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Numerical Investigation of PV/T System by Using Graphene Based Nanofluids

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ABSTRACT

The effective use of solar radiation can be maximized by the implementation of a novel hybrid device referred to as a photovoltaic thermal collector (PV/T), which has the capability to simultaneously generate both electrical and thermal energy. As temperature increases, the efficiency of the photovoltaic (PV) cell drops. The present work employs graphene nanofluids as a means to decrease the temperature of the system in order to evaluate the photovoltaic thermal (PV/T) performance. The PV/T system is subjected to Computational Fluid Dynamics (CFD) simulation, wherein graphene nanofluids of different volume concentrations (ϕ = 0%, 0.1%, 0.2%, and 0.3%) and mass flow rates ($\dot{m}$ = 0.065, 0.075, and 0.085 kg/s) are employed. The PV/T system demonstrated enhanced performance as a result of the implementation of the proposed approach, which effectively reduced the temperature of the solar cell during the period of maximum solar radiation, spanning from 9 AM to 4 PM. The utilization of the system was employed for the generation of thermal and electrical energy due to its respective thermal and electrical efficiency of 67% and 11.5%. The completed research has demonstrated that the integration of graphene nanofluids has the potential to enhance the efficiency of PV/T systems.

1. Introduction

The rise in carbon dioxide (CO_2) emissions can be attributed to human-caused events and the combustion of fossil fuels during recent decades, resulting in the adverse effects of global warming and environmental degradation. Solar energy is experiencing a significant increase in popularity as a renewable energy source, mostly attributed to its abundant availability and capacity to directly generate power through the utilization of solar photovoltaic (PV) modules [1,2]. The conversion of solar energy into electrical energy is reliant on the utilization of a solitary photon from the sun's

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spectrum for the generation of electricity. Consequently, the panel has the potential to increase its temperature by up to 50°C over the surrounding air temperature. The electrical output power, fill factor, and conversion efficiency of a PV cell are negatively affected by a rise in cell temperature, resulting in a decrease in open-circuit voltage [3,4]. The photovoltaic thermal (PVT) system exhibits significant potential as a renewable energy source. The technology exhibits significant commercial promise due to its ability to simultaneously produce both electrical and thermal energy [5]. Solar energy systems consist of two primary components: photovoltaic (PV) panels, which convert sunlight into electricity, and thermal collectors, which generate heat for water and air. Solar heating systems and photovoltaic (PV) technology are frequently employed as distinct entities [6]. The photovoltaic module captures a portion of solar light and converts it into electrical energy. The remaining energy is retained as thermal energy within the working fluid, which can be utilized for thermal applications such as space heating and water heating [7].

Air-based PV/T is the most popular type because it is easy to set up and doesn't cost much at first. Using a liquid working fluid, like liquid, lowers the thermal capacitance of these systems and makes them cooler [8]. Nanofluids contain solid particles and tiny materials as technology advances. Nanoparticles that are suspended or floating have the ability to change the thermal and transport characteristics of the base fluids. Typical properties of nanoparticles are distinct. Due to their size ratio and other characteristics, for example, these particles have a sufficient physical dimension and low kinetic energy [9]. Khanjari *et al.,* [10] thought about using Ag and Al_2O_3-water nanofluids to keep the PV/T system cool. A numerical program was set up for the entity. The findings of the study indicate that the presence of alumina water results in a 12% increase in the heat transfer coefficient, but the presence of Ag-water leads to a 43% increase in the same coefficient. In their study, Hussien *et al.,* [11] conducted experimental research on the application of Al_2O_3-water nanofluid as a coolant for PV/T systems, specifically focusing on forced convection. Various concentrations of nanofluids were employed, spanning from 0.1 to 0.5 with an increment of 0.1%, in order to evaluate the influence of the mass fraction. The findings indicated that the temperature of the PV module reached around 79.1°C when water was utilized as the only base fluid. In studies (both electrical and thermal), Sardarabadi *et al.,* [12] studied the impact of SiO_2-nanofluid as a coolant on the performance of PV/T systems. The results revealed a 3.6% overall system efficiency gain when 1.0 weight percent was used in place of water and a 7.9% overall system efficiency increase when a 3.0% weight fraction was used. The study conducted by Radwan *et al.,* [13] investigated the operational effectiveness of the PV/T system through the evaluation of the volume fraction and mass flow rate of Al_2O_3 and SiC-water nanofluids. According to the authors, the SiC-water nanofluid exhibits superior cooling capabilities in comparison to the Al_2O_3-water nanofluid for PV panel applications.

Furthermore, Agyekum *et al.,* [14] conducted an experimental study to investigate the effects of simultaneous dual surface cooling on the output performance of photovoltaic (PV) modules. The observed temperature decrease was 23.55°C. The outcome of this experiment led to a significant enhancement of approximately 30.3% in the power output of the panel. The photovoltaic (PV) module that experienced cooling measures had an average efficiency of 14.36%, whereas the uncooled panel achieved an efficiency of 12.83%. In a previous investigation [15], researchers explored the application of a thermo-electric cooling mechanism for the purpose of cooling a photovoltaic (PV) panel in authentic weather circumstances. The experimental findings indicate a notable decrease in temperature within the modified photovoltaic (PV) module, namely the cooled panel. The average temperature observed for the cooled PV module was 33.37℃, in contrast to the temperature of 45.60℃. The PV module temperature experienced a decrease of 12.23℃, leading to an improvement in electrical efficiency by 5.07%. The present experimental inquiry, as documented in prior research [16], seeks to enhance the efficiency of solar photovoltaic (PV) panels by the use of a composite comprising inexpensive aluminium reflectors, aluminium sinks, and a mixture of phase change material (PCM) and Zinc oxide (ZnO) nanoparticles. Based on the findings of the environmental analysis, it can be inferred that the reflector/PV/PCM/nanoparticles system exhibits a higher CO_2 avoidance rate (18.75%) in comparison to the PV/PCM system (10%), as compared to the conventional PV panel system. The study conducted by Seepana *et al.,* [17] involved a comprehensive investigation of the thermo-enviro-economic aspects of a hybrid photovoltaic (PVT)/thermoelectric generator (TEGs) system. A comparative study was conducted to examine the differences between a standard photovoltaic (PV) system, a photovoltaic-thermal (PVT) system with water, and a PVT system with thermoelectric generator (TEG) and nanofluid. The comparative analysis yielded significant results indicating that the PVT/Water and PVT/TEG/nanofluid configurations exhibited temperature reductions of 25.1% and 41.2%, respectively, in comparison to the reference PV panel. The electrical efficiency of the PVT/Water and PVT/TEG/nanofluid panels experienced enhancements of 5.8% and 8.5%, respectively.

Seepana *et al.,* [18] also investigated the impact of a fanless CPU heat pipe on the performance of a photovoltaic (PV) module. This study presents and discusses a comparative analysis of two photovoltaic (PV) panels: one that is cooled and one that is uncooled. The analysis focuses on several factors, including electrical energy, exergy performance, economic considerations, embodied energy, and energy payback. The primary findings of the investigation indicate that the mean temperature decrease resulting from the cooling procedure is 6.72℃. Seepana *et al.,* [19] also conducted a study on the application of a passive cooling method utilising a discontinuous aluminium heat sink. The present work introduces a novel passive cooling system that involves the utilisation of specifically designed aluminium sheets affixed to the back surface of the photovoltaic (PV) module. Based on the findings, it was determined that the mean temperature of the cooled panel over the duration of the experiment was 41.09℃, while the referenced panel had a recorded average temperature of 51.08 ℃. The study [20] introduced a passive cooling mechanism designed for the purpose of cooling a photovoltaic (PV) panel. The cooling system under consideration consists of a composite structure of aluminium fins and paraffin wax, which is incorporated on the rear side of the photovoltaic (PV) panel. The electrical efficiencies of the cooled panel and the referenced modules are 14.30% and 13.60%, respectively. This indicates a 5.15% enhancement in the electrical efficiency. Furthermore, the research conducted by reference [21] integrates both active and passive cooling techniques in order to enhance the electrical efficiency of a photovoltaic (PV) module. The cooling system employed for the panel consisted of aluminium fins and an ultrasonic humidifier integrated into a heat sink. The ultrasonic humidifier was employed to create a humid atmosphere on the posterior surface of the photovoltaic module. The cooling procedure employed in the study effectively decreased the temperature of the panel by an average of 14.61°C.

The thermal component of the system comprises of tubes that contain a mixture of nanofluid and paraffin, with the presence of multi-walled carbon nanotube (MWCNT) nanoparticles. The impact of incorporating fins within the paraffin zone was investigated by conducting a numerical simulation, as documented by M. Sheikholeslami [22]. The study involved the implementation of three different fin configurations, namely the I-shape, short base arrow, and long base arrow. These configurations were tested at four distinct levels of Reynolds number (Re), specifically 25, 750, 1250, and 1750. The arrangement of short base arrows has been optimised to obtain maximum useable heat. The optimal heat transfer has been attained for the arrangement of arrows with short bases. The dispersion of multi-walled carbon nanotube (MWCNT) nanoparticles results in a significant increase in heat generation, specifically by around 9.58%, when the inlet flow is optimised. The study has documented the minimum temperature observed in the paraffin zone for arrows with shorter bases, and it has been observed that an increase in the Reynolds number results in a decrease in temperature by around 1.05%. To optimise the electrical performance, an additional thermoelectric layer has been affixed onto the absorber. The system consists of two distinct zones for hybrid nanofluid flow. The first region is a circular duct that is equipped with a turbulator. The second region is a micro channel that is fitted with jet impingement from the previous study [23]. The laminar regimes of both zones have been employed, utilising a single-phase formulation to determine the characteristics of the hybrid nanomaterial. By choosing the turbulator with the highest degree of rotation, there is an improvement of around 1.41% in electrical efficiency and an increase of about 5.72% in useable heat. This study [24] has examined the effects of climatic factors and dust deposition on the efficiency of solar panels. To enhance heat dissipation, a trapezoidal cooling channel has been affixed to the lower section of the panel, which integrates ternary components. The efficiency of the photovoltaic-thermal (PVT) system experiences a reduction of approximately 13.14% and 16.6% when the wind speed and dust deposition increase. The reduction of CO_2 emissions has been seen to decrease by approximately 15.49% in the presence of dust particles, but it exhibits a rise of approximately 17.38% with the introduction of ambient temperature nanofluid. The production of a functional fluid has been achieved by combining water with Fe_3O_4–TiO_2–GO nanoparticles. The efficiency of the photovoltaic-thermal (PVT) system experiences a reduction of approximately 13.14% and 16.6% when the wind speed and dust deposition increase. The application of CO_2 mitigation techniques have been seen to result in a reduction of about 15.49% in the presence of dust particles. Conversely, an increase of approximately 17.38% in CO_2 mitigation has been observed with the rise of ambient temperature. In a study conducted by Khalili *et al.,* [25], an investigation was carried out on the addition of a novel thermoelectric layer beneath the Tedlar layer, with the aim of enhancing the electrical output. The cooling system is comprised of cooling ducts and restricted jets, whereby both zones are filled with a hybrid nanofluid as the working fluid. The duct has been constructed utilizing three distinct geometries, namely circular, triangular, and 3-lobed shapes. To augment the convective rate, Y-shaped fins have been incorporated within the ducts. The proposed model was simulated using a numerical approach to analyse laminar flow in both fluid zones. The triangle duct, when equipped with fins and subjected to a jet, has demonstrated the highest recorded performance among all configurations. In comparison to a circular pipe, the total performance of the triangular duct is found to be 9.97% superior.

