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Performance evaluation of photovoltaic thermal hybrid system using copper oxide nanofluids

Govind S Menon*
Cochin University of Science and Technology, School of Engineering, CUSAT P.O, Cochin, Kerala, 682022, India, govindsmenoncusat@gmail.com, +919496823410
Jacob Elias
Cochin University of Science and Technology, School of Engineering, CUSAT P.O, Cochin, Kerala, 682022, India, jacobcusat@gmail.com
S Murali
ICAR-Central Institute of Fisheries Technology, Matsyapuri P.O., Cochin - 682 029, Kerala, India, murali.s@icar.gov.in
Manoj P Samuel
ICAR-Central Institute of Fisheries Technology, Matsyapuri P.O., Cochin - 682 029, Kerala, India, manoj.samuel@icar.gov.in

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* Corresponding Author

Abstract: The effect of cooling a flat plate collector integrated photovoltaic thermal (PVT) hybrid system with copper oxide nanofluid at different concentrations was compared with a non-cooled system. The Photovoltaic thermal hybrid system was designed with an efficient serpentine coil-based thermal absorber setup and was tested using various nanofluid concentrations. Copper oxide nanofluid empowered the system to attain significant electrical and thermal performance at higher concentrations. The electrical efficiency of the hybrid photovoltaic system increased by 17.61% at 0.05 M nanofluid concentration. The average value of the thermal efficiency increased by 71.17% at 0.05M nanofluid concentration. The thermal efficiency of the nanofluid-cooled module was found to be much better due to the improved heat absorption of nanoparticles. The solar panel surface temperature of the nanofluid-cooled system reduced from 68.4 °C (non-cooled system) to 44.74 °C (0.05 M) at noon. The highest efficiency values are achieved at a 0.05 M concentration of nanofluid.

Keywords: *Electrical efficiency, Hybrid, Molar concentration, Nanofluid, Photovoltaic, Thermal efficiency*

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Nomenclature

Abbreviations	*Descriptions*
M	Molar concentration
PV	Photovoltaic
PVT	Photovoltaic Thermal
V	Voltage
A	Ampere
°C	Degree Celsius

1. INTRODUCTION

A photovoltaic thermal system is a hybrid co-technology invention integrating a photovoltaic panel (PV) and thermal accumulator that simultaneously produces thermal and electrical energy. It is a hybrid system generating heat and electricity from a single unit with provision for excess solar panel heat removal [1], thereby increasing the system's overall efficiency [2]. In a photovoltaic thermal (PVT) device, the heat produced by the panel is transmitted to an aluminium plate and removed by convection using water flowing through the cooling pipes. The solar panel is finally cooled by the collector system, which extracts excess heat from the lower side of the panel [3]. The hybrid co-generation system reduces the temperature of the solar panels by combining a photovoltaic module with a thermal collector [4].

Compared to a standard PV module, the average cell temperature in a semi-transparent PV-thermal hybrid collector utilizing CuO, Al_2O_3, TiO_2, and water-based nanofluids was reduced by a considerable level according to Ref. [5]. Tiwari et al., [6] compared the nanofluid-cooled PVT system to the non-cooled PV system, panel temperature of the PVT system was reduced. According to Kim and Kim [7] the thermal efficiency of the solar photovoltaic thermal hybrid collector was increased when CuO, TiO_2, and Al_2O_3 nanofluids were used instead of water.

Typical fluids cannot achieve high heat exchange levels in the system due to their limited thermal conductivity. Adding small solid particles to common fluids will increase the heat conductivity and specific heat, which becomes the solution to those issues [8]. Nanofluids are two-phase structures, with one phase existing in a solid and the other in a liquid state. Nanoparticles are prepared by dispersing them in a base fluid and mixing them with a surfactant solution. The most popular method for the preparation of nanofluids is the two-step process as per Yu and Xie [9]. Nanoparticles are initially produced as dry powders. In the second processing stage, ultrasonic agitation stirs the material into a fluid for dispersion. As particle concentration increases, the flat tube collector's ability to transfer heat also increases. Copper oxide nanofluids were used in the study. Higher volume concentration contributed to the settling on the surface of heat transmission. The effect of nanoparticle size and the solid-liquid interface on nanofluid-specific heat capability is addressed by Sharma et al., [10]. Shakir et al., [11] experimented using different nanofluids in their experimental work to cool the PV panel and created a hybrid photovoltaic thermal solar collector (PVT). Shakir et al., [11] also found that utilizing Copper oxide (CuO) nanofluids resulted in greater electrical efficiency than using ZnO/nanofluids or TiO_2/nanofluids. According to a study by Ibrahim et al., [12], nanofluid cooling resulted in a considerable boost in electrical and thermal efficiency when compared to usage of base fluid alone.

