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Effect of Changing the Water Flow Rate on the Efficiency of Hybrid PV/T Uncovered Collectors without Glasses: Numerical Study

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ABSTRACT

The flat-plate collector is one of the most frequent types of collectors because it is simple to manufacture and it is relatively inexpensive in comparison to other collectors. The primary objective of this work is to improve the collector's efficiency, which can be accomplished by increasing the heat transfer quantitatively. This can be accomplished by increasing the efficiency of the collector. In this research employs hybrid photovoltaic panels through electrical generation and, on the other hand, takes advantage of the lost heat, which has reduced efficiency to useful heat, by transporting them through fluid and benefiting from them through industrial and domestic applications. The model was studied numerically by ANSYS computational code, where simulations were carried out on CFD and steady state thermal, as well as the effect of solar radiation, at a value of 10, on the layer of photovoltaic cells. Besides, several values of flow rate (0.02, 0.025, and 0.03) were used and compared. The current findings show that the efficiency of the current panel under consideration increased significantly, and the value of flow of 0.03 was the optimal value that led to obtaining suitable efficiency and a relatively acceptable water temperature.

Keywords:
Hybrid PV; Enhancement; Wasting thermal energy; Recovery and development; CFD

1. Introduction

As fossil fuels are being depleted, there is an urgent need to find alternative energy sources to meet the rising energy demands of the future and of future generations. Solar power has quickly become the most widely adopted alternative energy source. It's superior in quality and quantity, readily available everywhere, consistently effective in practical applications, and environmentally benign once turned into useful forms and put to use. One of the most common and simplest ways to harness the power of the sun's rays for later use is with a solar collector. Around the world, many new technologies and initiatives are being undertaken to help reduce fossil gas intake [1]. While the emphasis has been on the electricity and transportation sectors, the commonplace subject of renewable energy and heat manufacturing has advanced on the basis of photovoltaic thermal collectors (PV/T) [2, 3].

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Das *et al.,* [4] designed and tested experimentally and numerically a thorough heat transfer analysis for a hybrid PVT that takes heat transfer impedance and conductivity heat production. Their findings show that taking into account thermal contact resistance and Ohmic loss at the PV layer greatly minimizes the inaccuracies. Numerically, Rejeb *et al.,* [5] designed a model and analyzed it for a unique PVT collector with the best improvements, optic coating, and heat transfer resistance across PVT sheets. Besides, Maadi *et al.,* [6] designed a PVT model and test it by include fluid movement, heat transport, and the tracking of sun rays in a glass collector. Herrando *et al.,* [7] designed numerically a modal with CFD-FEM and assess the effectiveness of sheets and tubes with various absorption sizes and materials.

Numerically and experimentally, Barone *et al.,* [8] designed and created a reduced-cost model of a liquid PVT collector, as well as testing and dynamical analytical model research to access the results of energy, economy, and ecology under various conditions. Ibrahim *et al.,* [9] numerically investigated the effectiveness of several absorber models in order to select the one with the best average efficiency. Numerically and experimentally, Souliotis *et al.,* [10] studied the functional temperature range (40-60 C), the variations among the highest electrical efficiency for glazed and unglazed systems are just 0.3-0.4%.

Wodołazski *et al.,* [9] is co-simulated with a single-phase inverter to show its full transient behavior. Variables like as wind speed, solar radiation intensity, and ambient temperature were also studied in relation to the PV-TEG system. Ansys software was used to create the numerical model that took into consideration the effects that Thomson, Seebeck, and Joule's heat have on the TEG system. Its effect on overall electricity efficiency was also investigated. Passive heat sink's heat transfer surface and forced air circulation had a favorable effect on total heat transfer, which kept electrical efficiency high. It is possible to determine the power characteristics of a PV-TEG system in real time by simulating the single-phase inverter. The research presented has the potential to serve as a starting point for optimizing the performance of a real-world PV-TEG-inverter hybrid system design.

Khan *et al.,* [10] consider the aerodynamic lift force operating on the solar structure when developing a counterbalance for rooftop-mounted solar systems. Because of their one-of-a-kind layout, solar power facilities may have an overestimated or underestimated load when compared to global construction requirements. Estimating wind loads on solar panels for design purposes and finding important design scenarios is a common application of Computational Fluid Dynamics (CFD) simulations. Simulations using Computational Fluid Dynamics (CFD) typically necessitate a lot of computing power, and it might take a long time to determine the best possible geometry configuration through iteratively tweaking the geometry. This research proposes using Computational Fluid Dynamics (CFD) and genetic algorithms to optimize a strategy for reducing the impact of lift force on solar photovoltaic (PV) arrays mounted on rooftops. A genetic algorithm was used to find a layout of a solar photovoltaic plant in which the wind lift force was minimized by varying the tilt angle and pitch between two rows of solar panels. Only combinations with an efficiency ratio of 80% or above were considered. In this study, we compare and contrast three distinct solar photovoltaic (PV) plant architecture designs for use on rooftops. To optimize a 2D array of photovoltaic (PV) panels, ANSYS Fluent was applied to a model including two parallel rows of panels. For all three of these scenarios, the results showed that the difference in wind-liftforce between the optimum design and the highest lift force configuration was 50%.

Farhan *et al.,* [11] used to harness the energy contained inside sunshine. Panel heating during the day, however, reduces voltage output and leads to wasted energy-electricity. Computational Fluid Dynamics (CFD) was used to model and evaluate the effectiveness of the water and aluminum oxide (Al2O3) nanofluid cooling system used in this PV panel. The thermal performance of uncooled, water-cooled, and Al2O3 nanofluid-cooled solar panels are compared in this study. The solar panel's lowest temperature was found by experimenting with several input coolant temperatures and mass flow rates (20, 25, 30, 35, and 40 °C) and coolant flow rates (16.5, 33, 66, and 99 L/h). The lowest possible solar panel temperature, essential for energy storage, was promised by Al2O3 nanofluid-cooled solar panels at the greatest flow rate and the lowest input coolant temperature, 99 L/h and 20°C, respectively. The temperature of solar panels was reduced by 41% to 60% with the use of nanofluid coolant. These findings provide evidence of nanofluid's potential as a coolant.

