collector surface. In the case of perpendicularity, the thermal efficiency is maximized. Fig. 7 shows the relationship between the degree of inclination and thermal efficiency.

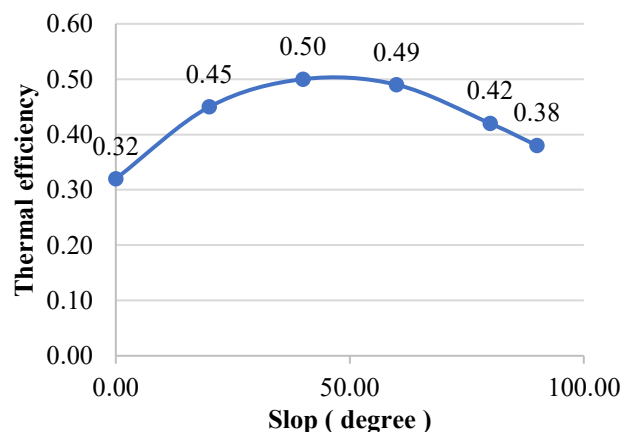
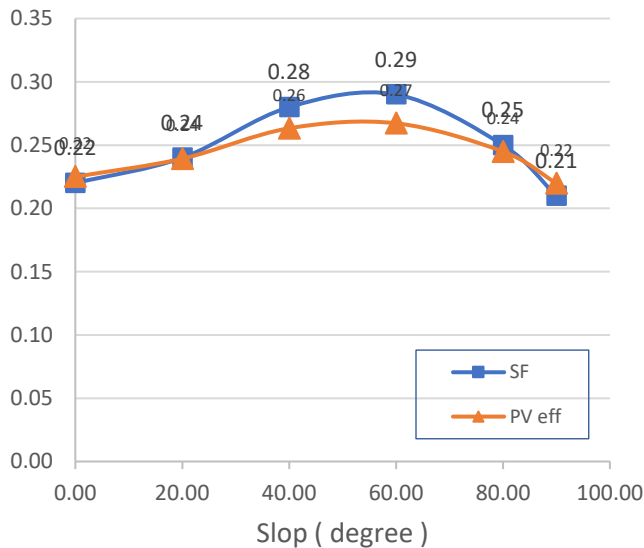


Figure 7. Effect of slope value on thermal efficiency.

When studying the effect of the solar collector's angle of inclination on the solar fraction (SF), it was observed that SF increases with increasing inclination. At the angle of inclination 0°, the solar fraction was 22%, and it increased to reach the maximum value of the solar fraction of 29% at the inclination angle of 58°. After that, the thermal fraction continued to decrease as the angle of inclination increased. This increase and decrease are explained by the increase and decrease in incident solar radiation resulting from not making the most of it due to its non-perpendicularity. When studying the effect of the angle of inclination on the efficiency of solar panels (PVe<sub>eff</sub>), a behavior similar to that of the solar fraction was observed, with the maximum efficiency of the panels recorded. It has a value of 27% at an angle of inclination of 58°, for the same reasons mentioned above, and Fig. 8 shows the relationship between them.