Although the literature mentions solar thermal systems with different heat absorber configurations, additional research is needed on photovoltaic thermal modules without glazing. Very few researches compare the performance of non-cooled PV systems with PVT systems using Copper oxide nanofluids (CuO) at different concentrations. The main aim of the present study was to evaluate the cooling property of solar panels related to the reduction in temperature of solar panels and increase in efficiency. In order to evaluate an unglazed PVT system fabricated as a serpentine tube absorber system, a study was carried out using different concentrations of copper oxide nanofluids. This was done because copper nanofluids have high specific heat, which is a crucial parameter for heat transfer when compared to other nanofluids. The PVT hybrid system produces renewable energy in addition to thermal and electrical energy. In contrast to previous research, the experiment employed nanofluids with three different concentrations, and the results were compared with a non-cooled PV system. The solar panel surface temperature was significantly reduced. By comparing this study to earlier research, the PVT system's overall efficiency value is higher.

2. MATERIALS AND METHODS

2.1. Materials and Systems

Copper oxide nanoparticles, Cetyl Trimethyl Ammonium Bromide surfactant, and demineralized water (base fluid) were used in the present study. 5 g nanoparticles with a size less than 50 nm were used. Nanofluids of three different concentrations were prepared based on the molecular weight of the nanoparticle, the volume of the base fluid, the weight of the surfactant and was stirred using an ultrasonicator system.

The electrical components consisted of the photovoltaic module which is a polycrystalline panel with a maximum power of 100 W, the specification of batteries as 110 A- hr and 12 V, and a charge controller (6 A and 12 V). The PVT system consisted of a PV panel, an absorber (Aluminium) plate, casing, and heat-absorbing pipes (Copper) located underneath the PV module. The cross-section of components of the PVT system is given in Fig. 1.

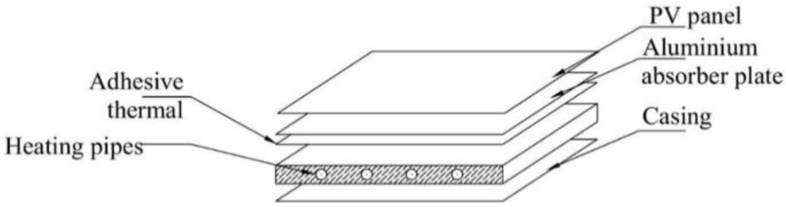

Figure 1. Cross-sectional view of the components of photovoltaic-thermal hybrid system.

2.2. Experimentation and Procedure

The photovoltaic thermal module is attached to a tank, a direct current pump, temperature sensors, and pipes. PVT system is placed at an angle based on the latitude of the location. A submersible DC pump is used to control the flow of the nanofluid, which is placed inside the liquid storage tank. Temperature sensors are installed in the tank to monitor the cooling medium's intake and output temperatures. The experiment was done for six months from January 2020 to June 2020 from morning till evening (10 AM-4 PM). The experiment was done at ICAR-CIFT, Cochin, India. The experimentation was done for the highest flow rate. The parameters measured during the experimentation are short-circuit current, open-circuit voltage, solar radiation, the surface temperature of solar panels, and the temperature at the nanofluid's input and exit. The component diagram of the PVT experimental system is displayed in Fig. 2. Fig. 3 displays the photovoltaic thermal hybrid system in the working condition. The experiment was carried out under identical atmospheric conditions. The experiment was initially done using a non-cooled PV system. Then the PVT system was fabricated and then testing was done on the PVT system. The nanofluid flow rate was calculated from the DC pump specification as 6 Lıter/min (maximum flow rate).

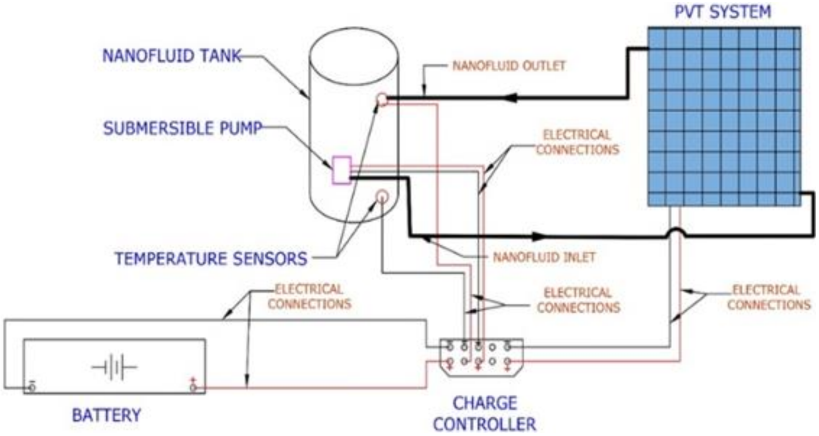

Figure 2. Component diagram of photovoltaic thermal hybrid experimental system.

Figure 3. Photograph of the photovoltaic thermal system in working condition.

2.3. Instrumentation

The instrumentation details are given in Table 1.

Table 1. Instrumentation details of the system.

