Impact of Alumina Nanoparticles Additives on Open -Flow Flat Collector Performance for PV Panel Thermal Control Application

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Impact of Alumina Nanoparticles Additives on Open-Flow Flat Collector Performance for PV Panel Thermal Control Application

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Abstract: Photovoltaic Cells are devices made of semiconductor materials that is used to convert solar energy to electrical energy in the form of a constant current. The efficiency of the photovoltaic cell increases with the increase in solar radiation while its generation efficiency decreases with the increase in Photovoltaic Cell temperature above the standard temperature. Therefore, researchers implement methods to decrease overheating. One of these methods is using PV/T. This paper presents an experimental and numerical study on the performance of the Photovoltaic/Thermal (PV/T) system by using Nanofluids with a new design (novelty; sphere fins in open flow flat collector) of the water collector. Experiments were carried out in Iraq/Baghdad/University of Technology. Nanofluids Al_2O_3/water was used at different volume concentration ratio as 1%, 2%, and 3% for cooling of PV panel. The influence of new design of collector and Nano additives on the PV/T performance at various operational parameters have been simulated and evaluated using ANSYS Fluent software to solved the Navier-Stockes and energy equations. Numerical results noticed a decrease in the surface temperature of the collector by 5.1% when using a Nano liquid with a concentration 1% compared to its temperature when using water only, while it decreases by 6.2% and 7.8% when using concentrations 2% and 3%, respectively at flow rate 3.5 l/min. The evaluation result demonstrates that the performance of PV/T system increased, also the Nanoparticles helped to system enhances.

Keywords: Open flow flat collector; PV/T system performance; Nano additives; PV/T collector

1. Introduction

Solar energy is one of the most popular and widespread types of clean energy and that is because it is considered one of the safest sources[1, 2]. The Earth annually receives solar energy that exceeds the amount of the total amount of annual consumed energy by humans. The utilization of this huge amount of solar energy will help in protecting the environment and strengthening the global economy and reducing harmful emissions[3]. To benefit from incoming solar radiation, it is converted into other types of energy to facilitate storage, transportation, and use for different needs. There are two main ways of conversion of solar radiation to other types of useful energy. The first way is the solar thermal system and the second way is the solar photovoltaic cell[2, 4].

Photovoltaic Cells (PV) are devices made of semiconductor materials and manufactured in different sizes and can be linked together in the form of arrays in series or parallel circuits according to use. The efficiency of the photovoltaic cell increases with the increase in solar radiation while its generation efficiency decreases with the increase in Photovoltaic Cell temperature above the standard temperature[5]. PV panels are designed to work in specific conditions depending on the geographic region they are used in. For example, there are some PV panel which work with the highest efficiency at these conditions: (1000 W/m^2 solar radiation and 25° C), and thus the efficiency decreases when the temperature increases over 25° C, therefore, researchers implement methods to decrease overheating. One of these methods is using PV/T system[6].

The flat solar collectors are widely used for solar water heater and space heating in buildings where low and medium operating temperature is considered for domestic hot water production[6,7]. Ismaeel etal.[8] to quantify the thermal and electrical efficiency, theoretical and practical investigations of the influence of the fins on the solar hybrid air collector were conducted. Use air as for heat transfer, for solar cells and to boost electrical efficiency lowering the operating temperature will help you get a decent level. It was determined that cooling medium such as fins are required. The fins are a crucial aspect of the development of absorbent elements to accomplish the PV/T hybrid's high-power thermal and electrical efficiency[9-12]. Reda etal. [13] found to be suitable for warm temperature applications by applied energy, the PVT system helps decrease collector heat loss, when solar cells operate as a heat absorber, as well as when a windshield is added, heat loss is reduced even further, but reflecting losses rise.

In recent years, the use of Nanofluids has become widespread, especially in the applications of heat transfer and the utilization of solar thermal radiation due to their good physical and chemical properties[14]. To improve the heat transfer efficiency of the used conventional fluids (water, thermal oils, etc.), solid materials are added in Nano sizes with good thermal specifications and high conductivity, which gives a noticeable increase in the heat transfer efficiency of the base fluid. These fluids are called Nanofluids[14, 15]. Nanofluid are compounds of a base liquid mixed with a solid substance. The solid substance contains Nano scale sizes ranging from 1-100 Nano-meters. These materials are mixed with the liquid in studied proportions to give the Nanofluid additional specifications in thermal conductivity and heat transfer substances[16]. In another works, pure water was used as a coolant in a solar thermal collector system and compared with the use of a Nanofluid consisting of water and Al_2O_3-ZnO alone[17, 18] and mixed with ethylene glycol[19] as a surfactant. The particle size used (10-30 nm) recorded an increase of 4.1% in Overall system efficiency as well as a 4.6% increase in usable energy efficiency.