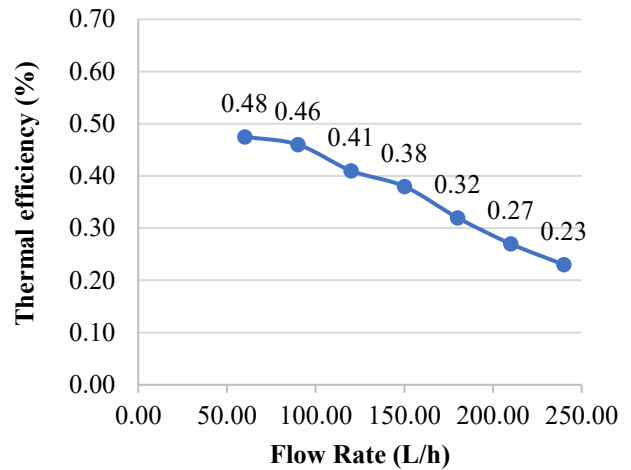


**Figure 8.** Effect of slope value on the solar fraction and solar panel efficiency.

**4.4. The Effect of Water Flow Rate in the System**

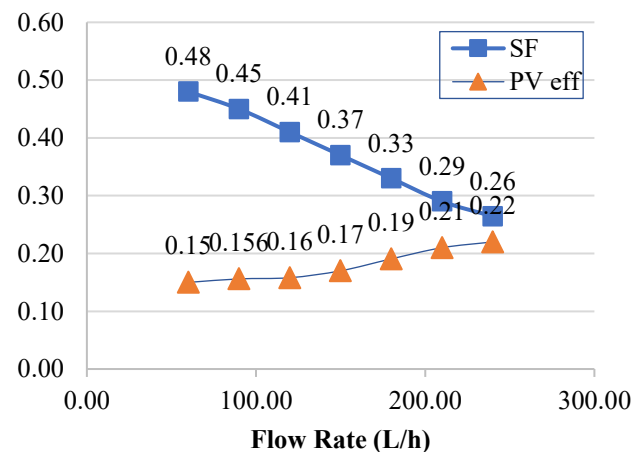
The process of simulating changes in the water flow rate in the solar collector system was carried out by varying the thermal efficiency, with the other variables held constant. The results were observed that when the value of the flow rate is (60 L/h), the value of the thermal efficiency is 48%, and when the flow rate increases, the thermal efficiency decreases to reach 28% at a flow rate (240 L/h), as a result of the decrease in the amount of heat acquired by the water by the solar collector due to the low temperature on both sides of the solar collector at entry and exit, since the flow rate is large as shown in Fig.9.

The simulation also showed that the water flow rate affected the solar fraction (SF), with the thermal contribution decreasing as the flow rate increased. The thermal contribution was recorded at 48% at the flow rate (60 L/h), and the value of the solar fraction was 26%. At a flow rate of 240 L/h, due to the flow velocity, which reduces the difference between the temperatures at entry and exit of the solar collector, the effect of the flow rate on the value of solar panel efficiency (PVe<sub>eff</sub>) was simulated.



**Figure 9.** Effect of water flow rate on the thermal efficiency.

The increase was directly between the flow rate and the efficiency of the panels. The efficiency of the solar panels recorded an amount of 15% at a flow rate of (60 L/h) and increase to 22% at a flow rate of (240 L/h) due to the cooling feature of the panels by the solar collector tubes attached to it in which water flows, also as a result of the low temperature. The temperature of the flowing water inside the tubes of the solar collector, and Fig.10, show the relationship between the flow rate and each of the solar contribution (SF) and solar panel efficiency (PVe<sub>eff</sub>).

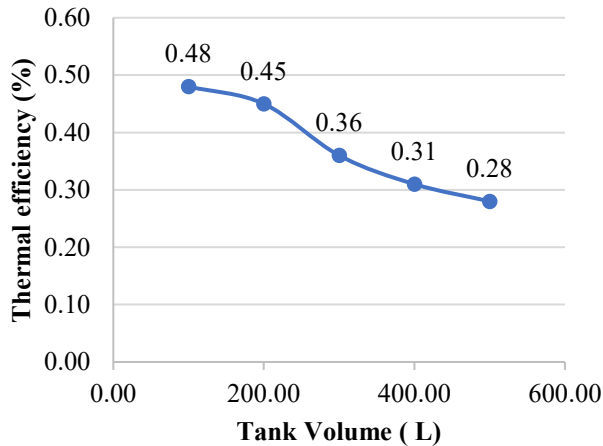


**Figure 10.** Effect of water mass flow rate on the solar fraction and solar panel efficiency.

**4.5. The Effect of Water Tank Volume**

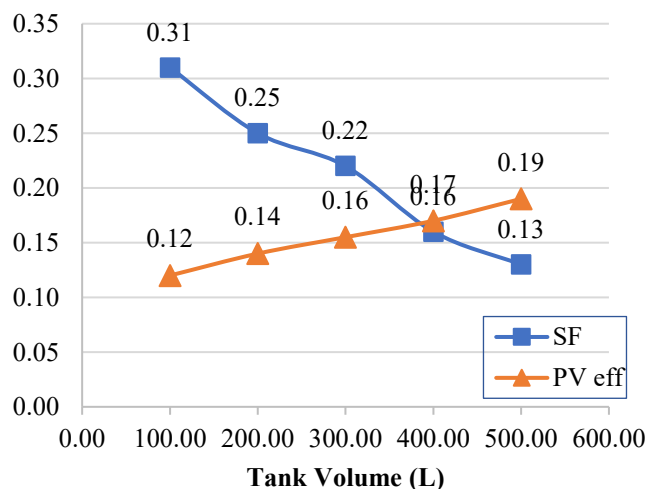
The effect of changing the water tank volume on the thermal efficiency of the solar collector was investigated with the other factors held constant, and the data were extracted from the program. It was observed that when the volume of the water tank increased, this led to a decrease in the thermal efficiency of the solar collector; the thermal efficiency value was 48% when the volume of the tank was equal to (100 L). The value of thermal efficiency decreases as the size of the water tank increases, so that the thermal efficiency reaches 28% when the volume of the tank is ( 500 L). This inverse proportion is

because the water temperature inside the large tank is low due to the amount of hot water It enters the tank from the solar collector so small in amount, which leads to water leaving the tank and reaching the solar collector at a low temperature, which causes a decrease in the thermal efficiency of the solar collector and Fig. 11, illustrate the relationship between the size of the tank and thermal efficiency.