Sl No.	Name of the instrument	Range	Accuracy
1	Pyranometer	0-1500 W/m^2	± 1%
2	DC Clamp meter	40-400 A & 400 mV-600 V	± (2% + 5) & ± (0.8% + 1)).
3	Infrared thermometer	30-260 ˚C	± 0.01 ˚C
4	Digital temperature controller	50-110 ˚C	± 0.01 ˚C
5	Submersible DC pump	6 L/min	

The nanofluid flow rate was calculated from DC pump specification as 6 L/min (maximum flow rate).

2.4. Efficiency Calculation

The electrical efficiency can be calculated from the following equation [13], where electrical efficiency is the ratio of output power to input power:

$$\eta_{ele} = (V_{OC}\ I_{SC}\ FF) / (W\ A) \tag{1}$$

W = Solar Radiation Irradiance in W/m^2, FF is the fill factor

Irradiance is the radiant flux received by a surface per unit area. A is the area of the solar panel. The area of a solar panel refers to the amount of surface area that the panel covers. The area of the panel is important because it determines how much energy the panel can produce.

A = *Solar Panel area* which is equivalent to 0.632 m^2 (*Length of the solar panel surface* × *Breadth of the solar panel surface* = 102 cm × 62 cm)

V_{OC} = *Open Circuit Voltage* (*V*) and I_{SC} = *Short Circuit Current* (A). *FF* is the *Fill Factor*.

$$\text{Fill factor} = 100\ (\text{Maximum Power}) / (V_{OC}\ I_{SC}) \tag{2}$$

The thermal efficiency can be calculated from the following equation [14], where;

$$\eta_{therm} = \frac{(m\ C\ (Tout - Tin))}{(A\ W)} \tag{3}$$

m = kg/s is the water mass flow rate and C (J/kgK) is the specific heat capacity of the fluid. (T_{out} -T_{in}) is the difference between temperature of hot water outlet and temperature of inlet water and A is the Area of the flat plate collector and W is the Solar irradiance as stated.

The overall efficiency can be calculated from the following equation [7] as follows:

$$\eta_{\ overall} = Thermal\ efficiency + Electrical\ efficiency \tag{4}$$

2.5. Uncertainty Analysis

Power measurement is given by,

$$P = E\ I \tag{5}$$

where E and I are measured as in Ref. [15]

$$E = V \pm 2\ V \tag{6}$$

where V is the open circuit voltage,

$$I = A \pm 0.2\ A \tag{7}$$

where A is the short circuit current.

Uncertainty in power (w_P) is given by [15];

$$wP = \sqrt{\left(\left(\frac{\partial R}{\partial\ x1}\right)\ w1\right)\left(\left(\frac{\partial\ R}{\partial\ x1}\right)\ w1\right) + \left(\left(\frac{\partial\ \ R}{\partial\ x2}\right)\ w2\right)\left(\left(\frac{\partial\ R}{\partial\ x2}\right)\ \ w2\right)} \tag{8}$$

$$wP = \sqrt{(\frac{\partial\ \ P}{\partial\ E}\ \ \mathrm{wE})^2\ + (\frac{\partial\ \ P}{\partial\ I}\ \ \mathrm{wI}\ )^2} \tag{9}$$

where, $\frac{\partial\ P}{\partial\ E} = I$ and $\frac{\partial\ P}{\partial\ I} = E$

Where V and I are the average values of open circuit voltage and short circuit current. w_E and w_I are the uncertainty intervals of voltage and current.

3. RESULT AND DISCUSSION

3.1. Electrical Efficiency

3.1.1. Fluctuations in the surface temperature of the photovoltaic panel

The hourly fluctuations in PV panel surface temperature for the nanofluid-cooled and non-cooled systems are depicted in Fig. 4. The findings indicated that the non-cooled PV system temperature ranged from 44.55 °C to 68.4 °C, with an average temperature of 57 °C. When comparing the nanofluid-cooled PVT system to the non-cooled PV system, a mean panel drop in temperature of 23.66 °C was achieved. These results are in concurrence with those described by Tiwari et al., [6]. Water and nanofluid cooling reduce the panel temperature by 10.0 °C and 20.0 °C, respectively, at noon. They also presumed that based on the cooling technique, a 32% decline in module temperature during the hot summer might enhance the PV module's electrical efficiency by 57%.

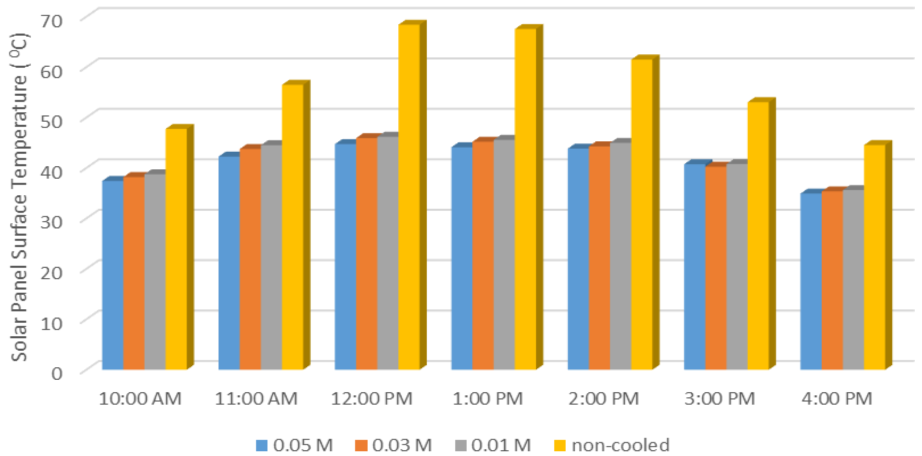

Figure 4. Changes in the surface temperature of photovoltaic panels on an hourly basis using nanofluid cooling and non-cooled system (photovoltaic system).