Researchers conducted many different experimental and theoretical studies to examine the effects of Nanofluids on the efficiency of solar photovoltaic cells by controlling the type and percentage of Nano material added to fluid, the volumetric flow rate of the Nanofluid, the concentrations of solar radiation, and other variables[20, 21]. Also recording the difference in the efficiency of cells for each of these variables was essential and comparing it with the performance of the photovoltaic solar cell alone or cooled with water only and without Nano – additives. Samylingam et al.[22] used silica (SiO_2) with water as a Nano -cooling fluid in a solar thermal collector with mixing ratios by 1% wt. and 3% wt. They concluded that the overall efficiency of the system increases by 3.6% and 7.9% when using Nanofluid with 1% and 3%, respectively. While Praveen etal.[23] used CuO/water as a coolant in the PV/T system to study its effect on the cell performance, where 1% wt. and 2% wt. of the nanoparticle were used with a volumetric flow rate 40 l/h and got the highest efficiency value 13% and 45%.

In industry, cost saving is the most concern by reduced power consumption. The temperature reduction for PV panel by using nanomaterial's additives to water for PV/T increases power generation and improve the cooling process for PV panel[24- 26] therefore, in this current study, the new model of open flow flat collector with sphere fins was applied to cooling the PV panel after enhancing the flat collector performance by add alumina nanoparticles to water for increase heat transfer rates. The investigation of PV/T has been performed and evaluated using experimental and numerical methods.

2. Experimental Facility

2.1 Layout of the PV/T System

The flat collector’s performance is influenced by the working environment. The new flat collector model developed and built in this thesis has been put at the University of Technology in Iraq's solar research location. The latitude is N33.3123°, the longitude is 44.446 E, and the height is 21.23m. Meteorological data measured inside the University for the Dawn Portion of the day (7 am - 7 pm); as a working time of the flat plate collector are as follows:

- The average wind velocity was (1.7 m/s).
- The solar radiation intensity range was (24 to 1112 W/m^2).
- The average ambient air temperature was 34℃ and range was (26~43 ˚C).
- The average ambient air pressure was (100200 Pa) and range was (99891~100540 Pa).

The temperature drop from the flat plate collector surface is determined by the amount of solar radiation reaching the back surface of the PV panel, the area of the collector, and the absorber materials. Because the future goal is to increase the amount of electricity generated by the PV panel by using new flat collector model, it is suggested that it be installed in an open environment and use water as a solar radiation absorbing medium.

As a result, the absorber material would be flowing water mixed with various types of Nanoparticles, while the collector cover material could be high conductivity plates of aluminum, preferably for investigation objectives. The collector area could be calculated based on the size of the PV panel and the amount of heat that reaches this cover in the model location. The collector has a slope angle of 30° to improve the solar radiation projection model within its daily range[21].

2.2 Specification of New Design of Open Flow Flat Collector

The new design utilizes aluminum uniform bulges connected with collector cover from bottom to provide powerful heat transfer and water movement with slow streamlined manner. This can be achieved because the velocity components of water flow are more valuable when the collector cover was without bulges. In the new design of the present work, new model of bulges utilized sphere shape. The open flow flat collector geometry for this model has a number 120 sphere bulges, a 25 mm diameter, and is made of aluminum to allow powerful heat transfer. These bulges were distributed uniformly on the bottom surface of the collector cover so that there were 8 spheres within one row, while the number of rows was 15, as shown in Fig.1. The collector body has dimensions of 600×1100×30 mm, a 13 mm inlet and outlet diameter, it is made of steel. To connect collector cover was used number of screws and rubber band used to prevent water leakage from the edges of the collector.

2.3 Experimental setup

Experimental investigation of PV panel cooling system design for power generation is an objective of the present study. The subtract heat energy was done using open flow flat collector system by depending on closed circle water flow. The thermal collector (absorber) is attached to the back of an off-the-shelf PV panel. To get a first estimate of the characteristics of PV/T system, all experiments were carried out by comparing with PV system and a part of the collected energy is extracted as electricity instead of heat.