In this paper and based on the above survey, it's clear that PV/T collectors are generally the best sort of sun-powered gatherers. Therefore, the work aims to focus on hybrid photovoltaic thermal (PV/T) collectors and comparing two types under different flow rates.

2. Computational Methodology

The design process was done using Solid Works software. The computational model consists of photoelectric cells, a glass panel, and curved Risers, as shown in Figure 1. Dimensions of the Panel: 214×1.4 [cm], hydraulic diameter (DH) = 0.03 [m]. The modelling and simulation process was done by Ansys software version 15. In the PV panel, just the PV cell surface wasused for modelling since it has consistent heat transfer across layers.

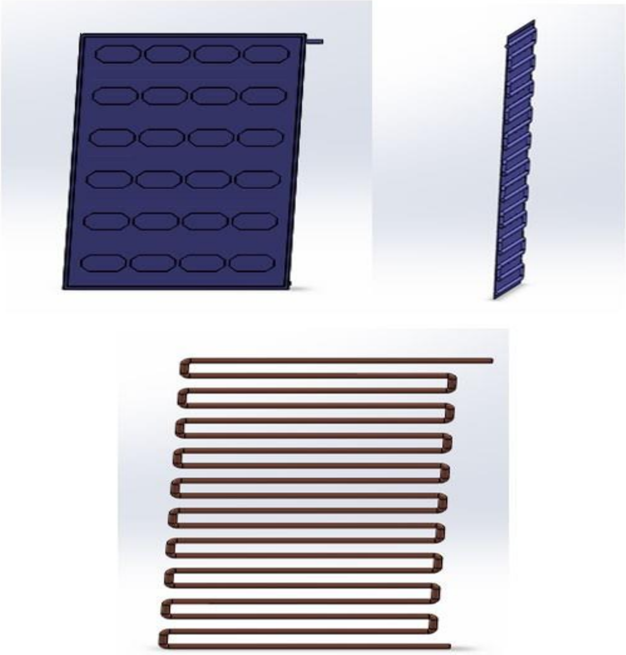

Fig. 1. Panel parts of the current study

Table 1 displays the design panel specifications with all dimensions, while Figure 2 shows themesh grid of the current model.

Table 1
Design panel specifications under consideration

Material	Thermal conductivity $[WW/m.K]$	Dimensions[Cm]	Number	Density $[Kg/m^{33}]$
RISER	390	3	20	8830
PV	148	0.5	677	2330

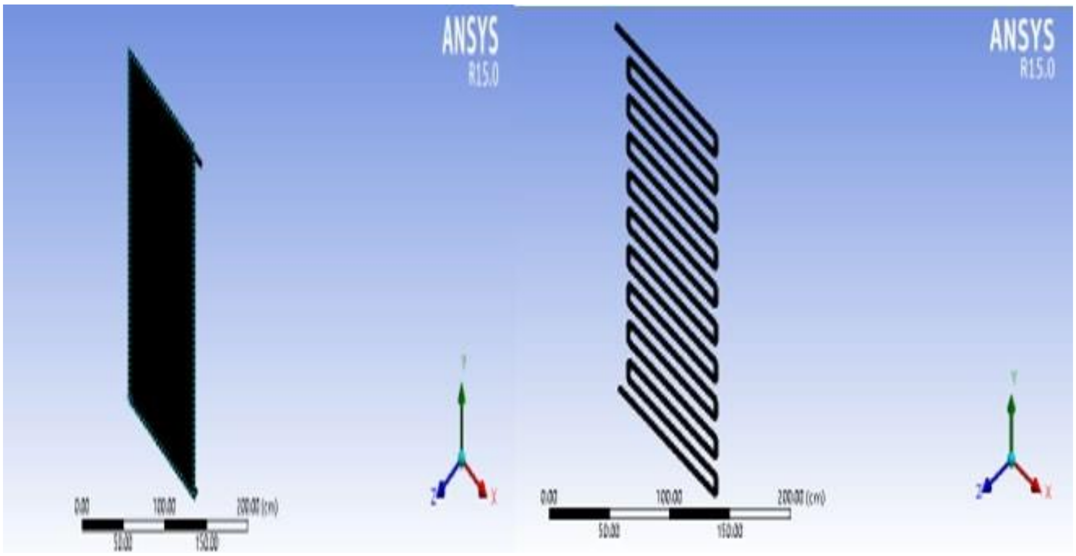

Fig. 2. Mesh of panel and risers

After the design process by Solid Works, the model was entered into the Ansys programme, and the finished elements were applied to the board in order to obtain the most accurate solutions. The nodes and elements are on rows 418247 and 1361894. The working fluid is water, and the outlet pressure is atmospheric pressure. Table 2 shows the boundary conditionsof the current study.

The mathematical formulation for fluid flow and heat transfer in natural ventilation in a room integrated with solar chimney and evaporative cooling with different modes and absorber media models was developed under the following assumptions:

i. Conservation equations with three dimensions.
ii. Incompressible flow in a steady state
iii. Heat transfer through the glass cover and absorber plate in three dimensions is
iv. accomplished through conduction.
v. Air flow in the channel has been considered turbulent.
vi. For the density variation, the Boussinesq approximation was used.
vii. All properties are evaluated at a temperature that is considered to be standard.

Table 2
Boundary conditions

Parameter	Value		
Ambient temperature	288 [K]		
inlet temperature	288[K]		
Water specific heat	4180 $[J/Kg.K]$		
Irradiance	1000 [W/m^2]		
Convection heat transfer coefficient	10 [W/m^2]		
water Flow rate	0.02$[Kg/s]$	0.025$[Kg/s]$	0.03$[Kg/s]$

2.1 CFD Model Setting and Parameter

For the present work, a second-order upwind scheme was used for momentum and energy equations, standard simple was used for pressure. Under – relaxation factors were used, 0.3 for pressure, 1 for density, 1for body forces, 0.7 for momentum equation, and 1 for energy equation. To have converged, the flow solution must be stable after all equation residuals have been reduced to approximately 1000-800 for energy equation and 1000-400 for continuity equation, they required (1200 – 1400) iterations as shown in Figure 3.