The numerical investigation conducted by Khalili *et al.,* [26] examined the impact of confined jet impingement on the efficiency of a photovoltaic thermal solar unit that was equipped with a thermoelectric generator. This investigation specifically focused on the presence of a hybrid nanofluid. A unique approach to the cooling of the photovoltaic (PV) unit has been introduced. The photovoltaic (PV) panel is integrated with a thermoelectric (TE) generator, while the cooling system incorporates a heat transfer tube (HTT) that is integrated with a confined jet impingement (CJI) heat sink. Hybrid nano-powders consisting of ND-Co_3O_4 were utilized in this study, with varying mass concentrations of 0.05%, 0.1%, and 0.15%. These nano-powders were then combined with water to serve as the cooling fluid. The ambient and cooling fluid input temperatures are established as 30^oC and 27^oC, respectively, while the wind velocity is set at 1 m/s, maintaining consistent working conditions. The highest achieved system has electrical and thermal efficiencies of around 84% and 15.44%, respectively, when exposed to a solar irradiation level of 760 W/m^2. The study [27] examined the turbulent flow of an oil-based hybrid nanofluid within an absorber tube of a concentrated solar system. The parabolic plate has been positioned beneath the tube to focus the sun irradiation. The boundary condition of the tube was considered as a changing heat flux. The inclusion of a turbulator within the circular tube leads to an augmentation in secondary flow. The outputs included reports of both the thermal (Sgen,th) and frictional (Sgen,f) components of irreversibility. As the quantity of tape rows rises, there is an observed enhancement of about 69.23% in the value of Sgen,f, whereas the value of Sgen,th experiences a drop of approximately 3.67%. An increase in the pitch ratio results in a decrease of around 11.25% in Sgen,th, whereas the frictional component experiences an increase of approximately 76.7%.

The study conducted by M. Sangeetha *et al.,* [28] examined the impact of nanofluids, specifically MWCNT, Al_2O_3, and TiO_2, on temperature reduction. The results indicated that MWCNT led to a temperature decrease of 48%, while Al_2O_3 and TiO_2 resulted in reductions of 37% and 36% respectively. The enhancement of the reduction in cell temperature was achieved through an increase in the mass flow rate of the nanofluids. The multi-walled carbon nanotubes (MWCNT) exhibited significant efficacy in comparison to alternative nanofluids. The researcher's investigation of the thermal conductivity of four nanofluids (MWCNT/water, CuO/water, and SiO_2/water) revealed that MWCNT/water exhibited the highest thermal conductivity, reaching a maximum value of 11.3% at a volume fraction of 1% [29]. Numerous studies have demonstrated that the utilization of nanofluid has considerably enhanced the efficiency of photovoltaic/thermal (PV/T) systems, as evidenced by a range of scholarly investigations [30-36]. Based on the examination of existing scholarly works, it has been observed that nanofluids incorporating carbon-based nanoparticles exhibit superior performance compared to alternative nanofluid compositions. There is a dearth of study on carbon-based nanomaterials, specifically graphene nanoplatelets, in the context of photovoltaic/thermal (PV/T) systems. Furthermore, there is a limited amount of simulation studies conducted on the utilization of these materials in such systems. The effectiveness of solar photovoltaic/thermal (PV/T) systems can be assessed by the use of computational fluid dynamics (CFD) ANSYS simulation. In this particular study, a nanofluid comprising of graphene nanoplatelets (GnP) diffused in water (H_2O) is employed.

This study introduces the utilization of graphene-based nanofluids as the working fluid for examining the numerical analysis of the overall performance of the photovoltaic/thermal (PV/T) system. The simulation results are compared with the experimental data from reference [37] in order to validate their accuracy. The simulation was conducted using several GnP volume concentrations of 0.1%, 0.2%, and 0.3% and varying mass flow rates of 0.085 kg/s, 0.075 kg/s, and 0.065 kg/s. The temperature of the nanofluids at the input was held at a consistent value of 20°C. This study investigates the influence of mass flow rate and solar irradiation on the performance and temperature uniformity of a photovoltaic-thermal system. The analysis focuses on key parameters like the temperature of the PV panels, the temperature of the GnP outlets, as well as the thermal efficiency and electrical efficiency of the system. This study maintains consistent operating parameters, despite manipulating mass flow rates and sun irradiance levels [38]. Table 1 shows the abbreviations lists.

Table 1
Abbreviations lists

Abbreviations	Name
PVT	Photovoltaic thermal
PV	Photovoltaic
CFD	Computational fluid dynamic
GnP	Graphene nanoplatelets

2. Methodology

2.1 The Geometric Model of the PV/T System

The design of the simulation model shape for the PV/T system is based on the research conducted by Venkatesh *et al.,* [37], as depicted in Figure 1(a) presented below. The illustrated design presented above depicts an elementary PV/T system comprising an absorber plate, cylindrical pipe, rectangular solar panel, and fluid domain. SolidWorks software was used to create the three-dimensional model geometry for the PV/T system. It is then loaded into ANSYS Workbench for analysis. The dimensions of the PV cell and absorber plate are length of 350 mm, width of 250 mm, and thickness of 2 mm, respectively. The length of the pipe is 200 mm, with inner and outer diameters of 8 mm and 10 mm, respectively. Figure 1 (b) depicts the specific dimensions for the model sheet and tube shape.

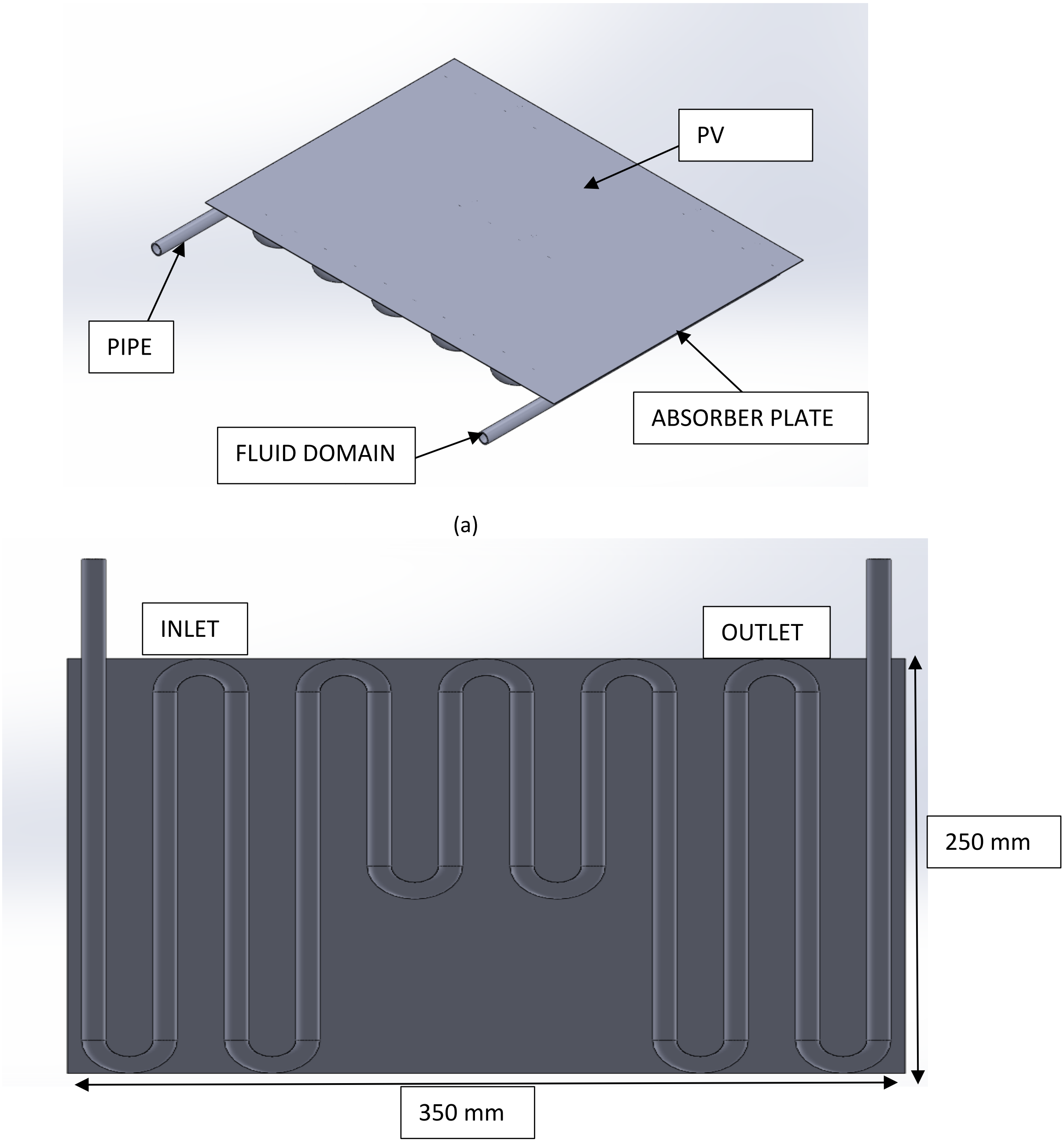


Fig. 1. Geometric model of sheet and tube for the PVT system (a) Side view (b) Bottom view

2.2 Mesh Analysis

The photovoltaic thermal system has layers with two unique geometries. Several examples include the geometries of rectangular solar panels and absorbers, the fluid domain, and the geometry of a cylindrical pipe. The meshing technique employed in this study is founded upon the research conducted by the authors referenced [39]. The element size technique is employed for the purpose of generating a mesh that conforms to the bounds of a rectangular shape. The tetrahedral meshing technique was employed to discretize the pipe and fluid domains. The PV/T model consists of a total of 1192486 meshing elements. Figure 2 depicts the mesh structure of the model, meanwhile Table 2 shows the model parameters of a PV/T system.