The experiment was done for six months from January 2020- June 2020 from morning till evening (10 AM-4 PM). The experiment was done at ICAR-CIFT, Cochin, India. At noon, when the highest irradiance was observed, the temperature of the solar panel was 44.74 °C (highest concentration: 0.05 M), 45.93 °C (medium concentration: 0.03 M), and 46.19 °C (lowest concentration: 0.01 M). The temperature of the non-cooled system (PV) at noon was 68.4 °C due to the highest energy photon absorption. An increase in temperature-related resistance in the panels was attributed to a reduction in voltage inside the electrical circuit. The mean temperature of the solar panel dropped from 42.34 °C (lowest concentration) to 41.86 °C (medium concentration) to 41.15 °C (highest concentration). Alzaabia et al., [16] observed an average value of the non-cooled system's panel surface temperature of 57.04 °C. The PVT module's temperature was cooled by 15% to 20%. The PV module temperature dropped because of nanofluid cooling. Compared to a standard opaque module, the average cell temperature in a semi-transparent PV-thermal hybrid collector utilizing CuO, Al_2O_3, TiO_2, and water-based nanofluids was reduced by 11.2 °C, 10.7 °C, 10.2 °C, and 9.4 °C, respectively [5].

3.1.2. Fluctuations in photovoltaic thermal panel short circuit current and open circuit voltage

Fig. 5 illustrates the changes in photovoltaic-thermal panel short circuit current over time in a cooled and non-cooled system and Fig. 6 shows the changes in open circuit voltage over time in a cooled and non-cooled system. The maximum assimilation of the photon energy causes a decline in the open-circuit voltage in response to an enhancement in short circuit current. The open-circuit voltage drops as the short circuit current rises. The open circuit voltage increased as the panel temperature decreased, reaching a maximum of 22.05 V (0.05 M concentration). At noon, the open circuit voltage varied from 21.03 V (0.05 M concentration) to 20.73 V (0.03 M concentration) to 20.43 V (0.01 M concentration) to 18.26 V (non-cooled system), while the short circuit current varied from 5.9 A (0.05 M) to 5.79 A (0.03 M) to 5.62 A (0.01 M) to 5.2 A (non-cooled system).

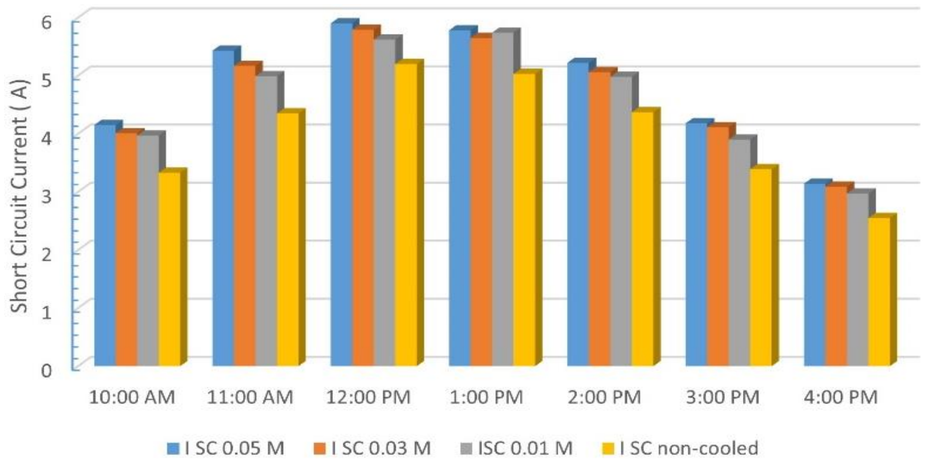

Figure 5. Fluctuations in photovoltaic thermal hybrid panel short circuit current over time in a cooled and non-cooled system.