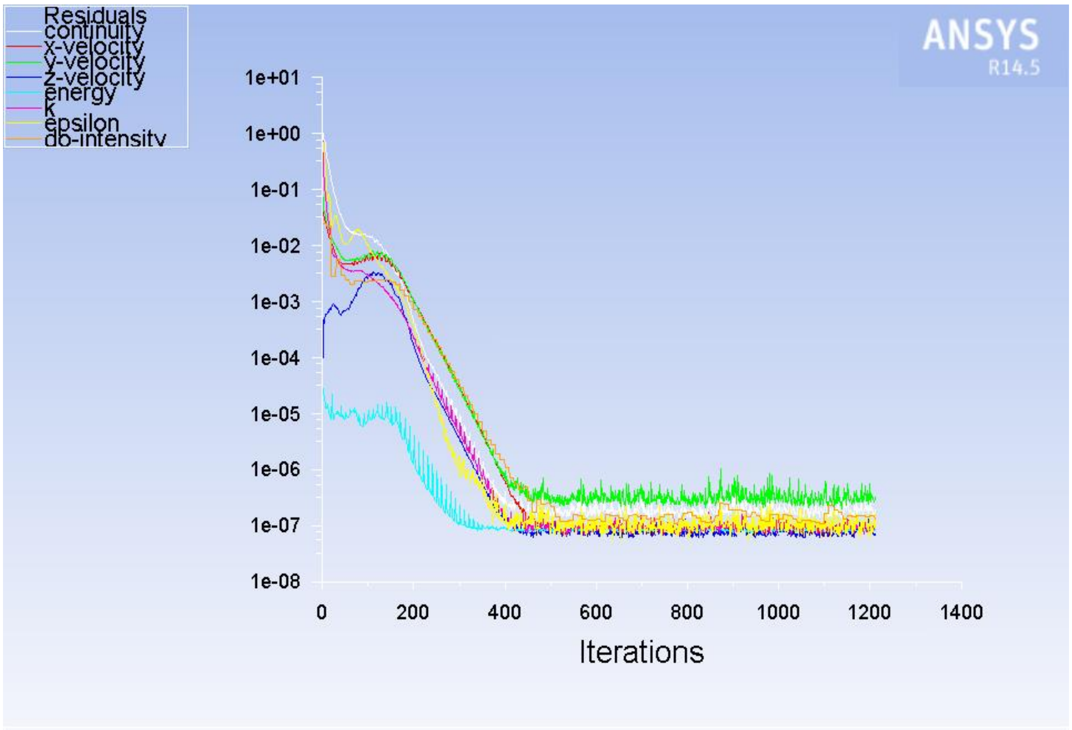

Fig. 3. ANSYS FLUENT iteration of the work

2.2 Grid Independence Test

An investigation of grid independence was carried out to find the proper mesh. The test was performed on the velocity along the chimney. Seven different grids were checked (187,353 elements, 356,753 elements, 591,543 elements, 842,651 elements, 966,531 elements, 1,162,122 elements, and 1,296,425 elements). There are relatively small (typically less than 5 percent) differences between the respective grid no. 6 (1,162,122 elements) and grid no. 7 (1,296,425 elements) results for the most stringent quantities of the velocity along the chimney. This indicates that both of the two grids are approaching grid independence as shown in Figure 4.

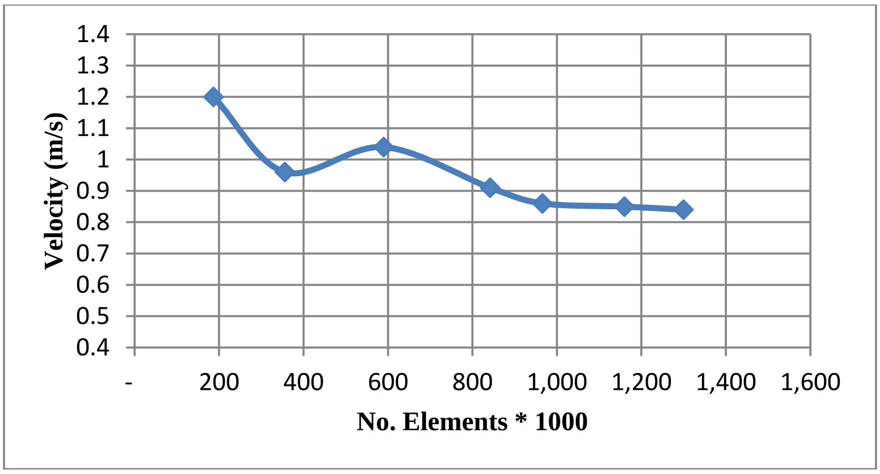

Fig. 4. Grid Independency Test: Mean air velocity of solar chimney with number of grid elements

2.3 Data Reduction

The primary objective of the development of PVT hybrid solar collectors is to increase the efficiency of the photovoltaic panels [11]. The working principle of PVT hybrid collectors is that they contain compact PV cells with tubes for the heat exchange process, where heat is absorbed and then transferred to HTF [12, 13]. This process aims to benefit from electricity generation and will not benefit from the resulting heat. For example, to heat household water or use high-temperature heat to generate electricity through thermoelectric plants [14, 15]. Toget the amount of thermal energy Q_u for a PVT collector under the right conditions, use equation [16].

$$Q_u = A_c.[\tau\alpha.\, I_T - U_L(T_{pm} - T_a)] \quad (1)$$

Where:

Q_u : Useful heat gain (W)
A_c: Absorber plate area (m^2)
τ : Glass cover transmittance coefficient
α: Absorber plate absorptance coefficient
I_T: Irradiance incident normal to the absorber plate (W/m^2)
U_L: Overall heat loss coefficient ($W/(m^2\ C^{\circ})$)
T_{pm}: Absorber plate mean temperature (C°)
T_a: Ambient temperature (C°)

To get the thermal payback of the hybrid PVT collector through the equation [17-19]:

$$\eta c = Qu/Ac.IT \quad (2)$$

The useful heat gain Q_u can be represented in terms of working fluid mass flow rate $\dot{m}$ inletand outlet temperatures T_{fi} and T_{fo} respectively as follows [19-22]:

$$Q_u = \dot{m}\ .\ C_{pf}(T_{fo} - T_{fi}) \quad (3)$$

Where:

$\dot{m}$: Mass flow rate (kg/s)
Cpf: Working fluid specific heat ($J/kg\ k$)
Tfi: Inlet temperature (k)
Tfo: Outlet temperature (k)

3. Results and Discussion

In order to investigate how coolant influences the board, the experiment was carried out in two stages: during the first stage, the impact of solar radiation was investigated in the absence of water, and during the second stage, water was used.