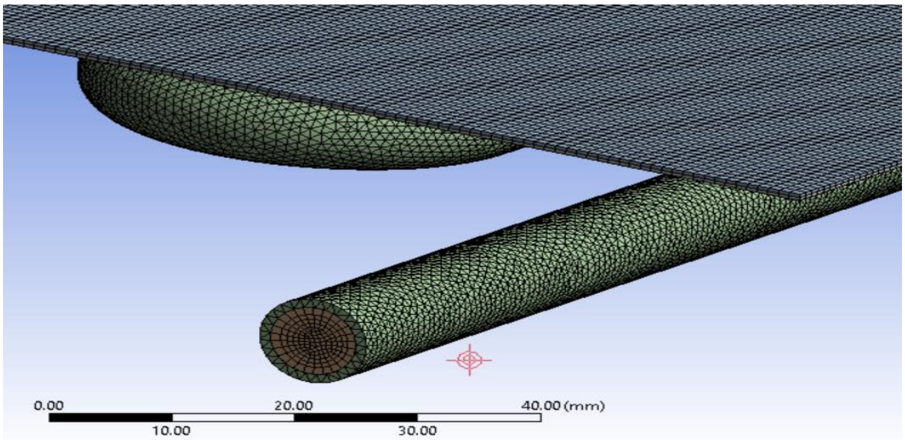


Fig. 2. Mesh structure of sheet and tube geometry for the PV/T system

Table 2
The model parameters of a PV/T system

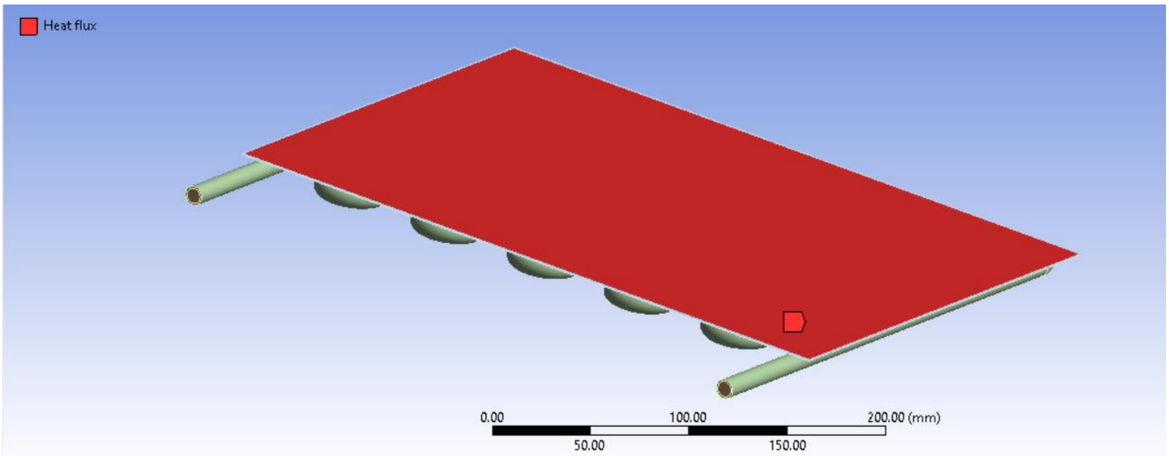
Component	Parameter	Value
Pipe	Material	Copper
	Inner and outer diameter	8 mm and 10 mm
	Density, ρ	8978 kg/m^3
	Thermal conductivity, k	387.6 W/m K
Absorber plate	Material	Copper
	Length	250 mm
	Width	350 mm
	Thickness	2mm
	Density, ρ	8978 kg/m^3
	Thermal conductivity, k	387.6 W/m K
PV panel	Material	Silicon
	Length	250 mm
	Width	350 mm
	Thickness	2mm
	Density, ρ	2329 kg/m^3
	Thermal conductivity, k	148 W/m K
	References cell efficiency, η_r	12%
	Temperature coefficient, β	0.0045 1/°C
	Absorptance, α	0.9

2.3 Boundary Conditions

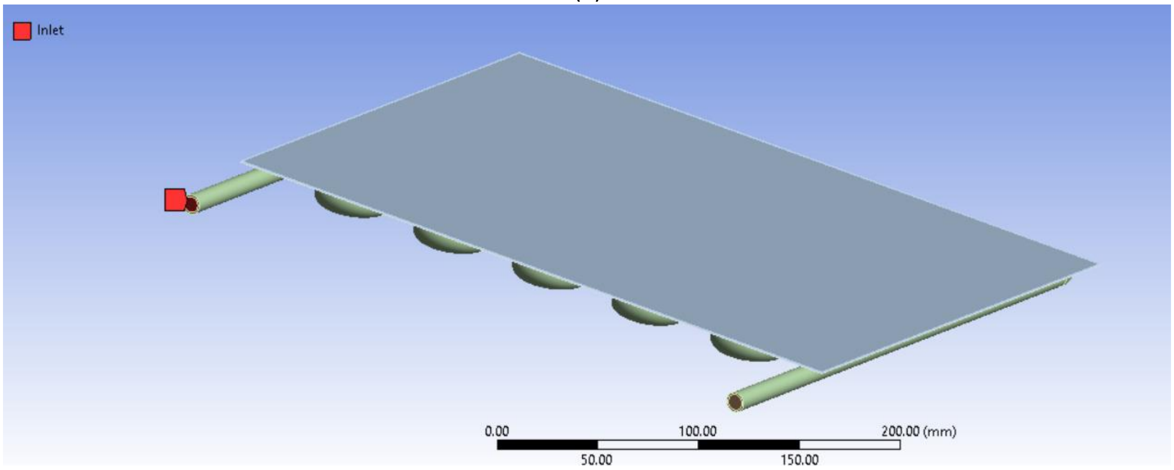
Table 3 and Figure 3 present the boundary conditions derived from the investigation conducted by Karaaslan *et al.,* [39], which were then integrated into the computational fluid dynamics (CFD) software ANSYS.

Table 3
Boundary conditions

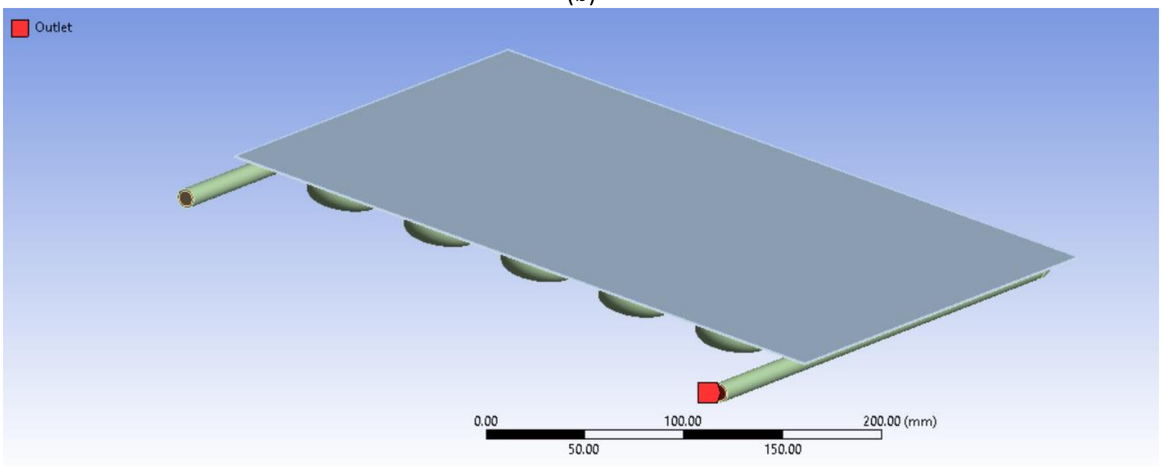
	Value	Unit
Heat flux	varies	W/m^2
Outlet pressure	1	atm
Inlet velocity	variation based on the mass flow rate, specifically at rates of 0.065, 0.075, and 0.085 kg/s	m/s
Inlet temperature	293	K



(a)



(b)



(c)

Fig. 3. (a) Heat flux, (b) inlet, (c) outlet of the boundary conditions for the model PV/T system

2.4 Thermophysical Properties of Graphene Based Nanofluid

In order to attain maximum efficiency, it is essential to understand the characteristics of the working fluid that impact both flow and heat transmission. In this simulation of a photovoltaic/thermal (PV/T) system, water and graphene nanofluids were employed as the working fluids. The experimental settings for graphene and water in this study are derived from previous research findings as cited in reference [40] for graphene and reference [39] for water. The characteristics of graphene nanoparticles (GnP) at a temperature of 298 K are summarized in Table 4.

Table 4
Thermophysical characteristics of graphene nanoparticles at a temperature of 298K [43]

	Density (kg/m³)	Specific heat (J/kg K)	Thermal conductivity (W/m K)
Graphene	2000-2500	643-2100	6-5000

According to the literature [37], the volume fractions of the graphene nanofluids are 0.1%, 0.2%, and 0.3%. The correlations shown in Table 5 were used to calculate the properties of graphene nanofluids. The thermophysical properties of the graphene nanofluids are displayed in Table 6.