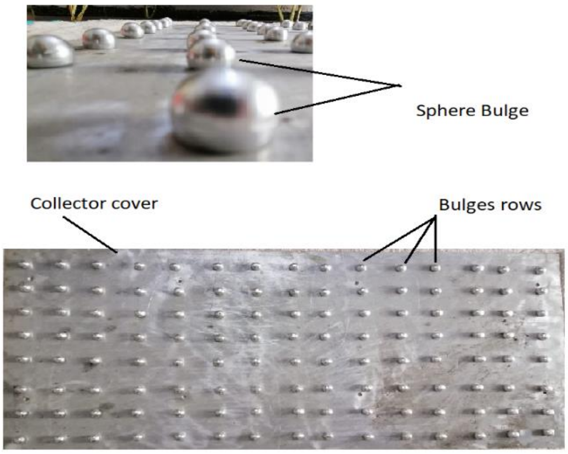


Fig. 1: Photos of the structural of a new open flow flat collector.

Both the PV panel and PV/T system inclined with 30° from the horizontal plane. Temperatures for different regions of the PV/T system were measured by temperature measurement unit and the water flow rate was measured by flow rate device before entering the collector. To control the water flow rate accurately, one-way valves were used, as illustrated in Fig.2.

Fig. 2: Experimental setup of the PV and PV/T system.

Experiment methods were carried out on sunny days, avoiding overcast days or clouds. All temperature testing on the open flow flat collector model were performed to become acquainted and confident with the measuring process. Temperature measurements are classified into numerous categories; Group-A was used three thermocouples for measuring PV panel surface, Group-B was used two thermocouples for measuring inlet and outlet water temperature, and Group-C was used three thermocouples for measuring collector surface, as shown in Fig.3. All thermocouples were used by type-k with selector switch and digital thermometer. All specific properties for all parts of the temperature measurement system are shown in Table 1. Flow meter model M-15 measuring range 1-7 l/min instrument is connecting with water flow line can measure and volumetric flow rate.

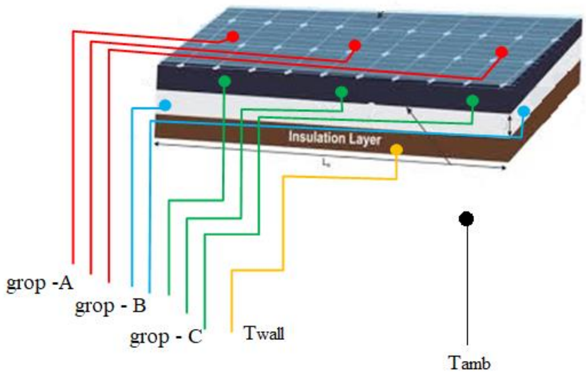


Fig. 3: Positioning schematic of temperature measurement in the PV/T system.

Table 1. All specific properties for all parts of temperature measurement system.

Thermocouples position	Accuracy	Reader Thermometer – Tm-936
2 points, inlet and outlet collector	± 0.3	Accuracy ± (0.2 % + 0.5℃)
6 points, on PV panel and PV/T system	± 0.2	
3 points, on Collector cover	± 0.2	
4 points, to measuring Ambient temperature, collector body	± 0.2	

2.4 Preparation of Nanofluids

The Nano material mixture is simply not a liquid-solid mixture. Preparation of Nanofluid is the first key step in applying Nano phase particles to change the heat transfer performance of conventional fluids. To get clear, describe, durable suspension, with low agglomeration of particles, a two-step method was selected to prepare the Nanofluids[22]: the first step is that the Nanoparticles and distilled water are mixed directly. The second step is the use ultrasonic vibrator for preparation of mixed aqueous Nanofluid, but longer time of high energy sonication can introduce defects. Nanofluid samples were prepared for different concentrations by dispersing pre-weighed quantities of dry particles and pure water. The all mixtures were then subjected to ultrasonic mixing (500 Watts, 70 Hz, German) for 15 to 20 minutes to break up any particle aggregates. The process results in uniform dispersions for the duration of the experiments. The concentrations used in the experiments are C = 1, 2, and 3% by volume.

The volume concentration is evaluated from the following equations.

$$\mathrm{Cn} = \frac{\textit{volume of nanopartical}}{\textit{volume of nanopartical} + \textit{volume of water}} \times 100 \quad (1)$$

$$\mathrm{Cn} = \frac{(m/\rho)_{nanopartical}}{(m/\rho)_{nanopartical} + (m/\rho)_{water}} \times 100 \quad (2)$$

Noting that the volume of pure water used in the test setup is 25 L. The Nanoparticles used in the preparation of Nanofluids are aluminum oxide Nanoparticles (γ Al_2O_3, gamma, 99%, and 20nm). The properties (density, viscosity, and specific heat) for the Nanoparticle used is shown in Table 2. Also all properties after preparing water/Nanoparticles appear in Table 3.