As can be seen in Figure 5, the temperature of the PV Panel was 314.6 when the firststep of the process was applied. In the second phase, numerous other values of water flow wereapplied. The panel temperature dropped to 311 [K] when the value of 0.02 was utilized, as canbe seen in figures 6, 7, and 8.

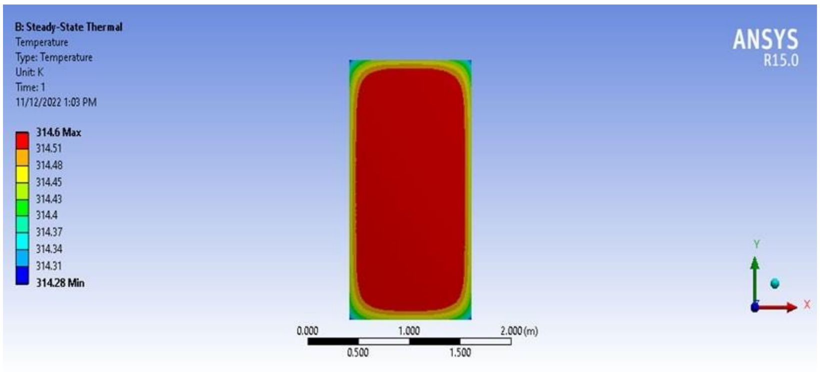

Fig. 5. Temperature gradient in PV panels without using water

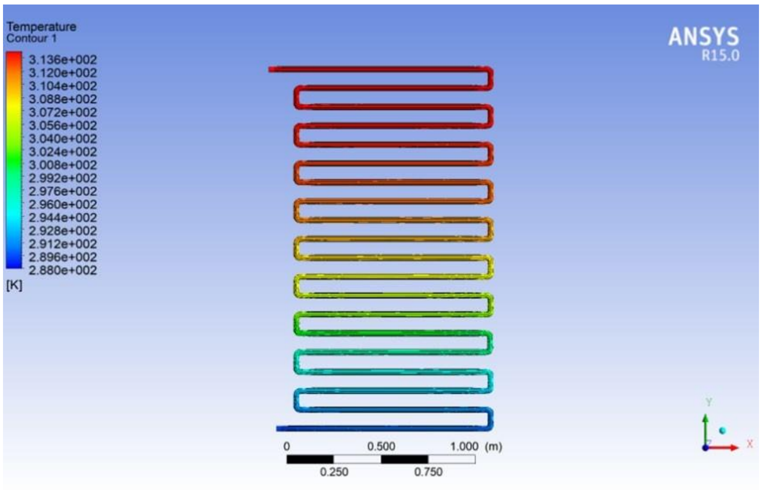

Fig. 6: Water temperature gradient for the value is 0.02

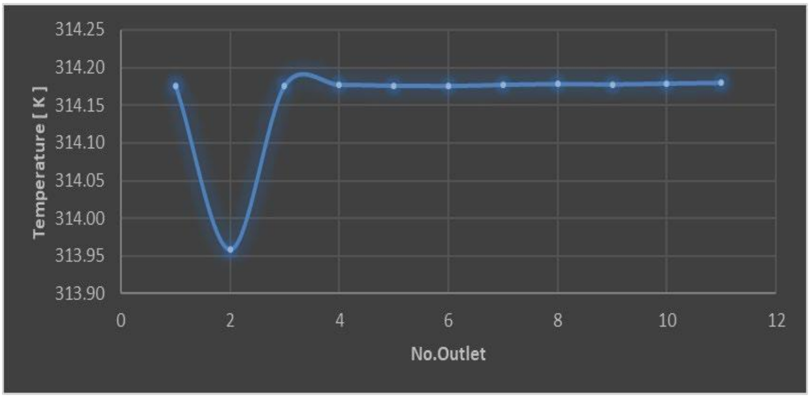

Fig. 7. Changes in outlet temperature value

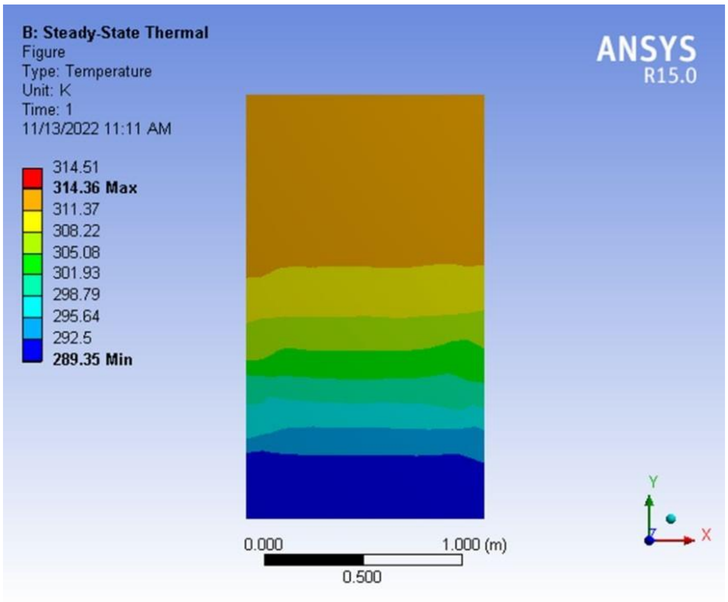

Fig. 8. Panel temperature gradient

For water flow at a value of 0.025, the panel temperature dropped to 306 [K]. The results are shown in Figure 9, 10, and 11.