Table 5
Correlations between the thermophysical properties of nanofluids

Thermophysical Properties	Correlations	Journals of Reference
Density	$\rho_{nf} = \phi\rho_p + (1-\phi)\,\rho_{bf}$	[41,42]
Viscosity	$\mu_{nf} = \dfrac{\mu_{bf}}{(1-\varphi)^{2.5}}$	[43]
Thermal conductivity	$k_{nf} = k_f \dfrac{k_s + 2k_{bf} - 2(k_s - k_{bf})\varphi}{k_s + 2k_{bf} + (k_s - k_{bf})\varphi}$	[44]
Specific heat	$C_{pnf} = \dfrac{(1-\varphi_p)\rho_{bf}C_{bf} + \varphi_p\,\rho_p C_p}{(1-\varphi_p)\rho_{bf} + \varphi_p\rho_p}$	[45]

Table 6
Thermophysical properties of the graphene nanofluids at 20°C

Nanofluids/Working fluid	Density (kg/m³)	Thermal conductivity (W/m K)	Viscosity (kg/m s)	Specific heat (J/kg K)
Water	997.00	0.607	0.00089000	4180.000
Graphene/water (ϕ = 0.1 %)	998.27	0.621	0.00089022	4172.112
Graphene /water (ϕ = 0.2 %)	999.540	0.634	0.00089045	4164.245
Graphene /water (ϕ = 0.3 %)	1000.81	0.645	0.00089067	4156.398

2.5 Governing Equations and Solver Settings

The Navier-Stokes, energy, and mass equations that affect a steady state flow are solved using numerical analysis. The mass equation, Eq. (1), the momentum equation, Eq. (2), and the energy equation, Eq. (3) are the governing equations based on research [39].

$$\nabla.\left(\rho_{nf}V_{nf}\right) = 0 \tag{1}$$

$$\nabla.\left(\rho_{nf}V_{nf}V_{nf}\right) = -\nabla P + \nabla\tau + \rho_{nf}g \tag{2}$$

$$\nabla.\left(\rho_{nf}V_{nf}C_{p,nf}T\right) = \nabla.\left(k_{nf}\nabla T\right) \quad (3)$$

The simulation implements the laminar flow model. The utilization of a pressure-based solver is necessitated by the flow's characteristics of incompressibility and low velocity. The pressure field is obtained through the utilization of the COUPLED methodology, which involves the comparison of pressure and velocity corrections. While the convergence time of the second-order upwind discretization approach is greater compared to the first-order method, it yields more precise outcomes.

2.6 Validation

Initially, simulations have undergone validation and testing procedures to ensure their accuracy. The simulation outcomes derived from this study have been verified through comparison with the findings of Venkatesh *et al.,* [37]. In order to establish the validation of the simulation outcomes, the solar radiation data utilized in the research conducted by Venkatesh *et al.,* [37] has been employed to simulate the results of the PV/T model. Specifically, the simulation was conducted for the time period between 9 am and 4 pm, as depicted in Figure 4.

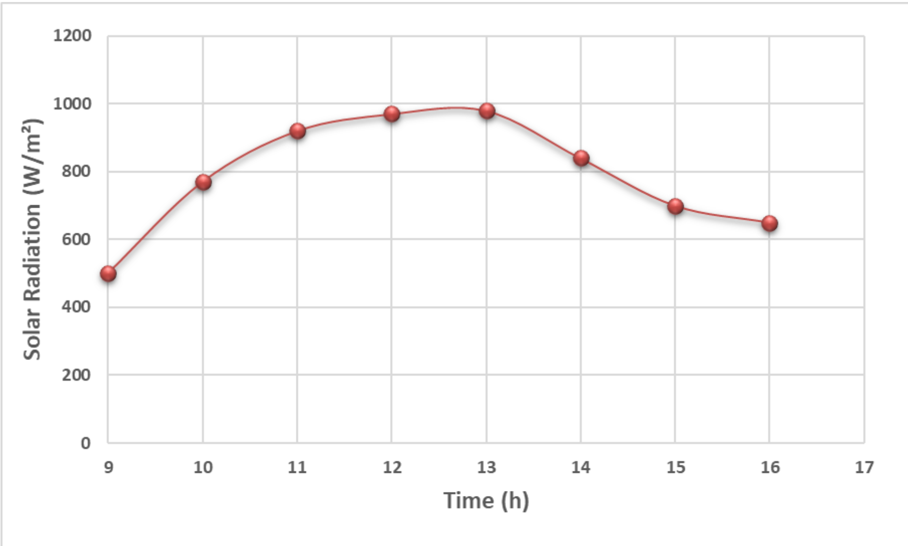


Fig. 4. Solar radiation between the period of 9 am to 4 pm

It is crucial to verify the results obtained from this simulation study on photovoltaic thermal (PV/T) systems utilizing graphene nanofluids as the working fluid, in accordance with the reference [37]. The validation process involves the analysis of temperature variations in the photovoltaic (PV) cell during the time period from 9 am to 4 pm.

The validation process involves comparing the panel temperature with time for various mass flow rates (0.065, 0.075, and 0.085 kg/s) while maintaining a constant volume concentration of 0.3%. The primary determinant of efficiency is the augmentation of the mass flow rate. The elevated intake velocity of graphene nanofluids is the primary determinant leading to an increased mass flow rate. As the mass flow rate of nanofluids increases, a greater amount of heat is absorbed from the photovoltaic (PV) cell. The Eq. (4) presented above is employed for determining the inlet velocity of graphene nanofluids as they traverse a pipe, while considering various mass flow rates.

$$\dot{m} = \rho v A \quad (4)$$

Figures 5 and 6 were generated using data obtained from the study conducted by Venkatesh *et al.,* [37]. These figures depict the temporal variation in panel temperature between the hours of 9 am and 4 pm. The temporal evolution of panel temperature in the PV/T system is examined for various mass flow rates, specifically focusing on the condition with the maximum at 0.3% volume concentration. The observation indicates a significant decrease in panel temperature as the mass flow rate of graphene nanofluids increases. At a mass flow rate of 0.065 kg/s, the highest recorded temperature is around 50°C, whereas at a mass flow rate of 0.085 kg/s, the highest recorded temperature is roughly 46°C.

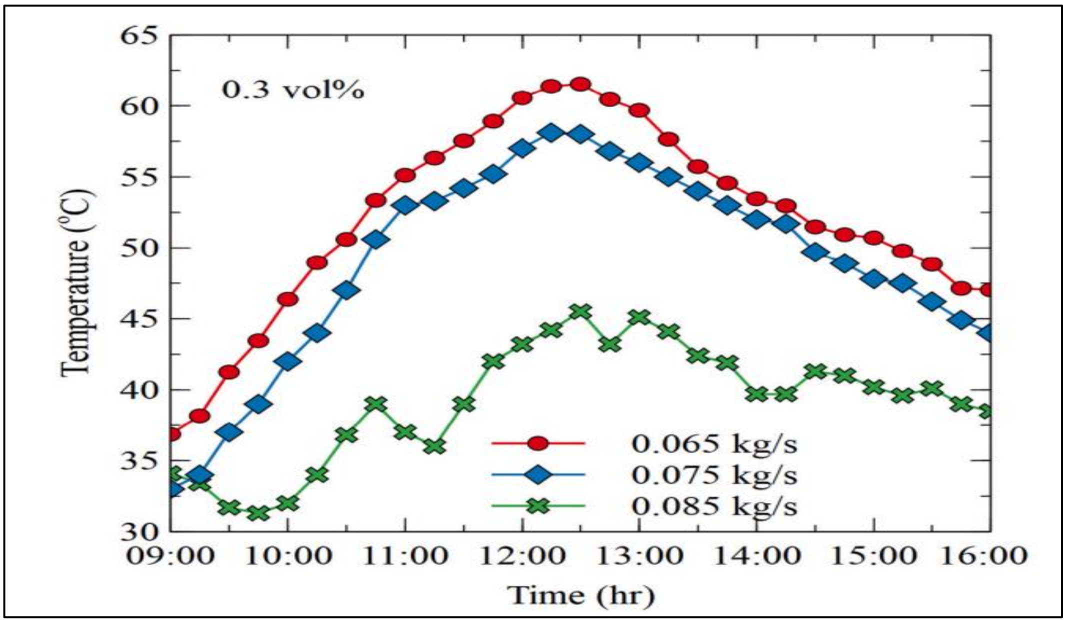
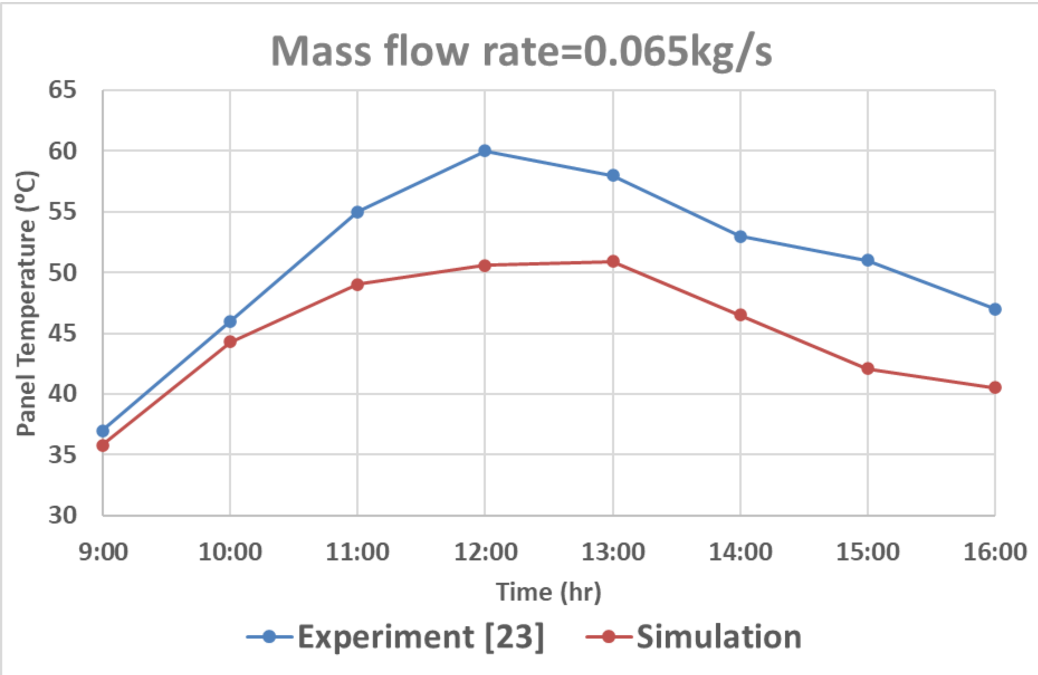
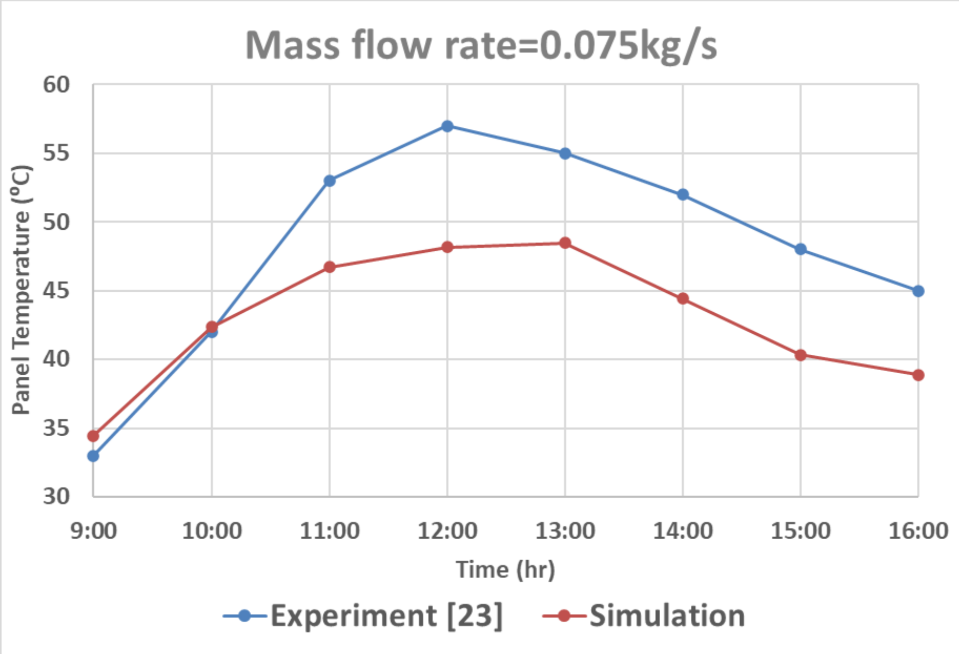