**Figure 11.** Effect of water tank volume on the thermal efficiency.

A simulation of the effect of varying the water reservoir volume on the solar fraction (SF) was also conducted. An inverse relationship was found between them, where the value of the solar fraction was 31% when the volume of the reservoir was (100 L). It decreased after that by increasing the volume of the reservoir to reach 13% when the volume of the reservoir (500 L) and the relationship of the size of the tank with the efficiency of the solar panels (PVeff) was also reviewed to show the results an inverse relationship between them, where the value of the efficiency of the solar panels was 12% when the size of the tank was (100L), to increase after that to 19% when the size of the tank was (500 L) as shown in Fig.12.



**Figure 12.** Effect of water tank volume on the solar fraction and solar panel efficiency.

## 5. Conclusions

- 1- When the surface area of the solar collector increases from (2 m<sup>2</sup>) to (8 m<sup>2</sup>), the thermal efficiency value increases directly to reach a value of 64%, and the (SF) value also increases by 18%, in addition to an increase of 7% for the efficiency of solar panels.
- 2- As the panel coverage factor (PF) increases from 0% to 100%, the thermal efficiency value decreases by 24%, and the SF value also decreases by 24%, resulting in a noticeable increase in the solar panel efficiency value by 17%.
- 3- When the inclination angle of the solar collector increases above 0°, the thermal efficiency increases until it reaches its maximum value at 40° inclination by 50% and then gradually decreases as the inclination angle increases. Likewise, as the inclination angle increases, the value of (SF) increases to reach its highest value at an inclination angle of 58°.
- 4- When the volumetric flow rate increases from (60 L/h) to (240 L/h), the thermal efficiency decreases by 25%, as well as a decrease in the SF value by 22% and an increase in the efficiency value of solar panels by 7%.
- 5- When the size of the water tank is increased from (100 L) to (500 L), this leads to a decrease in thermal efficiency by 20%, a decrease in the SF value of the solar collector by 18%, and a noticeable increase in the efficiency value of the solar panels by 7%.

## Acknowledgements

Thanks and appreciation to the Technical Engineering College in Mosul for their technical support in part of this paper.

## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

## Author Contribution Statement

This manuscript was contributed to by all authors. Mohammed Ahmed suggested software for the necessary simulation to obtain results and to study the effects and changes occurring in the PV/T collector. Both authors discussed the results and contributed to the final manuscript. Ahmed Khalid proposed the paper's problem and supervised the work's findings.

## References

- [1] S. Theeyzen and B. Freegah, "The effect of added wire mesh on the thermal efficiency of the flat plate solar water heater collector," *Results in Engineering*, vol. 24, Art. no. 103203, 2024. doi: <https://doi.org/10.1016/j.rineng.2024.103203>.
- [2] S. Jaafar, O. M. Salih, D. Safar, M. Safar, and H. H. Abdulkhudhur, "Performance evaluation of solar-PV panels for static and sun tracking system in Kirkuk-Iraq using SVM," *Mathematical Modeling of Engineering Problems*, vol. 12, no. 10, pp. 3553–3562, 2025. doi: <https://doi.org/10.18280/mmep.121021>.
- [3] M. Udit and Tiwari N. "Dual-axis solar tracking system with different control strategies for improved energy efficiency," *Computers and*