Table 2. The properties of two type's Nanoparticles used.

Property	**Al_2O_3 diameter 20 nm**
Cp (kJ/kg. K)	765
Density (kg/m^3)	3970
k (W/mK)	40

Table 3. Experimental results of the measured properties.

	Al_2O_3 (20 nm)- Water		
Nanoparticles concentration (Vol. %)	1	2	3
Density (kg/m^3)	1025.4	1055.2	1084.9
Specific heat (kJ/kg.K)	4.051	3.926	3.808
viscosity (N.s/m^2)	1.0827*10^{-3}	1.18*10^{-3}	1.26*10^{-3}
Thermal cond. (W/m.K)	0.867	1.11	1.78

3. Numerical Investigation

For engineering applications, CFD simulation techniques are an effective tool for depicting mechanical problems and understanding associated physical phenomena. The commercial CFD program ANSYS 17.0 FLUENT radiation model pre-processing tool (provides a solar load model with Nano material additives mixed with water at different conditions. That may be used to calculate radiation effects) was utilized in the current simulation. Sold-work ver. 2019, are used to model the open flow flat collector, there are various procedures that must be completed to run the simulations. The modelling is done in Solid work, and the mesh is then imported into the FLUENT radiation module for solution and post-processing as a solar collector issue. This simulation was carry out by into based on the characteristic nanomaterial's used Al_2O_3. To predict the thermo-hydrodynamic behavior of the system, a full standard numerical model of PV/T simulation was built. The model solving technique was accomplished by computational coding in (ANSYS) software.

A computational fluid dynamics (CFD) model is used to investigate the heat loads for the different Nano material additives to water and parameters, such as the inlet and outlet water temperature, temperature distribution on collector surface. Preparing a computational domain is the first step in CFD simulation. A new 3D-dimensional flat plate collector model created with Solid work program new collector model. The geometrical model of PV/T is shown in Fig. 4. This collector is designed with sphere bulges. The development of the computational grid, which is made up of computational cells, is one of the most significant operations in CFD. The governing equations are solved in computational cells. Unstructured meshing is used to mesh the collector domain with tetrahedral pieces. Because of the difficult geometry, unstructured tetrahedral meshing was used. A recommended strategy for removing the impact of mesh size is to pursue a mesh independent solution. The optimal grid size is chosen when the grid size has no effect on the solution.

The 3D meshed geometrical model of a flat solar collector is shown in Fig. 5. The fine meshing system produced the most accurate and similar findings for heat transfer inside the collector, velocity, and temperature distribution behavior under the impact of different Nano material additions. As a result, the tiny mesh was chosen for the simulations and result interpretation. New model nodes and fine mesh elements were 94844 and 523711, respectively. Also, this fine mesh was chosen for performing the simulations in addition to the interpretation of result. For all domain, 2.0×10^6 number of cells selected in all simulations according to grid dependency as shown in Fig. 6.

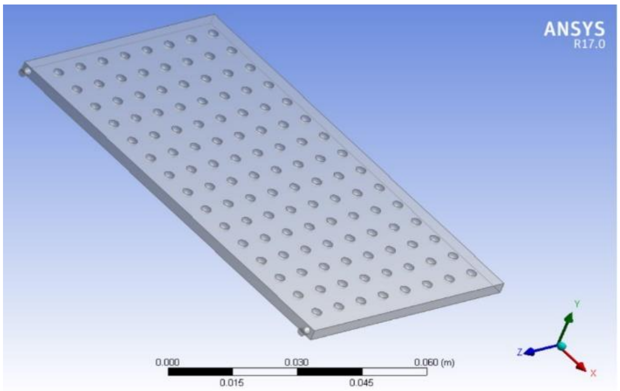


Fig. 4: Computational domain prepared of open flow flat collector model.

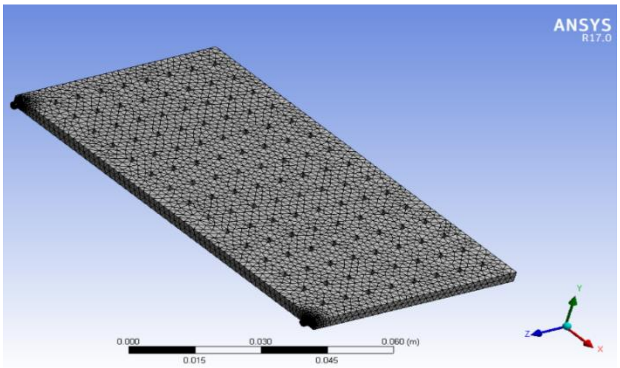


Fig. 5: Geometrical mesh of open flow flat collector model.