Fig. 5. The temperature of the panel over time (9 am to 4 pm) for different mass flow rates and a volume concentration of 0.3% [37]



(a)



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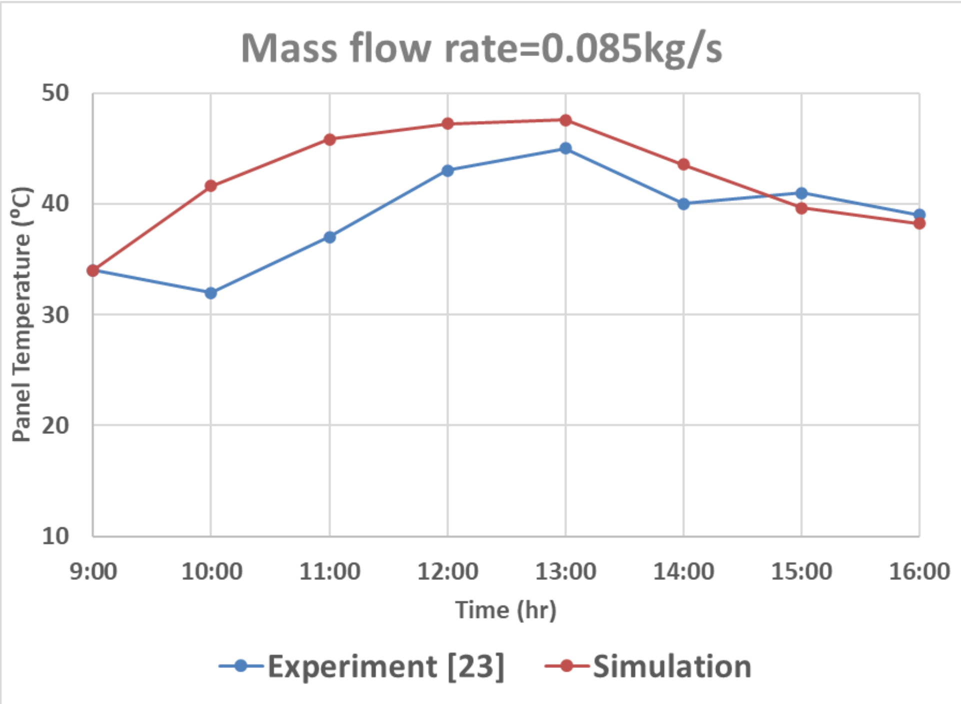


(c)

Fig. 6. Comparison between experimental [37] and simulation result according to the temperature of the panel over time (9 am – 4 pm) for different mass flow rates on a at 0.3% volume concentration (a) 0.065 kg/s (b) 0.075 kg/s (c) 0.085 kg/s

2.7 Grid Independent Test

The Grid Independent Test compares six different grids to determine mesh independence for a PVT system's panel temperatures as shown in Figure 7. The respective counts of the elements are 474575, 496348, 502088, 1192486, 1790723, and 2503631. The measurement of the temperature of the photovoltaic (PV) cells is conducted at 10 am, employing six grids. These grids are filled with graphene nanofluids, which have a volume concentration of 0.3 vol% and are circulated at a mass flow rate of 0.065 kg/s. From the fourth refinement iteration (1192486) onwards, the panel cell temperature, which is regarded as the optimal mesh quality for analysis, remains unchanged. The fourth grid, therefore, represents the optimal choice in this case, as may be deduced.

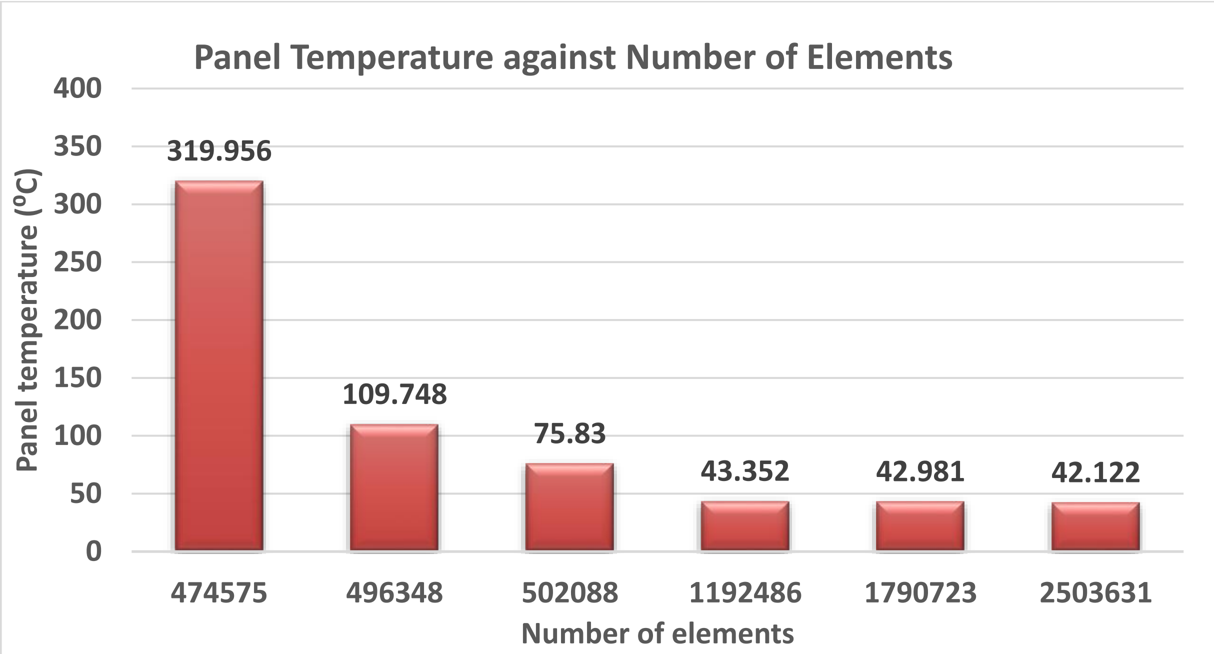


Fig. 7. Grid Independent Test of panel temperature at 10 am using six grids with a mass flow rate of 0.065 kg/s and a at 0.3% volume concentration

3. Performance of PV/T System
3.1 Data of Energy Analysis

The efficiency of a system is determined by the energy input and the work that this energy generates throughout the system. Photovoltaic thermal systems are systems that integrate both photovoltaic (PV) and thermal (T) elements. The integration of thermal and electrical efficiency yields the overall efficiency. The thermal efficiency equation, Eq. (5), electrical efficiency equation, Eq. (6), and overall efficiency equation, Eq. (7) are presented as follows [39].

$$\eta_{th} = \frac{\dot{m}C_{p,fluid}(T_{outlet} - T_{inlet})}{G_t A_c} \quad (5)$$

$$\eta_e = \eta_r[1 - \beta\ (T_P - T_r)] \quad (6)$$

$$\eta_t = \eta_{th} + \eta_e \quad (7)$$

The thermal efficiency (η_{th}) is obtained by using Eq. (5) where m = mass flow rate of nanofluid; $C_{P,fluid}$ = Specific heat capacity of nanofluid,]; T_{outlet} and T_{inlet} are the outlet and inlet temperatures of nanofluid (^{o}C); G_t = Total solar irradiation; A_c = area of the PV panel surface (m^2).

The calculation of the electrical efficiency (η_e) of the panel is determined by employing Eq. (6) where η_r = references cell efficiency (12%); β = Temperature coefficient (0.0045 1/°C),; T_p and T_r are the final PV and reference panel temperature (°C); G_t = Total solar irradiation; A_c = area of the PV panel surface (m^2).

According to Eq. (7), the overall efficiency is calculated by the addition of thermal efficiency (η_{th}) and electrical efficiency (η_e).