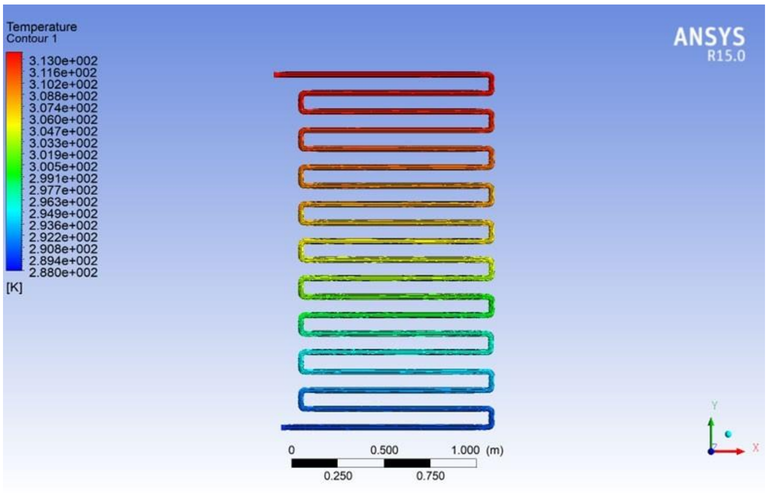

Fig. 9. Water temperature gradient for the value is 0.025

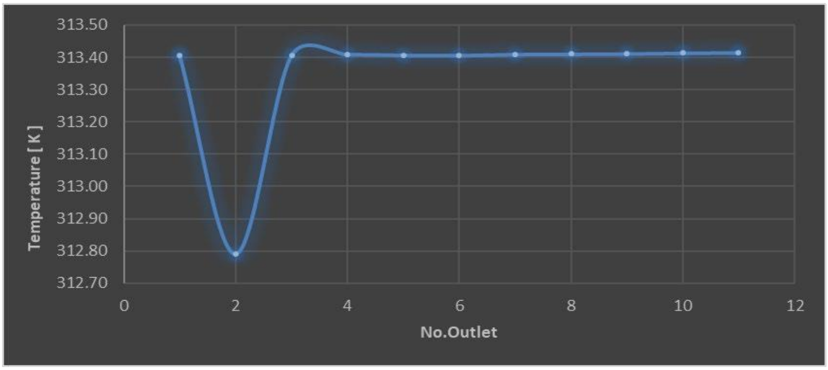

Fig. 10. Changes in outlet temperature values for the value is 0.025

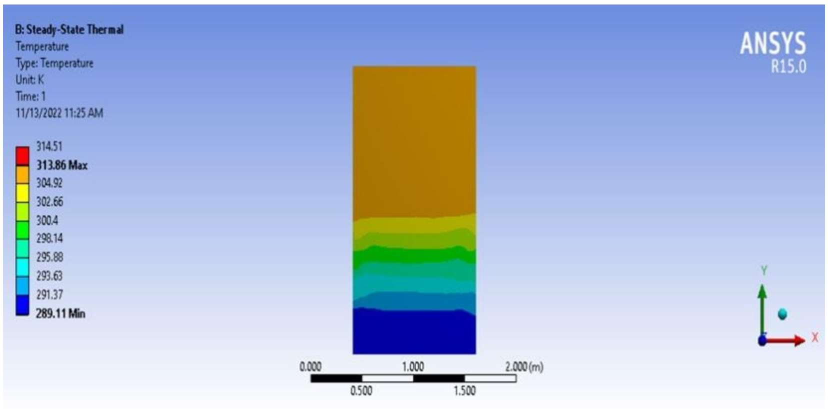

Fig. 11. Panel temperature gradient for the value is 0.025

In regard to flow 0.03, the plate temperature dropped to 302 K; the outcomes are depicted in Figure 12, 13, and 14.