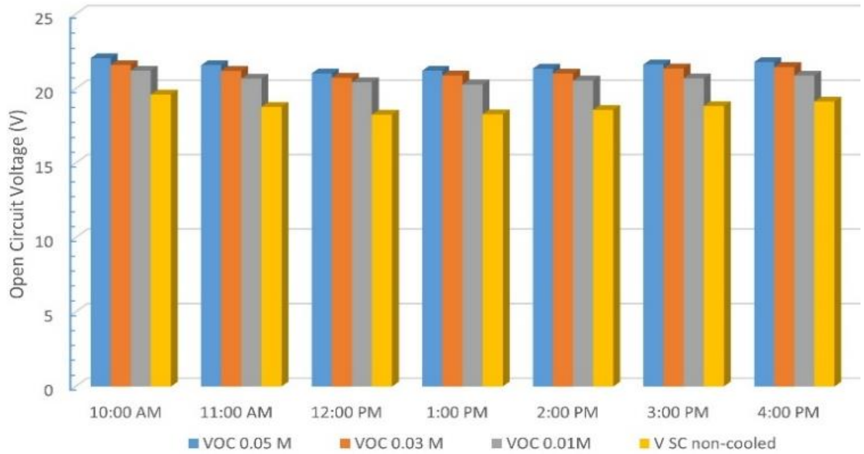

Figure 6. Fluctuations in photovoltaic thermal hybrid panel-open circuit voltage over time in a cooled and non-cooled system.

3.1.3. Changes in electrical efficiency with time

The deviation in electrical efficiency with time is shown in Fig. 7. In the daytime, the electrical efficiency (0.05 M) ranged from 16.4% to 18.85%, averaging 17.61% efficiency. The average value of electrical efficiency in a day while considering the various concentrations is 17.61% (0.05 M), 16.97% (0.03 M), and 16.31% (0.01 M). The system's electrical efficiency improved from 12.98% (non-cooled/non-cooled system) to 17.61% (highest concentration). Due to the maximal absorption of energy photons, a drop in open circuit voltage results from a rise in short circuit current, as shown in the figure. This observation agrees with that of Abdallah et al., [17], who opined that as concentration levels rise, electrical efficiency also rises. Elayarani and Mathiazhagan [18] reported that PV panel efficiency is between 12%, 14%, and 17% depending on the volume concentration of nanofluids, which include 0.1%, 0.3%, and 0.5%. Shakir et al., [11] also found that utilizing 11.8% Copper oxide (CuO) nanofluids resulted in greater electrical efficiency than using ZnO/nanofluids (11.6%) or TiO_2/nanofluids (11.5%).

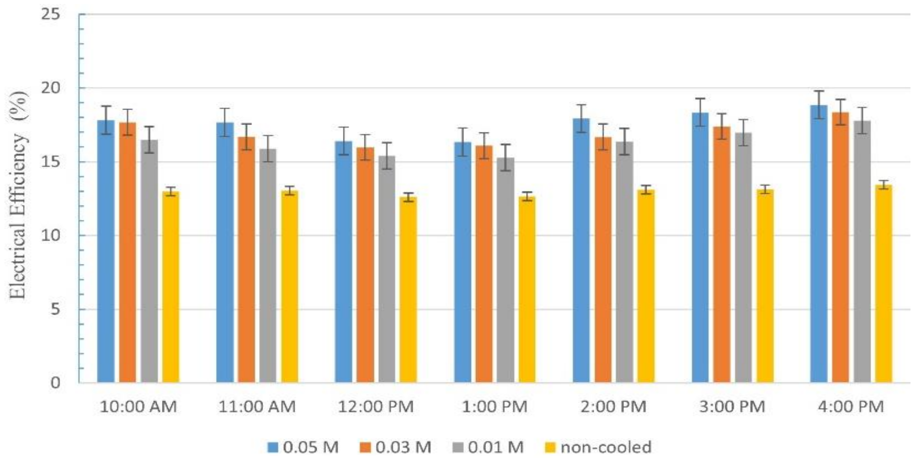

Figure 7. Fluctuations in electrical efficiency with time.

In this work, a serpentine sheet and tube-type heat extractor was connected an uncovered PV module with a cooling fluid. Usage of nanofluid to cool the system resulted in a decrease of 23.7 ^oC in the panel temperature. The electrical efficiency of the non-cooled system at noon was enhanced to 3.8% by using nanofluids of 0.05 M in the PVT system. During the day, the non-cooled system's average electrical efficiency was 12.98%, but it varied from 12.6% to 13.42% throughout the day. Jidesh et al., [5] revealed that the electrical efficiency of CuO, TiO_2, and Al_2O_3-based SPV-THC nanofluids, as well as water, was higher than that of traditional solar modules by 11.2%, 9.1%, 7.3%, and 5.9%, respectively. Recent research utilized water as the cooling medium and a nanofluid containing Copper oxide to minimize overheating of the PV panels and enhance electrical power output. During nanofluid cooling (for the highest concentration of 0.05 M), the panel temperature was between 34.93 ^oC and 44.74 ^oC at noontime (noon), and then the temperature reduced from 46.19 ^oC (0.01M) to 44.74 ^oC (0.05M) in the evening. The temperature of the solar panel at noon dropped from 68.4 ^oC (0.05 M concentration) to 44.74 ^oC (non-cooled system). The studies by Kazem et al., [19] on the effect of Copper oxide revealed that proper cooling leads to an improvement in electrical efficiency when compared to a traditional PV module, and this increase can be up to 25.3%. Similar outcomes were also attained by Lari and Sabin [20], when a hybrid PVT system cooled with silver nanofluid was used. The mean panel temperature was reduced by 22 ^oC. Consequently, the temperature of the nanofluid-cooled photovoltaic device dropped from 62.3 ^oC to 32.5 ^oC, leading to a 27% increase in electrical efficiency.