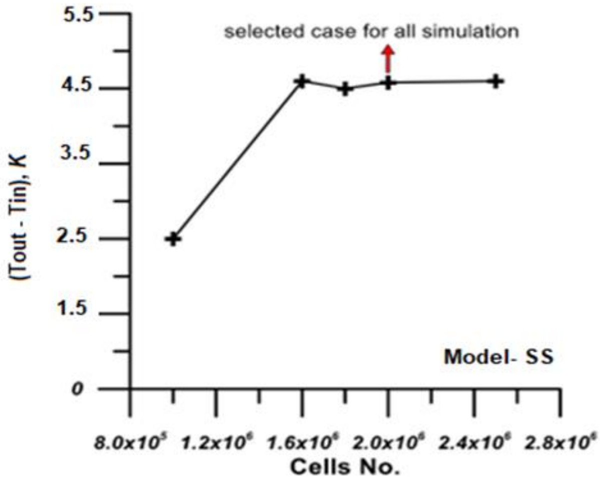


Fig. 6: Cell selected for all simulation model..

The 3D k-epsilon (k-ε) model of the energy system was used. According to the values of the turbulence kinetic energy and the turbulent dispersion rate are defined. The turbulence kinetic energy can be estimated from turbulence level.

3.1 Governing Equations Solving

Under turbulent and steady conditions, the PV/T model and domain were simulated in three dimensions. The governing equations of continuity, Navier-Stokes, and thermal energy are as represented in equations in 3D Cartesian coordinates[27].

Using terminology to express each term of velocity components gives (continuity equation).

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \qquad (3)$$

Momentum equation;

$$\rho\frac{D\vec{V}}{Dt}=\rho\vec{g}-\nabla\vec{p}+\frac{1}{3}\mu\nabla(\nabla.\vec{V})+\mu\nabla^2\vec{V} \qquad (4)$$

Energy equation;

$$\rho\, Cp\frac{DT}{Dt}=\nabla.K\nabla T+\beta T\frac{DP}{Dt}+\mu\emptyset \qquad (5)$$

β is the coefficient of thermal expansion, defined as

$$\beta=-\frac{1}{\rho}\left[\frac{\partial\rho}{\partial T}\right]_p \qquad (6)$$

Furthermore, the dissipation function is related to energy dissipation owing to friction. It is critical in high-speed flow and for extremely viscous fluids[22] is given in Cartesian coordinates by:

$$\emptyset = 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left[\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)^2\right] - \frac{2}{3}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)^2 \quad (7)$$

3.2 Boundary Conditions and Simulation Parameters

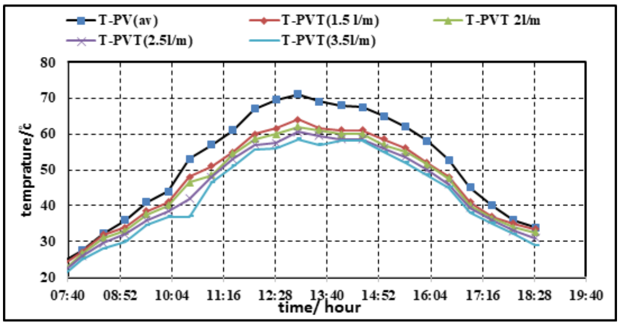
The flat solar collector PV/T measured data from the experimental model is used to calculate the values of the PV/T system's input parameters, which are temperature, Nanoparticles concentration (vol.%), and mixed mass rate. Table 4 shows the experimental parameters measured at the open flow flat collector's inlet and outflow, as well as on the collecting surface. The numerical simulation was then performed using identical experimental values. The open flow flat collector numerical simulation was completed successfully, with results compared to experimental data. Further assessment was accomplished by using significant values of the same parameters to investigate the impacts of increasing temperature, water/Nanoparticles flow rate, and Nanoparticles concentration (vol. %) on PV panel cooling. These parameters and variables were used as inputs to the CFD simulation, whereas the output parameters were related to temperature distribution, pressure distribution, velocity gradation of tangential and vertical components.

Table 4. Simulation parameters.