- Electrical Engineering*, vol. 111, p. 108920, 2023, doi: <https://doi.org/10.1016/j.compeleceng.2023.108920>
- [4] M. Herrando, et al., "A review of solar hybrid photovoltaic–thermal (PV-T) collectors and systems," *Progress in Energy and Combustion Science*, vol. 97, Art. no. 101072, 2023. doi: <https://doi.org/10.1016/j.peccs.2023.101072>
- [5] K. Fatima, A. F. Minai, H. Malik, and F. P. García Márquez, "Experimental analysis of dust composition impact on photovoltaic panel performance: a case study," *Solar Energy*, vol. 267, Art. no. 112206, 2024. doi: <https://doi.org/10.1016/j.solener.2023.112206>
- [6] U. R. J. Eiva, T. A. Chowdury, S. S. Islam, A. Ullah, J. N. Tuli, and M. T. Islam, "Comprehensive analysis of fixed tilt and dual-axis tracking photovoltaic systems for enhanced grid integration and energy efficiency," *Renewable Energy*, vol. 256, p. 123865, 2026, doi: <https://doi.org/10.1016/j.renene.2025.123865>
- [7] A. Fudholi, K. Sopian, M. H. Yazdi, M. H. Ruslan, A. Ibrahim, and H. A. Kazem, "Performance analysis of photovoltaic thermal (PVT) water collectors," *Energy Conversion and Management*, vol. 78, pp. 641–651, 2014. doi: <https://doi.org/10.1016/j.enconman.2013.11.017>
- [8] J. H. Lee, S. G. Hwang, and G. H. Lee, "Efficiency improvement of a photovoltaic thermal (PVT) system using nanofluids," *Energies*, vol. 12, no. 16, Art. no. 3063, 2019. doi: <https://doi.org/10.3390/en12163063>
- [9] A. Gupta, S. Agrawal, and Y. Pal, "Energy and exergy performance evaluation of a novel photovoltaic–thermoelectric system combined with tube and sheet serpentine water collector," *International Journal of Green Energy*, vol. 19, no. 4, pp. 365–379, 2022. doi: <https://doi.org/10.1080/15435075.2021.1946814>
- [10] O. K. Ahmed and Z. A. Mohammed, "Dust effect on the performance of the hybrid PV/thermal collector," *Thermal Science and Engineering Progress*, vol. 3, pp. 114–122, 2017, doi: <https://doi.org/10.1016/j.tsep.2017.07.003>
- [11] O. M. Hamdoon, "Improving the performance of a flat plate solar collector using nanofluid as working fluid," *Al-Rafidain Engineering Journal (AREJ)*, vol. 25, no. 2, pp. 37–45, Dec. 2020. doi: <https://rengj.uomosul.edu.iq/index.php/rengj/article/view/31113>
- [12] K. K. Rashid, I. I. Hamakhan, and C. C. Mohammed, "Tilt angle optimization and investigation of the behavior of a flat plate solar collector using MATLAB for Kurdistan climate conditions-Iraq," *International Journal of Heat & Technology*, vol. 40, no. 2. Pp. 583-591. doi: <https://doi.org/10.18280/ijht.400227>
- [13] W. H. Hamdon, M. U. Jasim, and M. S. M. Al-Hafidh, "The use of solar water heaters in Iraq: An economic study," *Al-Rafidain Engineering Journal (AREJ)*, vol. 27, no. 1, pp. 56–63, Mar. 2022. doi: <https://rengj.uomosul.edu.iq/index.php/rengj/article/view/30637>
- [14] M. Ghazy, E. M. M. Ibrahim, A. S. A. Mohamed, and A. A. Askalany, "Experimental investigation of hybrid photovoltaic solar thermal collector (PV/T)-adsorption desalination system in hot weather conditions," *Energy*, vol. 254, p. 124370, 2022, doi: <https://doi.org/10.1016/j.energy.2022.124370>
- [15] A. Alshibil, P. Víg, V. Erdélyi, J. Tóth, and I. Farkas, "Performance Assessments of Direct Contact Serpentine Tube Based Photovoltaic Thermal Module: An Experimental Comparison", *J. eng. sustain. dev.*, vol. 28, no. 4, pp. 473–479, Jul. 2024, doi: <https://doi.org/10.31272/jeasd.28.4.6>
- [16] K. R. Ali, M. H. M. Hariri, M. S. M. Othman, M. N. Abdullah, I. Adnan, and M. K. M. Desa, "Experimental investigation and performance assessment of a water-based hybrid bifacial photovoltaic-thermal solar energy system," *Applied Thermal Engineering*, vol. 283, p. 128947, 2026, doi: <https://doi.org/10.1016/j.applthermaleng.2025.128947>
- [17] Z. Y. Li, J. H. Gong, J. Wang, and P. D. Lund, "Optimizing research on flat-plate solar collector based on field synergy theory," *Energy Reports*, vol. 12, pp. 1977–1986, 2024, doi: <https://doi.org/10.1016/j.egy.2024.08.018>
- [18] A. T. Adeosun, B. M. Yisa, L. O. Aselebe, K. B. Kasali, M. O. Ibitoye, and A. R. Mohd Kasim, "Magnetohydrodynamic enhancement of solar collector efficiency using Al2O3–Cu hybrid nanofluids with variable thermal conductivity," *Journal of Taibah University for Science*, vol. 19, no. 1, Art. no. 2546192, 2025. doi: <https://doi.org/10.1080/16583655.2025.2546192>
- [19] X. Lin, Y. Xia, Z. Cheng, X. Liu, Y. Fu, L. Li, and W. Zhou, "Thermal performance analysis of porous foam-assisted flat-plate solar collectors with nanofluids," *Sustainability*, vol. 16, no. 2, Art. no. 693, 2024. doi: <https://doi.org/10.3390/su16020693>
- [20] I. Al-Masalha, A. S. Alsabagh, O. Badran, N. Alkawaldeh, T. M. Abu-Rahmeh, and A. Al Alawin, "Improving photovoltaic module efficiency using water sprinklers, air fans, and combined cooling systems," *EPJ Photovoltaics*, vol. 15, p. 41, 2024, doi: <https://doi.org/10.1051/epjpv/2024037>