In the current studies, the PVT panel's surface temperature rose from 34.93 ^oC to 44.74 ^oC for the highest concentration of nanofluid (0.05 M), with an average surface temperature of 41 ^oC. For 0.01M nanofluid concentration, the panel temperature ranged from 35.62 ^oC to 46.19 ^oC, with a mean panel surface temperature of 42.34 ^oC. The observations conform with those of Kazem et al., [21]. The study found that utilizing various concentrations of nanofluid for cooling improved the electrical efficiency of the PVT system. The average electrical efficiency of the PVT system increased by 7.97% for a 0.05 M concentration compared to 0.01 M, by 3.77% compared to 0.03 M, and by 35.67% compared to the non-cooled system. In a study by Ibrahim et al., [12] it was found that non-cooled PVT systems had an average electrical efficiency of 12.15% and reached a maximum panel temperature of 75.5 °C during noon. The electrical and thermal efficiency of the nanofluids increased by 6.76% and 39.6%, respectively, compared to the usage of the base fluid alone because of its more significant cooling effect.

3.2. Thermal Efficiency of the PVT System

3.2.1. Nanofluid outlet and inlet temperatures

Fig. 8 shows the nanofluid's inlet and outlet temperature in the photovoltaic-thermal hybrid system. The temperature of the nanofluid inlet and outlet steadily elevated from morning to evening throughout the experiment. The temperature at the nanofluid outlet was higher than the inlet temperature. During the daytime, the panel temperature increases due to increased solar radiation, allowing the circulating nanofluid to collect and retain as much heat as possible.

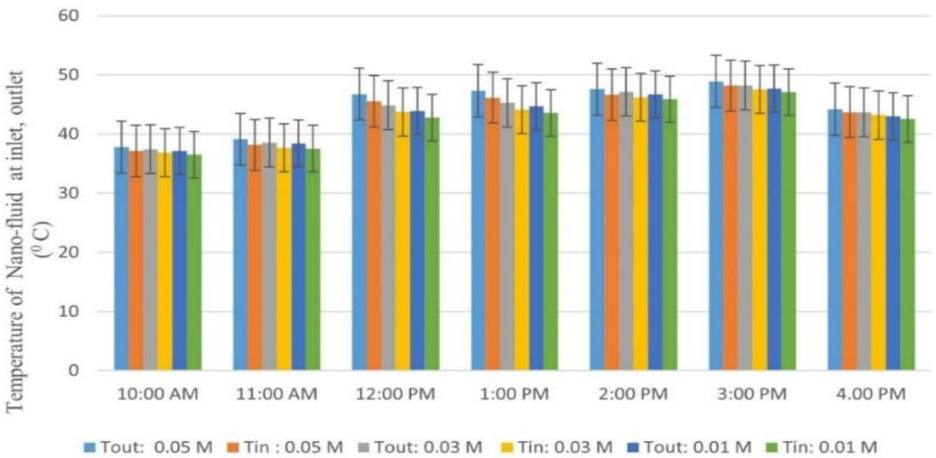

Figure 8. Fluctuations in the nanofluid inlet and outlet temperatures on an hourly basis.

The mean temperature of the nanofluid at the PVT system output throughout the day varied from 44.52 ºC (0.05 M) to 43.6 ºC (0.03 M) to 43.08 ºC (0.01 M), respectively. The mean value of the temperature of nanofluid at the input of the photovoltaic-thermal system throughout the day fluctuated from 43.65 ºC (0.05 M) to 42.74 ºC (0.03 M) to 42.26 ºC (0.01 M), respectively.

3.2.2. PVT panel thermal efficiency on an hourly basis

Fig. 9 shows the fluctuations in the PVT panel thermal efficiency on an hourly basis. The average value of the thermal efficiency varied from 71.17% (highest concentration), 69.20% (medium concentration), and 67.47% (lowest concentration). For 0.05 M concentration, the thermal efficiency varied from 62.01% to 78.41% from morning till evening. Compared to lesser concentrations, the thermal efficiency results reported for the highest concentration of nanofluid cooling were much higher. A higher thermal efficiency implies that more heat energy is stored as sensible heat in the nanofluid. The maximum heat absorption caused by the modified thermal and physical characteristics of the suspended nanoparticles in the solution is responsible for the increased thermal output seen in nanofluid cooling.