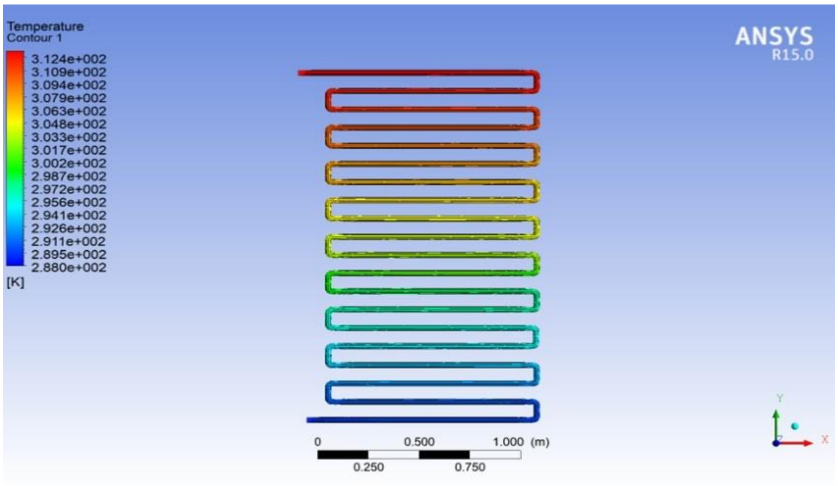

Fig. 12. Water temperature gradient for the value is 0.03

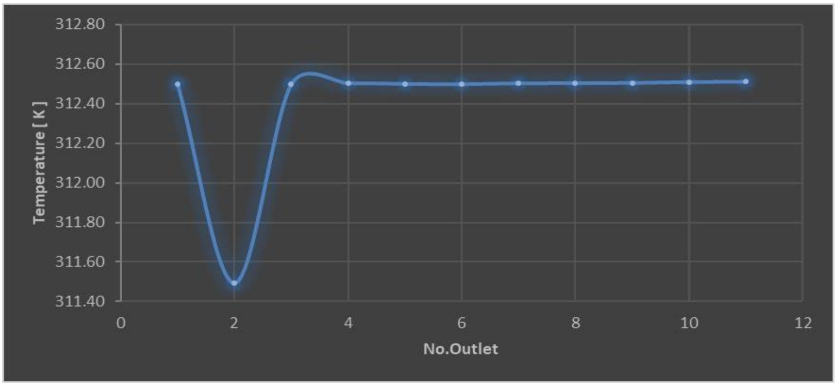

Fig. 13. Changes in outlet temperature values for the value is 0.03

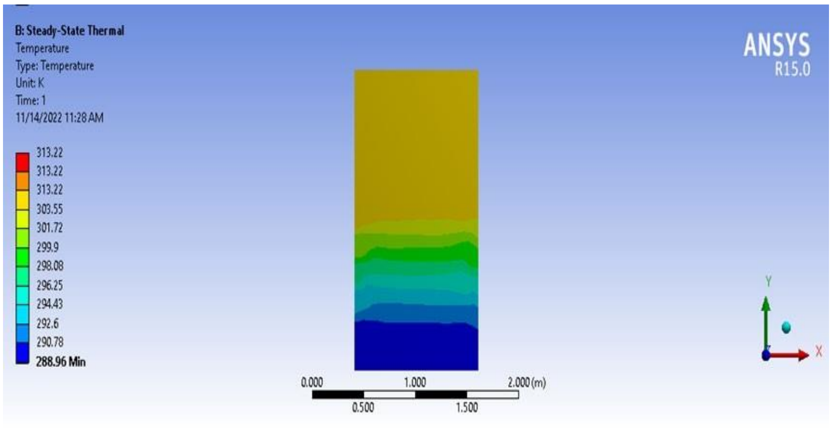

Fig. 14. Panel temperature gradient for the value is 0.03

Based on the temperature values at different mass flow rate values, the efficiency was deduced based on the two equations, Eq. (1) and Eq. (1). The related results shown in Table 3.

Table 3
Efficiency values depending on the temperature and flow

Mass flow rate	Temperature[K]	ηth
0.02	314.18	73%
0.025	313.41	88.50%
0.03	312.5	95%

By the way, comparisons of flow rate values, water temperature, and efficiency are shown in Figure 15, while Figure 16 presents comparisons of flow rate values and water temperature in terms of flow rate.

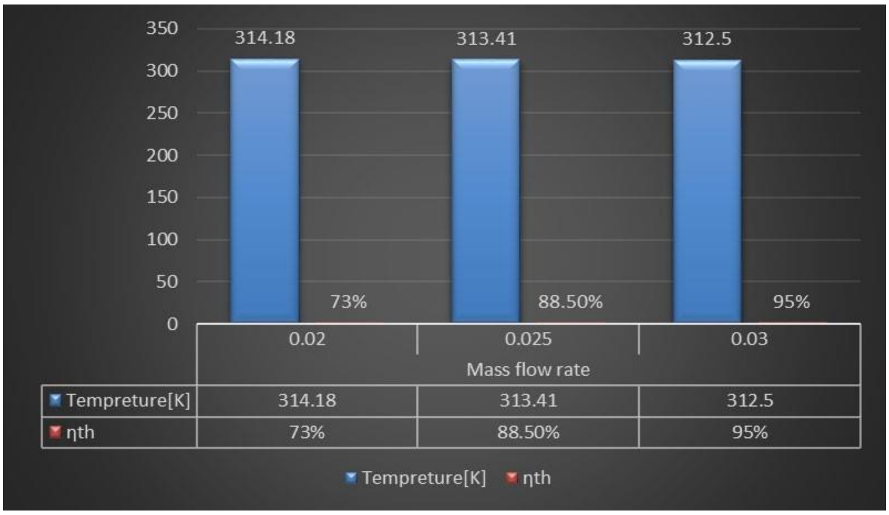

Fig. 15. Comparison of flow rate values, water temperature and efficiency

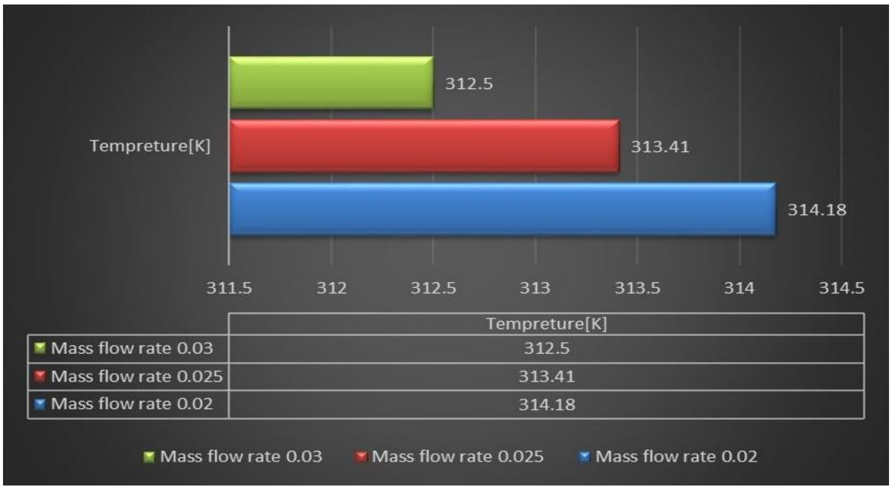

Fig. 16. Comparison of flow rate values and water temperature

Comparison of flow rate values and water temperature is shown in Figure 16, while Figure 17 presents a comparison of flow rate values and panel efficiency, and Figure 18 presents a comparison of flow rate values and panel temperature.