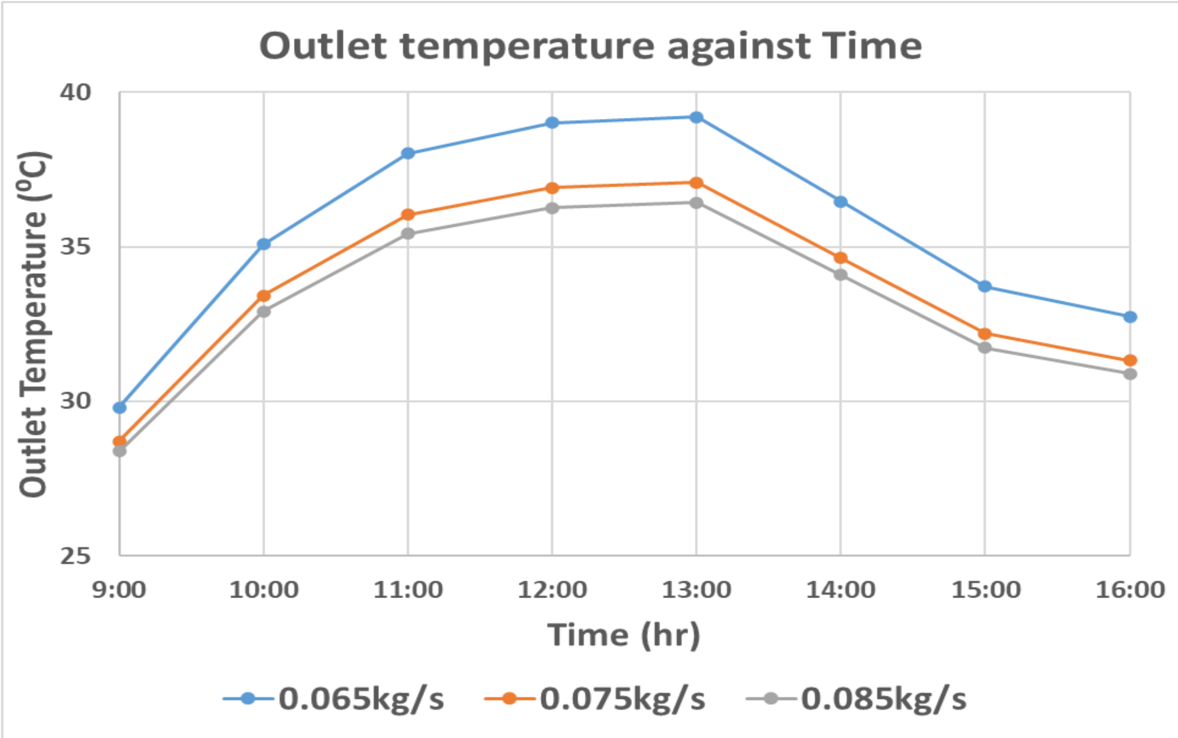
The mixing of graphene nanoplatelets (GnP) into the base fluid (water) resulted in an improvement in the performance of the PV/T system. The performance of the PV/T system was evaluated by conducting a computational fluid dynamics (CFD) simulation, whereby the mass flow rate and volume concentration of graphene nanoplatelets (GnP) in a nanofluid were systematically varied. This workshop, scheduled from 9 am to 4 pm, comprises an investigation of the effects of performance on panel and outlet temperatures, along with thermal, electrical, and overall efficiency.

3.2 Outlet Temperature and Thermal Efficiency

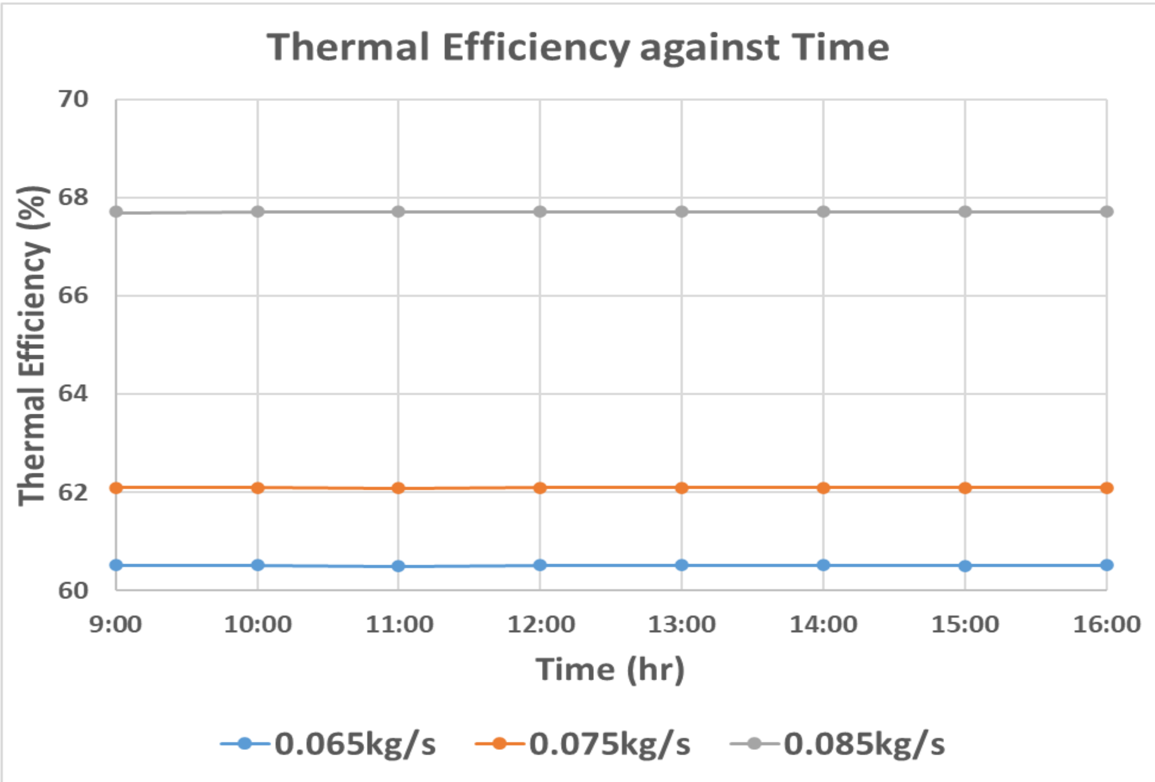
The thermal efficiency of the system is mostly influenced by the outlet temperature, given that numerical analysis is conducted under conditions of constant heat transfer and an inlet temperature of 20°C. The thermal efficiency of the PVT system is greatly influenced by the fluctuating mass flow rates of graphene nanofluids. Figure 8 illustrates the relationship between the outlet temperature and thermal performance of the photovoltaic/thermal (PV/T) system with respect to the mass flow of graphene nanoplatelets (GnP) at a constant volume concentration of 0.3%.

As depicted in Figure 8(a), the outlet temperature exhibits a proportional increase as the mass flow rate of graphene nanofluids is increased. The higher fluid velocity at the inlet results in an augmentation of the mass flow rate. As the mass flow rate is increased, a greater amount of heat is absorbed by the fluids from the solar cell. Conversely, when the mass rate gets higher, there is a reduction in the amount of energy consumed per unit of flow. During the time of maximum sun irradiation, specifically around 1 pm, it was observed that the peak temperature reached approximately 36°C for the lowest mass flow rate of 0.065 kg/s, while the highest mass flow rate of 0.085 kg/s resulted in a peak temperature of nearly 39°C.

The thermal efficiency of the photovoltaic-thermal (PVT) system is contingent upon two key factors: the mass flow rate of graphene nanofluids and the outlet temperature. The temporal fluctuation of thermal efficiency according to different mass flow rates at a peak volume concentration of 0.3 vol% is depicted in Figure 8(b). The variability of the difference between them is depending upon the mass flow rate, regardless of the lack of significant improvement in thermal efficiency over time. Figure 9 illustrates the temperature distribution at the outlet temperature for Graphene Nanoplatelets (GnP) at a constant at 0.3% volume concentration and different mass flow rates ($\dot{m}$ = 0.065, 0.075, and 0.085 kg/s) at the specified time of 1 pm. It is evident that, with an increase in the mass flow rate of the working fluids, there is no substantial alteration observed in the temperature distributions at the outflow. The solar panel that receives the largest amount of sun irradiation exhibits the lowest thermal efficiency, measuring approximately 61% for a flow rate of 0.065 kg/s at a volumetric concentration of 0.3%. Conversely, the solar panel that receives the least solar irradiation has the best thermal efficiency, measuring around 67% for a flow rate of 0.085 kg/s at a volumetric concentration of 0.3%. Consequently, the thermal efficiency of the PV/T system exhibits an upward trend when the mass flow rate increases and the output temperature decreases.

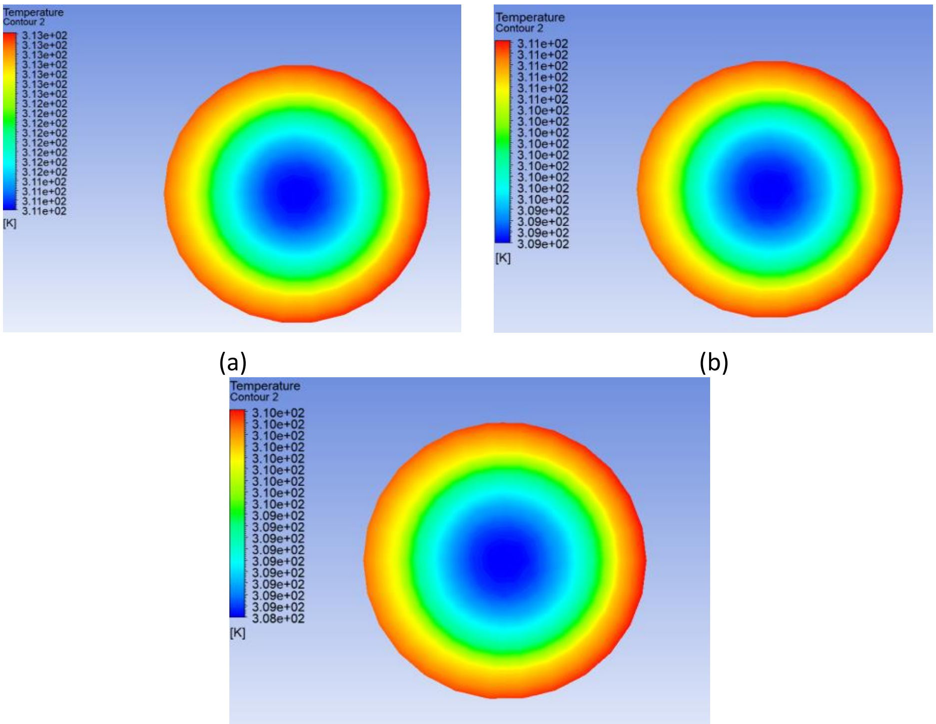


(a)