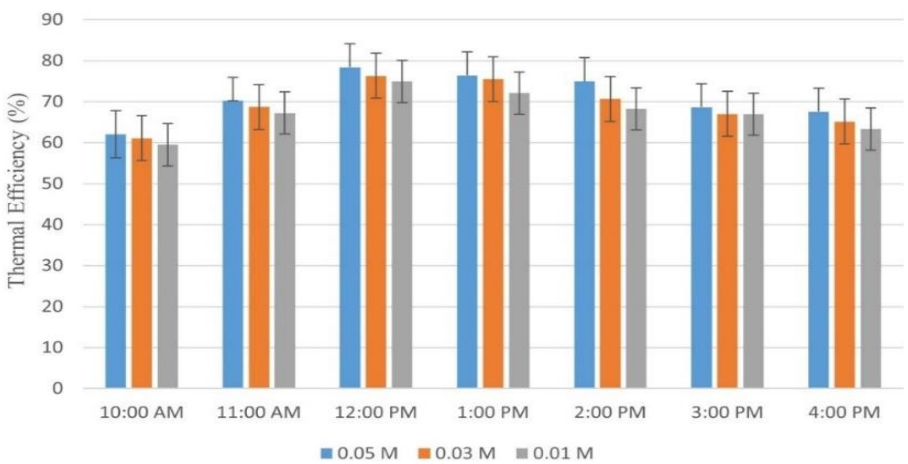

Figure 9. Fluctuations in the photovoltaic thermal hybrid panel thermal efficiency on an hourly basis.

During the cooling of the photovoltaic-thermal system using nanofluid at 0.05 M, the inlet and outlet temperatures of the nanofluid fluctuated from 37.8 ºC to 48.9 ºC for the outlet and 37.15 ºC to 48.2 ºC, respectively. The higher outlet temperature shows that the heat energy stored by the nanofluid is sensible heat. The maximum heat absorption caused by the modified thermal and physical characteristics of the suspended nanoparticles in the solution is responsible for the increased thermal output observed in nanofluid cooling. At noon time, maximum thermal efficiency was obtained, and it varied from 78.41% (highest concentration), 76.32% (medium concentration), and 74.95% (lowest concentration). Thermal efficiency has increased because of nanofluid cooling. Dissolved nanoparticles with modified physical and thermal characteristics absorb the maximum heat, resulting in increased thermal output for nanofluid cooling. Kim and Kim [3] reported that the sheet-and-tube PVT collector has a thermal efficiency of 66%. The current study's results align with those of Zamen et al., [22] who found a link between efficiency and nanofluid concentration (between 0 and 0.5%). The thermal efficiency of Aluminum oxide nanofluids is enhanced by the flow rate. The PVT thermal performance was 76.5% and 74.8% for varying concentrations at a maximum coolant flow rate. According to Kim and Kim [7] the thermal efficiency of the solar photovoltaic thermal hybrid collector was increased by 42.6%, 34.8%, and 19.7%, respectively, when CuO, TiO_2, and Al_2O_3 nanofluids were used instead of water. Similarly, Yousafi et al., [23] found that nanofluid-cooled PVT systems exhibited higher thermal efficiency compared to Aluminum oxide nanofluid-cooled systems. In the current studies for 0.05 M concentration, the mean value of thermal efficiency of the PVT system increased (percentage increase) by 5.48% (as compared to the lowest concentration) and increased by 2.84% (as compared to the medium concentration).

3.3. Overall Efficiency

Fig. 10 exhibits the hourly fluctuations in the overall efficiency of the photovoltaic-thermal system when cooled by Copper oxide nanofluid at various concentrations. The overall efficiency of the nanofluid system for a 0.05 M concentration ranged from 79.82% to 94.81%, with a mean efficiency of 88.25%. Fig. 10 shows that the overall efficiency improved significantly over the first two hours, reaching a maximum efficiency of 94.81% at noon for the nanofluid with the highest concentration. This is attributed to the increased solar panel temperatures and higher sun radiation between 10:00 a.m. and noon, thus elevating the photovoltaic panel temperature. So, the PVT system could utilize the maximum amount of thermal energy that was accessible. The current study results are in agreement with those of Al-Waeli et al., [24], where a Silicon carbide nanofluid-based photovoltaic thermal system was studied and achieved an overall efficiency of 88.9%.

The overall efficiency gradually reduced to 86.42% for nanofluids of 0.05M concentration at 4 p.m. The mean value of the PVT system's overall efficiency for three different concentrations varied from 88.25% (0.05 M), 86.18% (0.03 M), and 83.78% (0.01 M). The overall efficiency values ranged from 94.81%, 92.29%, and 90.35% for the three concentrations (at noon time). The PVT system's excellent overall efficiency was attained using a high-concentration nanofluid since its maximal heat absorption capacity is due to its increased thermal conductivity.