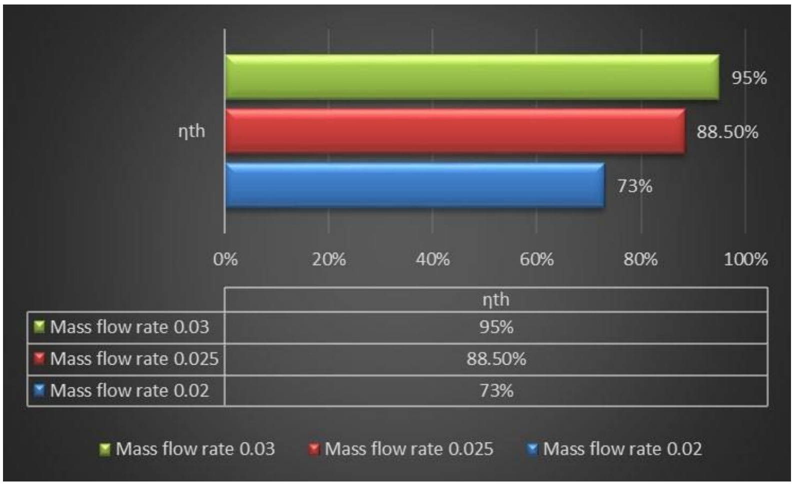

Fig. 17. Comparison of flow rate values and panel efficiency

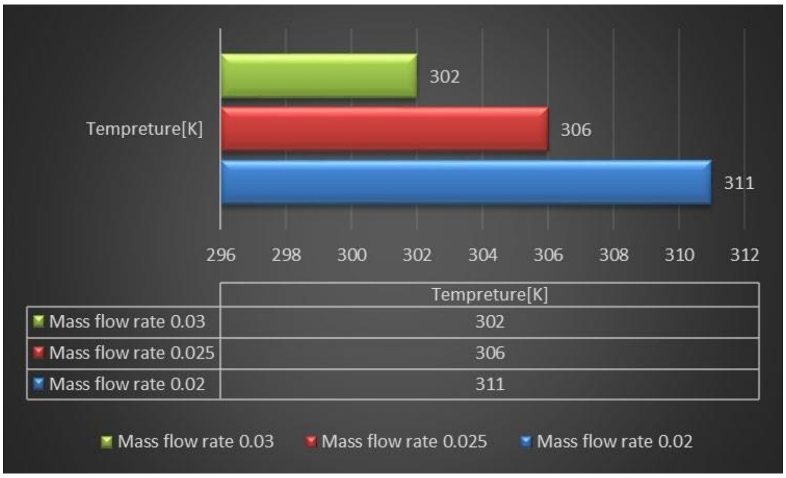

Fig. 18. Comparison of flow rate values and panel efficiency

Due to the accumulation of all of the heat produced by solar radiation and the absence of a heat exchanger such as refrigerant, it can be seen in Figure 5 that the temperature of the panel risesto 314.6 [K]. This is the case because the panel does not have a heat exchanger. Figure 6, 9, and 12 illustrate the process of heat transfer and heat exchange that occurs between the panel and the risers when water is used as a refrigerant. This process takes place while the water actsas a cooling medium. In addition, as can be seen in Figure 8, 11, and 14, there was a discernibledrop in the temperature of the panel in comparison to what is presented in Figure 18. In termsof the effectiveness of the panel, according to Table 4 and Figure 15 and 17, a rise in the efficiency ratio was noticed whenever the value of the flow rate increased. This was the case even if the flow rate remained constant.

Table 4
Nomenclature and abbreviations

S. No.	Abbreviation	Description
1	C_p	Heat capacity (4168 J/Kg. K)
2	I	Heat flux (W/w^2)
3	m	Mass of water (Kg)
4	PVT	Photovoltaic thermal collectors
5	CFD	Computational Fluid Dynamics
6	PV	Photovoltaic
7	T_1	Initial water temperature (^{O}c)
8	T_2	Final water temperature (^{O}c)
9	$T_{a)av}$	Average ambient temperature
10	$T_{w)av}$	Average water temperature
11	Al2O3	Aluminum oxide
12	TEG	A Triethylene Glycol

However, among the experimental conditions, the solar radiation is held at a constant value of 1000 [W/m^2], and the convection heat transfer coefficient is held at 10 [W/m^2]. The previous results showed that there was a decrease in the temperature of the panel, an increase in the efficiency, and an increase in the temperature of the water. In all three of the trials, this value was utilized, and each one had the same water-based refrigerant, the same distribution ofrisers, and the same number of risers overall. The only adjustment that was made to the parameter was since this is the water flow rate, the question that naturally follows is, "What isthe relationship of the flow to the efficiency change and the degree of the panel?" Going backto the first two equations, Eq. (2) and Eq. (3), you will observe that there is a clear connection betweenthe total amount of useable heat and the efficiency in the third equation. When there is a greaterdemand for heat, there is a corresponding rise in the value of efficiency. Concerning the flow rate, we see in the equation for the quantity of usable heat that there is a correlation between the amount of useful heat and the flow rate. This can be seen by looking at the flow rate variable. When the flow rate is increased, there is a corresponding increase in the amount of heat that can be utilized. As evidence of this, Figure 17 demonstrates that the efficiency was lower at a flow value of 0.02 than it was at a flow of 0.03, confirming what was just said.

4. Conclusion

For the purpose of the present numerical investigation, the circular-section PV/T collector flow was modeled using ANSYS. A heat flux of 1000 W/m^2, 288 K for the ambient temperature and the water's input, and flow rates of 0.02, 0.025, and 0.03 [Kg/s] were utilized in order to evaluate the PV panel area as well as the water outlet temperature. The first model was carried out using ANSYS

STEADY STATE without the utilization of a glass, while the second model was carried out by CFD with the utilization of water cooling. According to the findings, when the water flow rate was increased from 0.02 to 0.03, the heating rate of the panel surface reduced dramatically, which resulted in a gain in efficiency but a reduction in water production. These collectors can be developed in the future by developing photovoltaic cells that are capable of absorbing the greatest number of photons. This will enable us to generate electrical energy while also benefiting from the heat that is generated at the same time. Additionally, layers can be added to the panel in order to improve heat transfer and preserve it for the maximum amount of time. The ability of these cells to generate electrical energy and thermal energy throughout the day despite the presence of atmospheric elements such as dust, clouds, and snow is a feature that is not present in traditional collectors and highlights the importance of these cells. Traditional collectors are unable to generate either type of energy.