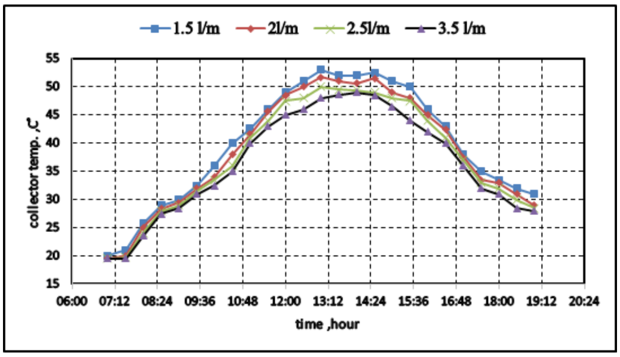
Temperature	**Water flow rate**	**Initial-reference values**
T_{co} = 303 K to 357 K T_{win}= 303 K to 314K T_{wo} = 325K to 345K	1.5l/min 2.0l/min 2.5l/min 3.5l/min	Density=1000kg/m^3 Tamb=303 k Viscosity=1.0016 kg/m.s Solar intensity 23 to 1112 Watt/m^2 Gravitational acceleration for (z-axis) = -9.81 m/s2
Nanoparticles concentration (vol. %)		
1% vol.	Al_2O_3 diameter 20nm	
2% vol.		
3% vol.		

4. Results and Discussion

Experimentally, by recording the surface temperatures of the photovoltaic cell during daylight hours with flow rates 1.5, 2, 2.5, and 3.5 l/min, it obtained a decrease in the cell surface temperature with increasing in flow rate as shown in Fig. 7(a) and comparing it with a photovoltaic cell without cooling at 1:00 pm where the percentages of temperature decrease were 10%, 12.6%, 14.7%, 17.6% at flow rates 1.5, 2, 2.5, and 3.5l/min, respectively. The highest temperature of the collector surface at 1:00 pm was 53℃ at a flow rate of 1.5 l/min, which decreased by 2.5% when using a flow rate of 2 liters per minute, and decreased to (5.6%, 9.4%) when using (2.5 and 3.5 liters per minute) respectively, as shown in Fig.7(b).



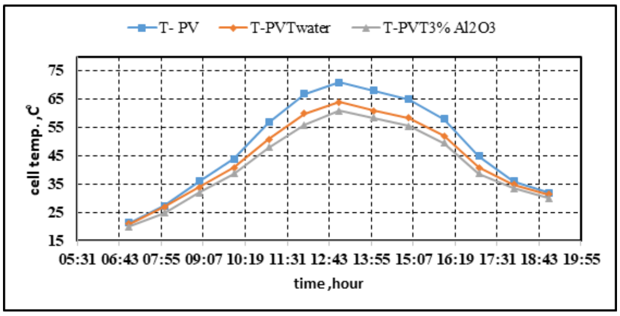
(a) The effect of coolant flow rate on the Pv panel surface temperature.



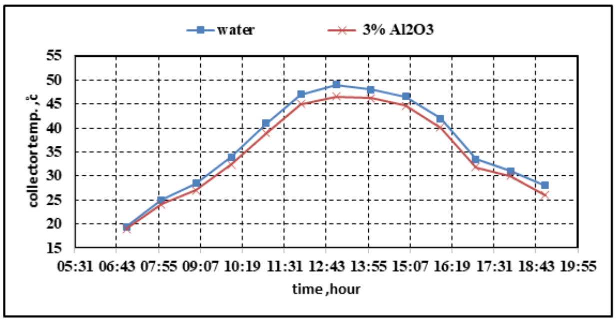
(b) The effect of coolant flow rate on the collector surface temperature.

Fig. 7: Variation of temperature for different water flow rate at daytime (a) for Pv panel surface, (b) for collector surface.

Fig. 8(a) represents the cell surface temperature during daylight hours for Al_2O_3 Nanofluid additives, at 1:00 pm, it note that using (Al_2O_3/water) at volumetric concentrations 3% reduces the Pv panel surface temperature 14%. While Fig. 8(b) shows the collector surface temperature at 1:00 pm, it noticed that using (Al_2O_3/water) at a volumetric concentration 3% reduces the collector temperature 17%.



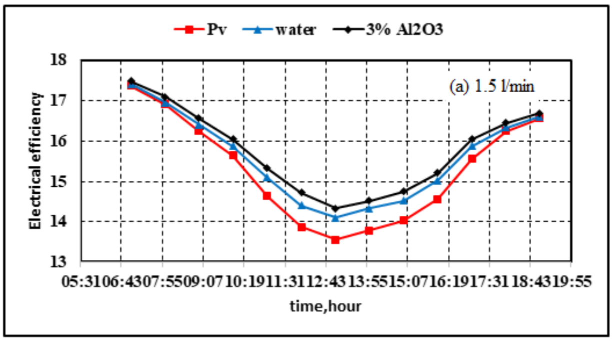
(a) The effect of Al_2O_3 additives on the Pv panel surface temperature.