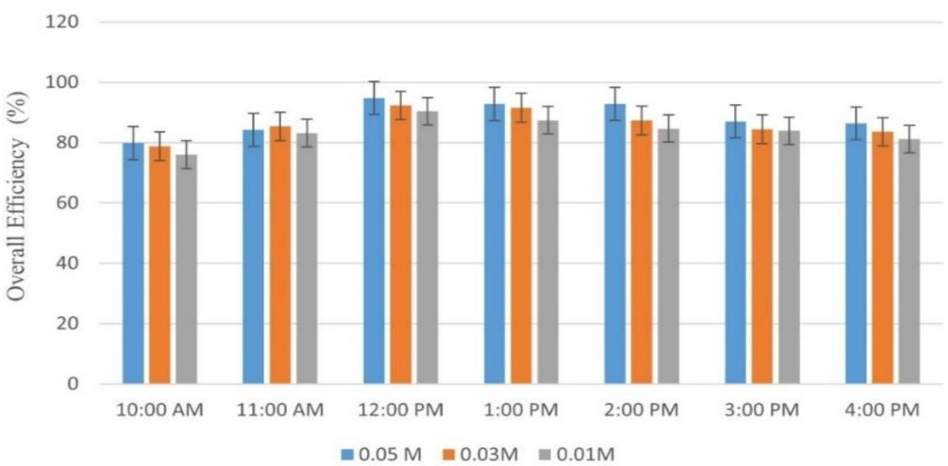

Figure 10. Variation of the overall efficiency measured on an hourly basis from the photovoltaic thermal system.

The overall energy performance of the collectors can be obtained by combining the typical thermal and electrical efficiency data [7]. The results agree with those of Alktranee et al., [25] wherein for the non-cooled PV module, the PVT system's electrical output and overall efficiency rose by 77.5% and 58.2%, respectively, at an increased volume concentration of 0.3%.

The findings indicated that the usage of different concentrations of nanofluid to cool the PVT system increased the overall efficiency (percentage increase) by 5.33% (0.05 M) (as compared to 0.01 M concentration) and increased by 2.40% (as compared to 0.03 M concentration). The average values of the various parameters of the experimentation are mentioned in Table 2.

Table 2. Resulting values of various parameters

System	Solar Panel Surface Temperature (^{0} C)	Open Circuit Voltage (V)	Short Circuit Current (A)	Electrical Efficiency (%)	Thermal Efficiency (%)	Overall Efficiency (%)
PVT-0.05 M	41.15	21.51	4.82	17.61	71.17	88.25
PVT-0.03 M	41.86	21.17	4.69	16.97	69.20	86.18
PVT-0.01 M	42.34	20.67	4.59	16.31	67.47	83.78
PV-Non cooled	57.04	18.78	4.03	12.98		

3.4. Uncertainty Analysis

At highest concentration of nanofluid, the average value of maximum power: P_{max}= 118.02 W (obtained by substituting open circuit current and short circuit voltage values from the experimentation in Eq. 5). The average value of minimum power: P_{min}= 90.136 W (substituting the parameter values in Eq. 5). The uncertainty in power w_P = ±10.555 W (substituting values of current and voltage and uncertainty intervals, w_E (2) and wI (0.2) in Eq. 9).

4. CONCLUSION

In the present work, the electrical and thermal efficiency of a serpentine, coil-sheet, unglazed flat plate photovoltaic thermal hybrid collector system was assessed utilizing nanofluids of Copper oxide at three different concentrations in comparison with a non-cooled PV system. Very few researches compare the performance of non-cooled PV systems with PVT systems using Copper oxide nanofluids at different concentrations. In order to evaluate an unglazed PVT system composed of a serpentine tube absorber system, a study was carried out using different concentrations of Copper oxide nanofluids. This was done because Copper nanofluids have a high specific heat, which is a crucial parameter for heat transfer when compared to other nanofluids. The PVT hybrid system produce renewable energy in addition to thermal and electrical energy. The solar panel surface temperature was significantly reduced, and the PVT system's overall efficiency value in this study is quite high when compared to previous references.

The findings revealed that by cooling the photovoltaic-thermal system using nanofluid, the efficiency of the system could be significantly enhanced. The average value of the thermal efficiency increased from 67.47% (0.01 M) to 69.20% (0.03 M) to 71.17% (0.05 M). For the highest concentration, the average value of thermal efficiency of the PVT system improved (percentage increase) by 5.48% (as compared to the lowest concentration) and increased by 2.84% (as compared to the medium concentration). The system's electrical efficiency improved from 12.98% (non-cooled system) to 17.61% (0.05M concentration). The electrical efficiency of the PVT system increased from 16.31% (0.01 M) to 16.97% (0.03 M) to 17.61% (0.05 M). For a 0.05 M concentration, the mean electrical efficiency of the PVT system improved (percentage increase) by 7.97% (in contrast to a 0.01 M concentration). It increased by 3.77% (as compared to a 0.03 M concentration) and by 35.67% (in a non-cooled system).

A temperature reduction of 23.66 ºC was obtained for nanofluid cooling at a 0.05 M concentration. The average temperature of the solar panel dropped from 42.34 ºC (0.01 M) to 41.86 ºC (0.03 M) to 41.15

ºC (0.05 M). The average value of the thermal efficiency varied from 71.17% (0.05 M), 69.20% (0.03 M), and 67.47% (0.01 M). The mean value of the photovoltaic thermal system- overall efficiency for three different concentrations varied from 88.25% (0.05 M), 86.18% (0.03 M), and 83.78% (0.01 M). At a 0.05 M nanofluid concentration, the highest efficiency values are obtained.

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