(b)

Fig. 8. (a & b) Outlet temperature and thermal efficiency against time for different mass flow rates focusing on the highest at 0.3% volume concentration



(a) (b)

(c)

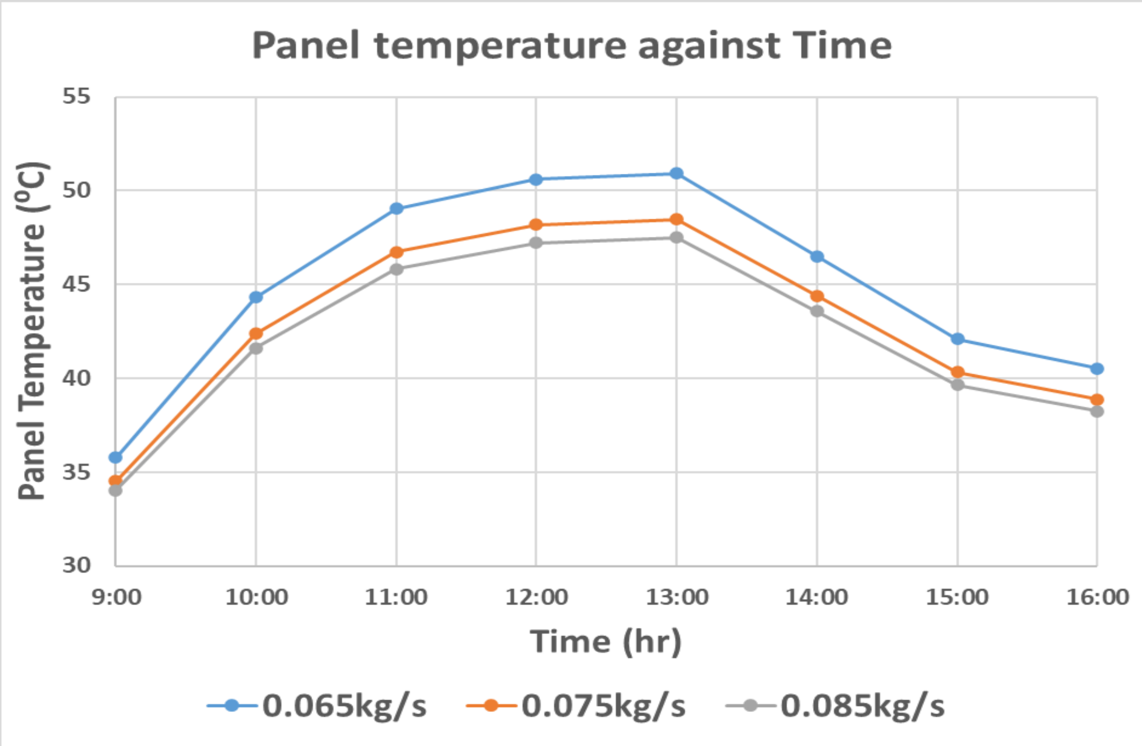
Fig. 9. Temperature distribution of outlet at time 1 pm for GnP by using different mass flow rates (a) 0.065 kg/s (b) 0.075 kg/s and (c) 0.085 kg/s at a constant at 0.3% volume concentration

3.3 Panel Temperature and Electrical Efficiency

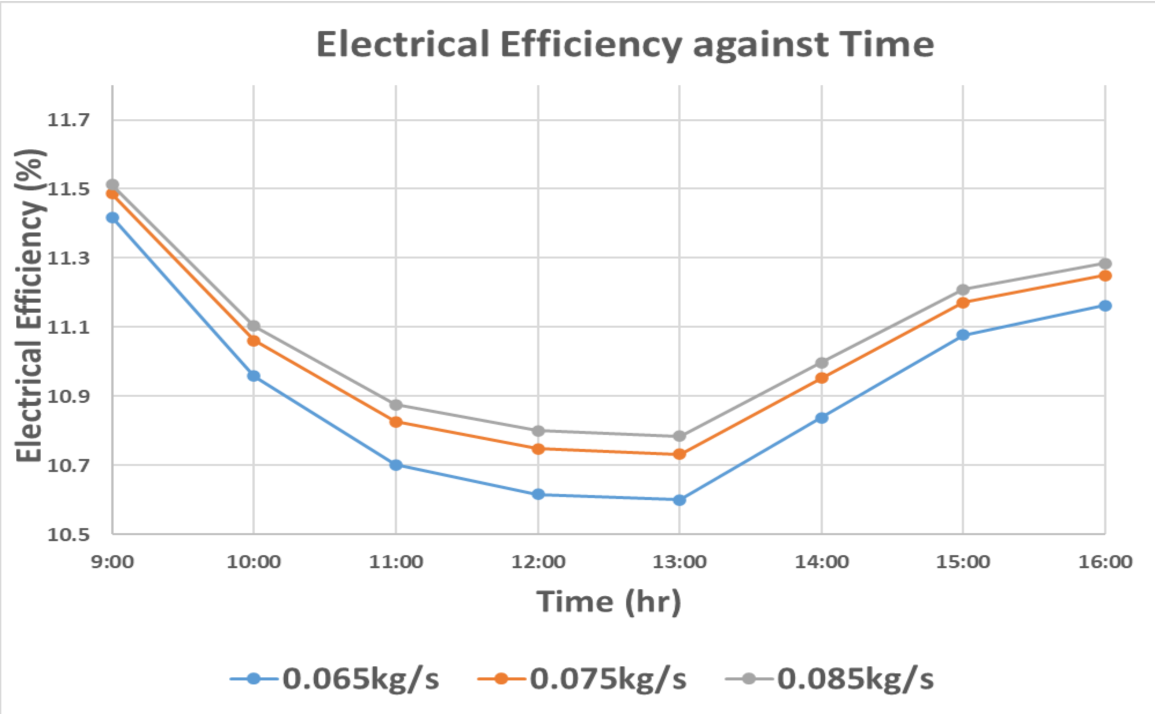
The panel temperature has a significant impact on the electrical efficiency of the PV/T system. Figure 10 depicts the panel temperature and electrical efficiency for various mass flow rates, specifically focusing on the greatest 0.3 vol% volume concentration.

According to the data presented in Figure 10(a), there is a negative correlation between the temperature of the panel and the mass flow rate, indicating that as the mass flow rate increases, the temperature of the panel falls. As the mass flow rate of the cooling nanofluid is increased, there is a corresponding decrease in the average cell temperature. This can be attributed to the enhanced heat transfer and convective discharge from the surface of the panel. At a mass flow rate of 0.065 kg/s, the greatest temperature recorded is around 51°C, while at a mass flow rate of 0.085 kg/s, the highest temperature recorded is approximately 46°C at 1 pm.

Both the temperature of the panel and the mass flow rate of the graphene nanofluids have a significant role in determining the electrical efficiency of the PVT system. Figure 10(b) illustrates the temporal variation of electrical efficiency for different mass flow rates, specifically at the highest volume concentration of 0.3 vol%. The optimal electrical efficiency is observed to be approximately 11.5% for a flow rate of 0.085 kg/s at a 0.3 vol% volume concentration. Conversely, the lowest electrical efficiency is determined to be around 10.6% for a flow rate of 0.065 kg/s at a volumetric concentration of 0.3%. Consequently, the enhancement of electrical efficiency occurs concomitantly with the reduction in both mass flow rate and panel temperature. Moreover, empirical evidence suggests that with each incremental rise of 0.010 kg/s at a concentration of 0.3 vol%, there is a corresponding increase in electrical output of approximately 0.2%. Figure 11 illustrates the temperature distribution of Graphene nanoplatelets (GnP) at a panel temperature for the time of 1 pm, while maintaining a constant at 0.3% volume concentration. The experiment involved employing different mass flow rates (ṁ = 0.065, 0.075, and 0.085 kg/s). It is evident that with an increase in the mass flow rate of the working fluids, there is no substantial alteration observed in the temperature distributions at the panel.

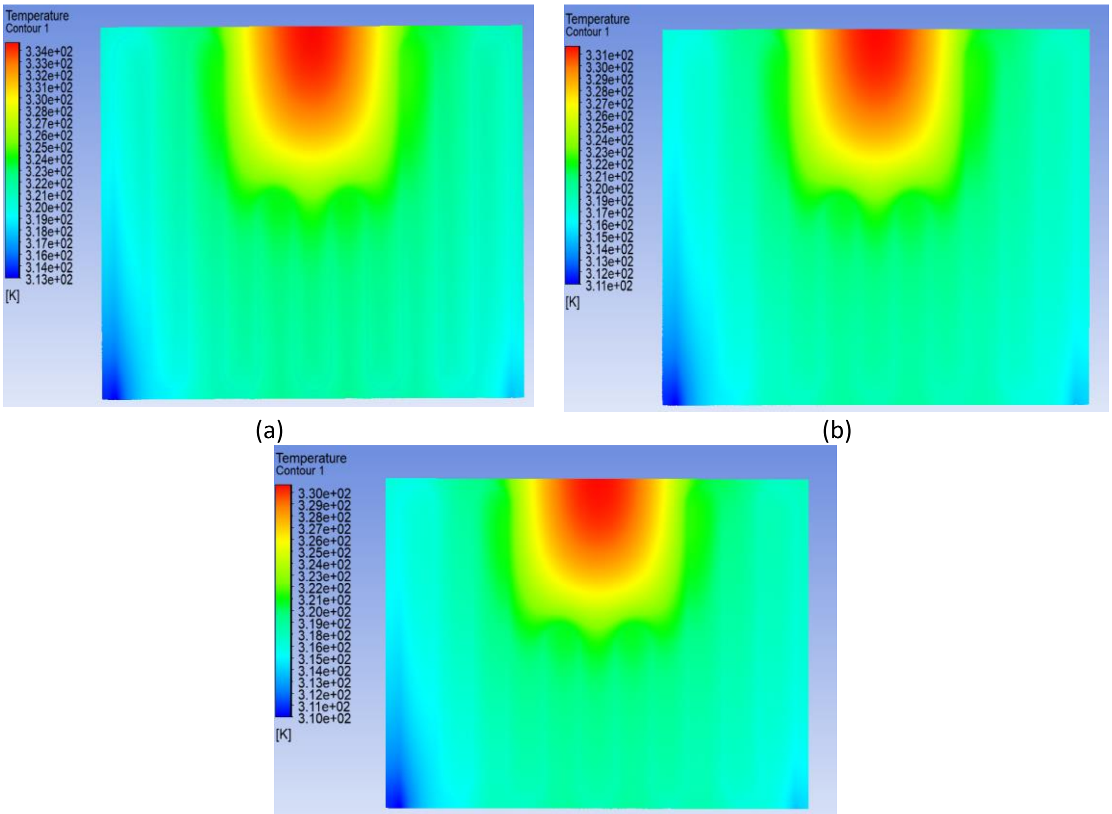


(a)