(b) The effect of Al_2O_3 additives on the collector surface temperature.

Fig. 8: Variation of temperature for a volumetric concentration 3% Al_2O_3/water and 3.5 l/min at daytime (a) for PV panel surface, (b) for collector surface.

Fig. 9 (a) shows the electrical efficiency of the PV panel which cooled by water and 3% Al_2O_3 volumetric concentration recorded during daylight hours and compared with the uncooled PV panel efficiency, where it notice an increase in the efficiency when using (Al_2O_3/water) Nanofluid as a coolant with volumetric concentration of (3%) by (6.5%) and (3.2%) when use water at flow rate 1.5l/min. While the increasing of the electrical efficiency when using (Al_2O_3/water) Nanofluid as a coolant with volumetric concentration of 3% was 10%, and increasing by 7% for using water at 3.5 l/m flow rate, as shown Fig. 9 (b).



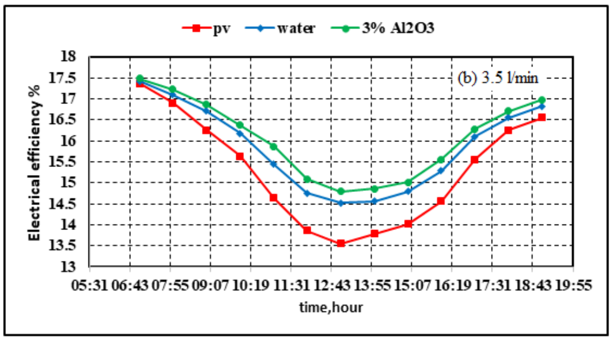
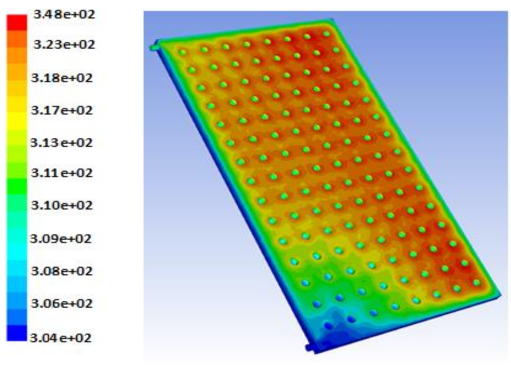
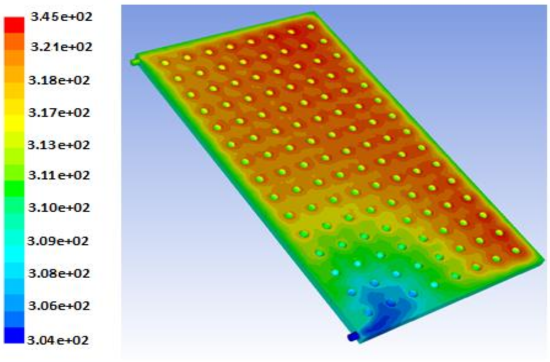


Fig. 9: Electrical efficiency of PV panel during daylight hours for Al_2O_3 Nanofluid at concentration 3%; (a) 1.5 l/min flow rate, and (b) 3.5l/min flow rate.

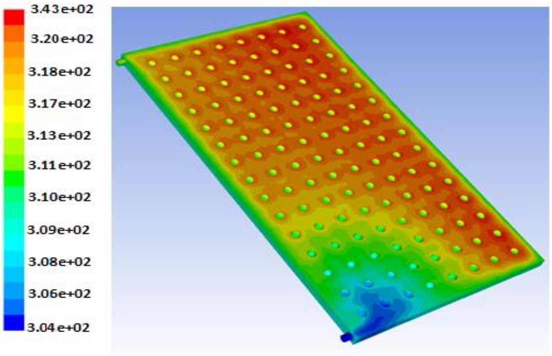
Numerically, Fig. 10 shows the contours of temperature distribution on the surface of the collector, at 1:00 pm when using Al_2O_3/water Nanofluid with different concentration 1%, 2% and 3% (v/v) and with 3.5 l/min flow rate. It notice a decrease in the surface temperature of the collector with an increase in the mixing ratio (concentration). While Fig. 11 shows the simulated results of average temperature of collector cover at different concentrations of Al_2O_3 Nanoparticles, it notice a decrease in the surface temperature of the collector by 5.1% when using a Nano liquid with a concentration 1% compared to its temperature when using water only, while it decreases by 6.2% and 7.8% when using concentrations 2% and 3%, respectively at flow rate 3.5 l/min. where it is low at the inlet of the collector due to the presence of a new coolant with a low temperature, and it rises relatively towards the outlet of the collector, where the temperature of the coolant increases when it absorbs heat from the collector cover, which is in contact with the back of the panel. Therefore, the collector's efficiency with using Al_2O_3 Nanofluid has been improved compared to the cooling by water.