References

[1] Tripanagnostopoulos, Y., M. Souliotis, and T. H. Nousia. "Solar collectors with colored absorbers." *Solar energy* 68, no. 4 (2000): 343-356. https://doi.org/10.1016/S0038-092X(00)00031-1

[2] Soulayman, S., ed. *Economical and Technical Considerations for Solar Tracking: Methodologies and Opportunities for Energy Management: Methodologies and Opportunities for Energy Management*. IGI Global, 2017. https://doi.org/10.4018/978-1-5225-2950-7

[3] Pang, Wei, Yanan Cui, Qian Zhang, Hongwen Yu, Linrui Zhang, and Hui Yan. "Experimental effect of high mass flow rate and volume cooling on performance of a water-type PV/T collector." *Solar Energy* 188 (2019): 1360-1368. https://doi.org/10.1016/j.solener.2019.07.024

[4] Das, Dudul, Pankaj Kalita, Anupam Dewan, and Sartaj Tanweer. "Development of a novel thermal model for a PV/T collector and its experimental analysis." *Solar Energy* 188 (2019): 631-643. https://doi.org/10.1016/j.solener.2019.06.005

[5] Rejeb, Oussama, Leon Gaillard, Stéphanie Giroux-Julien, Chaouki Ghenai, Abdelmajid Jemni, Maamar Bettayeb, and Christophe Menezo. "Novel solar PV/Thermal collector design for the enhancement of thermal and electrical performances." *Renewable energy* 146 (2020): 610-627. https://doi.org/10.1016/j.renene.2019.06.158

[6] Maadi, Seyed Reza, Meysam Khatibi, Ehsan Ebrahimnia-Bajestan, and David Wood. "Coupled thermal-optical numerical modeling of PV/T module–Combining CFD approach and two-band radiation DO model." *Energy conversion and management* 198 (2019): 111781. https://doi.org/10.1016/j.enconman.2019.111781

[7] Herrando, María, Alba Ramos, Ignacio Zabalza, and Christos N. Markides. "A comprehensive assessment of alternative absorber-exchanger designs for hybrid PVT-water collectors." *Applied energy* 235 (2019): 1583-1602. https://doi.org/10.1016/j.apenergy.2018.11.024

[8] Barone, Giovanni, Annamaria Buonomano, Cesare Forzano, Adolfo Palombo, and Orestis Panagopoulos. "Photovoltaic thermal collectors: Experimental analysis and simulation model of an innovative low-cost water-based prototype." *Energy* 179 (2019): 502-516. https://doi.org/10.1016/j.energy.2019.04.140

[9] Ibrahim, Adnan, Mohd Yusof Othman, Mohd Hafidz Ruslan, Mohammad Alghoul, M. Yahya, Azami Zaharim, and Kamaruzzaman Sopian. "Performance of photovoltaic thermal collector (PVT) with different absorbers design." *WSEAS Transactions on Environment and Development* 5, no. 3 (2009): 321-330.

[10] Wodołażski, Artur, Natalia Howaniec, Bartłomiej Jura, Andrzej Bąk, and Adam Smoliński. "CFD Numerical Modelling of a PV–TEG Hybrid System Cooled by Air Heat Sink Coupled with a Single-Phase Inverter." *Materials* 14, no. 19 (2021): 5800. https://doi.org/10.3390/ma14195800

[11] Khan, Asfand Y., Zeshan Ahmad, Tipu Sultan, Saad Alshahrani, Khazar Hayat, and Muhammad Imran. "Optimization of Photovoltaic Panel Array Configurations to Reduce Lift Force Using Genetic Algorithm and CFD." *Energies* 15, no. 24 (2022): 9580. https://doi.org/10.3390/en15249580

[12] Farhan, Ahmad Fawwaz Irsyaad Ahmad, Nur Atiqah Mohamad Aziz, Hassan Mohamed, Bidattul Syirat Zainal, and Hazlina Junoh. "Investigation of the Thermal Performance of Water and Aluminum Oxide Nanofluid as a Coolant for Solar Panels." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 106, no. 2 (2023): 87-102. https://doi.org/10.37934/arfmts.106.2.87102

[13] Souliotis, Manolis, Nektarios Arnaoutakis, Giorgos Panaras, Angeliki Kavga, and Spiros Papaefthimiou. "Experimental study and Life Cycle Assessment (LCA) of Hybrid Photovoltaic/Thermal (PV/T) solar systems for domestic applications." *Renewable energy* 126 (2018): 708-723. https://doi.org/10.1016/j.renene.2018.04.011

[14] Zondag, Herman A., DWd Vries, Anton A. Van Steenhoven, W. G. van Helden, and R. J. van Zolingen. "Thermal and electrical yield of a combi-panel." In *Proceedings of ISES Bi-annual Conference on CD-ROM*. 1999.

[15] Kolb, Gregory J., Roger Davenport, David Gorman, Ron Lumia, Robert Thomas, and Matthew Donnelly. "Heliostat cost reduction." In *Energy Sustainability*, vol. 47977, pp. 1077-1084. 2007.

[16] Skoplaki, Elisa, and John A. Palyvos. "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations." *Solar energy* 83, no. 5 (2009): 614-624. https://doi.org/10.1016/j.solener.2008.10.008

[17] Chow, T. T. "A review on photovoltaic/thermal hybrid solar technology." *Applied Energy* 87, no. 2 (2009): 365-379. https://doi.org/10.1016/j.apenergy.2009.06.037

[18] Riffat, Saffa B., and Erdem Cuce. "A review on hybrid photovoltaic/thermal collectors and systems." *International Journal of Low-Carbon Technologies* 6, no. 3 (2011): 212-241. https://doi.org/10.1093/ijlct/ctr016

[19] Florschuetz, L. W. "Extension of the Hottel-Whillier model to the analysis of combined photovoltaic/thermal flat plate collectors." *Solar energy* 22, no. 4 (1979): 361-366. https:// doi.org/10.1016/0038-092X(79)90190-7

[20] Shbailat, Suhaib J., and Mohammed A. Nima. "Possible energy saving of evaporative passive cooling using a solar chimney of metal foam porous absorber." *Energy Conversion and Management: X* 12 (2021): 100118. https://doi.org/10.1016/j.ecmx.2021.100118

[21] Shbailat, Suhaib J., and Mohammed A. Nima. "Effect of absorber plate height on the performance of solar chimney utilized with porous absorber and integrated with an insulated room." *Thermal Science* 26, no. 6 Part A (2022): 4775-4795. https://doi.org/10.2298/TSCI211008117S

[22] Abdul Hussein, Sarmad A., and Suhaib J. Shbailat. "Impact of bumpers position variation on heat exchanger performance: an experimental and predictive analysis using an artificial neural network." *Journal of Engineering and Applied Science* 70, no. 1 (2023): 1-20. https://doi.org/10.1186/s44147-023-00176-x