(b)

Fig. 10. (a & b) Panel temperature and electrical efficiency against time for different mass flow rates at 0.3% volume concentration



(c)

Fig. 11. Temperature distribution of panel at time 1 pm for GnP by using different mass flow rates (a) 0.065 kg/s (b) 0.075 kg/s and (c) 0.085 kg/s at a constant 0.3% volume concentration

3.4. Overall Efficiency of PV/T system

The overall efficiency of the PVT system is determined by the combination of its thermal and electrical efficiency. According to the data presented in Figure 12, it can be observed that when the flow rate is 0.085 kg/s at a volumetric concentration of 0.3%, the overall efficiency is around 79%. Conversely, when the flow rate is 0.065 kg/s at the same volumetric concentration, the electrical efficiency is determined to be approximately 71%. Furthermore, it should be acknowledged that with each increment of 0.010 kg/s at a 0.3% volume concentration, there is an observed enhancement of approximately 4% in the overall efficiency of photovoltaic/thermal (PV/T) systems.

Furthermore, it was observed that the utilization of 0.085 kg/s of graphene nanofluids at a concentration of 0.3 vol% resulted in a more substantial enhancement in overall efficiency compared to the implementation of 0.065 kg/s of graphene nanofluids at the same concentration, namely during the time period from 9 am to 4 pm. This improvement amounted to around 7%. The outcome of increasing the mass flow rate of graphene nanofluids is an enhancement in overall efficiency.

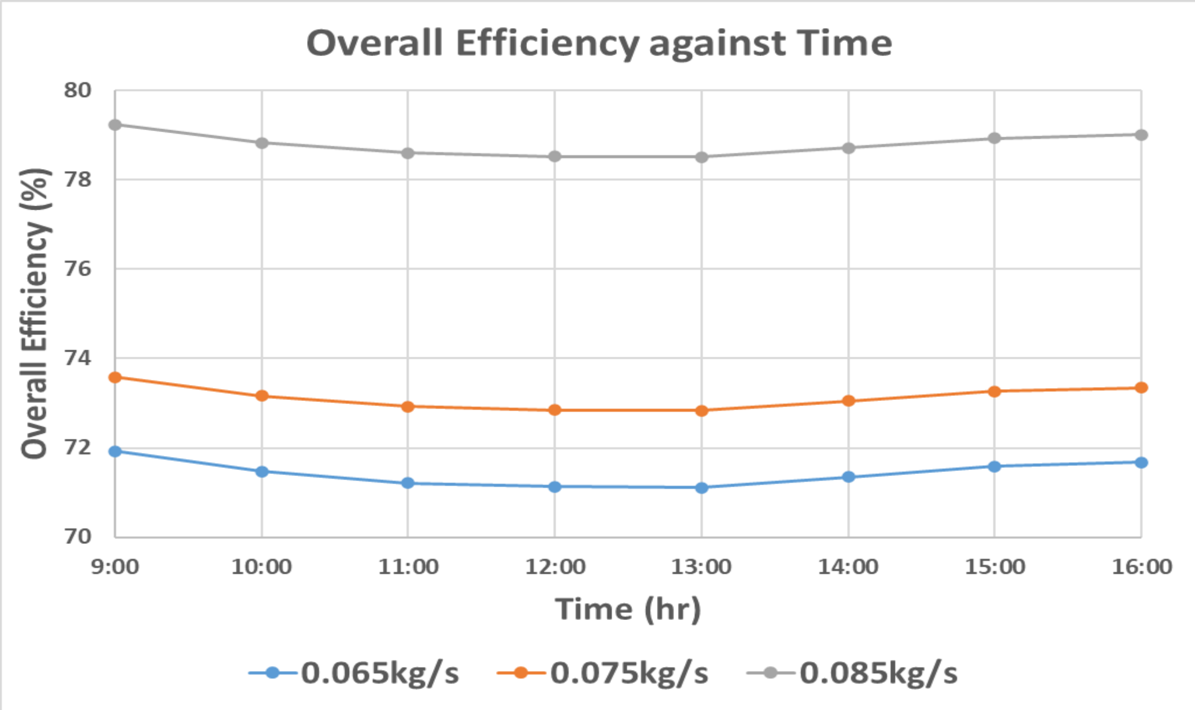


Fig. 12. Overall efficiency against time at the greatest 0.3% volume concentration at different mass flow rates

4. Conclusions

The numerical investigation focused on examining the performance of the hybrid solar PV/T system over the time frame of 9 am to 4 pm, while keeping the inlet temperature constant at 20°C. This was achieved by altering the volume concentration of GnP and the mass flow rate of the nanofluid.

The outlet temperature has a significant impact on the thermal efficiency of the system. The increase of the mass flow rate of graphene nanofluids leads to a simultaneous rise in the outlet temperature. The increased fluid velocity at the point of entry leads to an increase in the mass flow rate. As the mass flow rate is increased there is a rise in the quantity of heat received by the fluids from the solar cell. During the period of peak solar irradiation, particularly around 1 pm, it was observed that the maximum temperature reached roughly 36^{o}C for the lowest mass flow rate of 0.065 kg/s. Conversely, the highest mass flow rate of 0.085 kg/s yielded a peak temperature of nearly 39^{o}C. The thermal efficiency of the photovoltaic-thermal (PVT) system is determined by two primary parameters, namely the mass flow rate of graphene nanofluids and the output temperature. The solar panel that experiences the highest level of solar irradiation demonstrates the least efficient thermal performance, with a recorded efficiency of roughly 61%. This efficiency measurement was obtained under specific conditions, including a flow rate of 0.065 kg/s and a volumetric concentration of 0.3%. On the contrary, the solar panel that experiences the lowest level of solar irradiation demonstrates the highest thermal efficiency. Specifically, it achieves a thermal efficiency of approximately 67% when subjected to a flow rate of 0.085 kg/s and a volumetric concentration of 0.3%. The recorded decline in the outlet temperature, from roughly 39°C to 36°C, led to the recording of an enhancement in thermal efficiency, rising from around 61% to 67%. The alteration of the mass flow rate of GnP from 0.065 to 0.085 kg/s resulted in an observable change in thermal efficiency.

The temperature of the panel exhibits a substantial influence on the electrical efficiency of the photovoltaic/thermal (PV/T) system. As the mass flow rate increases, there is a corresponding decrease in the temperature of the panel. As the mass flow rate of the cooling nanofluid is augmented, a concomitant reduction in the average cell temperature is seen. The observed phenomenon can be ascribed to the increased heat transfer and convective dissipation originating from the panel's surface. At a mass flow rate of 0.065 kg/s, the maximum temperature observed is approximately 51^{o}C, but at a mass flow rate of 0.085 kg/s, the highest recorded temperature is roughly 46^{o}C, specifically at 1 pm. The experimental results indicate that the highest achievable electrical efficiency is approximately 11.5% when the flow rate is 0.085 kg/s and the volume concentration is 0.3 vol%. In contrast, it has been discovered that the minimum electrical efficiency is around 10.6% when the flow rate is 0.065 kg/s and the volumetric concentration is 0.3%. As a result, the improvement in electrical efficiency coincides with a decrease in both the velocity of mass flow and the temperature of the panel. Furthermore, based on practical data, it can be observed that for every 0.010 kg/s increase in flow rate at a concentration of 0.3 vol%, there is a proportional enhancement in electrical output of around 0.2%. Consequently, it is noticed that the increase in mass flow rate from 0.065 kg/s to 0.085 kg/s leads to a corresponding improvement in electrical efficiency, rising from approximately 10.6% to 11.5%.

The overall efficiency of the PVT system is depended upon a combination of its thermal and electrical efficiencies. The mass flow rate is measured to be 0.085 kg/s , while the volumetric concentration is determined to be 0.3%. The overall efficiency of the system is estimated to be approximately 79%. In contrast, it has been observed that at a volumetric concentration of the same magnitude, an electrical efficiency of roughly 71% is found when the flow rate is 0.065 kg/s. Moreover, it is important to understand that for every increase of 0.010 kg/s at a volume concentration of 0.3%, there is an observed improvement of around 4% in the total efficiency of photovoltaic/thermal (PV/T) systems. Moreover, it was observed that the utilization of a flow rate of 0.085kg/s of graphene nanofluids at a concentration of 0.3 vol% led to a more significant improvement in overall efficiency compared to the implementation of a flow rate of 0.065kg/s of graphene nanofluids at the same concentration, specifically during the time interval between 9 am and 4 pm. The findings of the experiment indicate that there is an improvement of approximately 7% in the overall efficiency when using graphene nanofluids with a concentration of 0.3 vol% at a flow rate of 0.085 kg/s.

Enhancing the efficiency of the PV/T system involves conducting numerous investigations into the selection of operative substances and fluids. These investigations include the examination of graphene nanofluids/nano-PCM, as well as graphene-water/glycol-based nanofluids associated with PCM. Furthermore, efforts are being undertaken to enhance the stability of nanofluids and decrease the production costs associated with nanofluid manufacturing through the implementation of industrial-scale production methods.

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