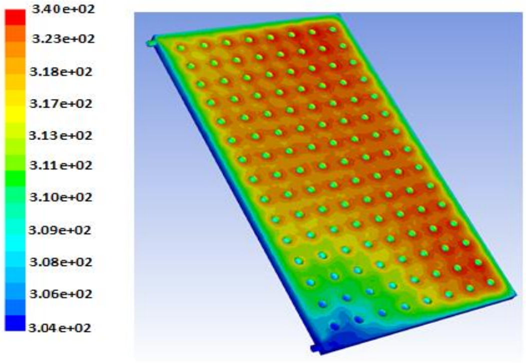
(a) Without Nano



(b) at 1% Al_2O_3



(c) at 2 % Al_2O_3



(d) at 3% Al_2O_3

Fig. 10: Contours of temperature distribution for collector with 3.5 l/min flow rate at 1:00 pm; (a) without Nano, (b) with 1% Al_2O_3, (c) with 2% Al_2O_3, (d) with 3% Al_2O_3.

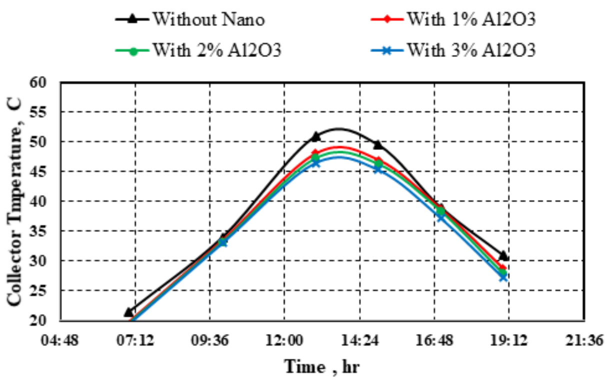


Fig. 11: Simulated results of average temperature of collector cover at different concentrations of Al_2O_3 Nanoparticles.

Fig. 12 shows the comparison of experimental results and numerical results of difference water temperature between the inlet and output at 1.5 and 3.5 l/min flow rates, where it found that the total difference (error) percentage between numerical and experimental were 11.6% and 8.7% for 1.5l/min and 3.5l/min, respectively.

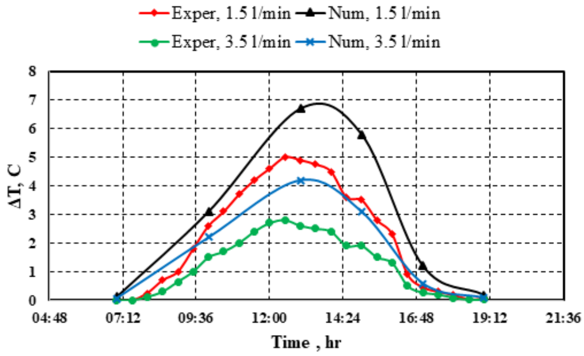


Fig. 12: Compared results of difference water temperature between the inlet and output at 1.5 and 3.5l/min.

5. Conclusions

In this work, new model of PV/T system was applied to cooling the PV panel after enhancing the flat collector performance by add Al_2O_3 Nanoparticles to water for increase heat transfer rates. The investigation of PV/T has been performed and evaluated using experimental and numerical methods. The main identified objectives of the current study have been achieved and the conclusions drawn from the results are summarized as below:

- Decrease in the collector temperature with an increase in the flow rates of the coolant. The highest temperature of the collector surface at 1:00 pm was 53℃ when 1.5 l/min, which decreased by 2.5% when using a flow rate of 2 l/min, and decreased to 5.6% and 9.4% when using 2.5 and 3.5 l/min, respectively.
- There is an increase in the electrical efficiency when using Al_2O_3/water Nanofluid as a coolant with mixing ratios of 3% (v/v) by 6.5% at flow rate 1.5l/min and it get an increasing in the efficiency was 10% at 3.5 l/min flow rate.

For the future works, carrying out experimental tests using porous media as a cover for the collector and studying their effect on the performance of the (PV/T) system.

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