Experimental Studies on Water-Based Al$_2$O$_3$ Nanofluid to Enhance the Performance of the Hybrid Collector

B. Srimanickam,$^1$ M. Elangovan,$^1$ Sachin Salunkhe,$^1$ Emad Abouel Nasr,$^2$
H. M. A. Hussein,$^{3,4}$ and Ragavanantham Shanmugam$^5$

$^1$Department of Mechanical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai 600062, India
$^2$Industrial Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia
$^3$Mechanical Engineering Department, Faculty of Engineering and Technology, Future University in Egypt, New Cairo 11835, Egypt
$^4$Mechanical Engineering Department, Faculty of Engineering, Helwan University, Cairo 11732, Egypt
$^5$Advanced Manufacturing Engineering Technology, School of Engineering, Mathematics and Technology, Navajo Technical University, USA

Correspondence should be addressed to Sachin Salunkhe; drsalunkhesachin@veltech.edu.in

Received 10 February 2022; Revised 10 May 2022; Accepted 14 May 2022; Published 13 July 2022

Copyright © 2022 B. Srimanickam et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Many research and significant worldwide efforts have been made to combat climate change. The purpose of this research was to maximize the productivity of a flat-plate hybrid collector with two kinds of cooling medium, namely water and water-based Al$_2$O$_3$ nanofluid. Effects of single-volume concentration (0.1%) of Al$_2$O$_3$ nanoparticles and four types of volume flow rates such as 0.5, 1.0, 1.5, and 2.0 litres/minute (LPM) were also examined which found that the best performance is achieved with 2.0 LPM. The experimental results found that the hybrid collector significantly depends on solar radiation, the surface geometry of the cooling channels, and the volume flow rates of the working medium. In addition, the performance of the hybrid collector improved with increasing volume flow rate. Maximum glazing surface temperature has been attained by water collector was 68.2°C, whereas water-based nanofluid has achieved its glazing surface temperature 63.8°C. As a result, the life of the solar panel has been increased significantly. This occurred because an increase in the volume flow rate increased the turbulence of the working medium, thus resulting in better performance of the hybrid collector. Besides, the results also showed that the distribution of working medium in the channel had played a major role in the heat transfer rate. The thermal efficiency was found to vary from 13.9% to 60.7% for all the four-volume flow rates of water. Similarly, thermal efficiency was attained from 16.8% to 79.4% for all the four-volume flow rates of Al$_2$O$_3$ nanofluid.

1. Introduction

Solar energy is a sustainable and green energy source, and solar power application has grown globally due to the desire to reduce carbon emissions [1]. Solar power generation via solar cells, on the other hand, has a weak power conversion efficiency, and electrical power is diminished as a result of electric performance owing to cell temperature increase [2]. A photovoltaic thermal (PVT) system composed of a photovoltaic (PV) module and a solar thermal collector has been presented as a substitute, which flows fluid to reduce the temperature of the PV cell while simultaneously producing low-grade heat and electrical power [3]. When compared to installing the PV module and the solar thermal collector individually, combining different systems offers the benefit of minimizing the installation space [4]. Much research on PVT technology has been done since the 1970s, and significant worldwide breakthroughs have resulted from these investigations [5]. The daily and yearly energy yields of the regular PV module and the PVT collector were compared by Aste et al. [6]. This meant that, while the PVT system’s electricity output was somewhat lower than that of a typical
PV module, the PVT technology had a high total efficiency because it also produced thermal energy. Many aspects connected to the collection of heat and electrical energy impact the overall performance of the PVT system [7]. The essential to building a solar collector’s cooling system is to regulate the flow rate of the heat transfer fluid, which can directly impact the operating temperature and overall system performance [8]. Bambrook and Sproul [9] altered the mass airflow rate through the PVT system, indicating improved thermal and electrical performances with increased frequency. Na et al. [10] studied the performance of a conical solar concentrator collector based on the flow rate of the coolants. According to the data, thermal efficiency improves with increased velocity but falls when the optimal flow rate is surpassed. Nassan et al. [11] found that nanofluids (CuO/water, Al2O3/water) have improved thermal characteristics. It is also shown that at the same concentration, the thermal efficiency of CuO/water was greater than that of Al2O3/water. Numerous studies were conducted to apply nanofluids to various fields by improving conventional heat transfer fluids [12]. Nanofluids are usually made of metal and oxide nanoparticles nanostructures, and many studies have been conducted to apply them to various fields by improving the thermal conductivity of heat exchangers.

The thermal efficiency of an evacuated tubular solar collector with nanofluid (CuO/water) was investigated by Lu et al. [13]. The application of the nanofluid improved the value of the heat transfer coefficient somewhat, increasing heat flow. They observed that the value of the heat transfer coefficient varied with nanoparticle concentration, with the bulk accumulation equivalent to the best heat transfer enhancement being 1.2 percent. Kang et al. [14] investigated the economics of single glazing flat collectors and U-tube solar collectors utilizing nanofluid (Al2O3/water). When compared to water as the working fluid, flat-plate and U-tube solar collectors using nanofluid with a nanoparticle size of 20 nm and a content of 1.0 vol percent exhibited 14.8 percent and 10.7 percent greater thermal efficiency values, respectively. Karami and Rahimi [15] investigated the cooling performance of PV module channels using the Boehmite nanofluid. The findings indicate that the nanofluid outperformed water in cooling performance, with the best electrical efficiency at 0.1 wt percent concentration. Al-Waeli et al. [16] investigated the PVT system employing nanofluid (SiC/water). Thermal properties of the nanofluid at a flow rate of 3 wt percent were enhanced to 8.2 percent when the temperature ranges from 25°C to 60°C. The overall capacity of the PVT system was around 88.9 percent, which was higher compared to the PV system. Al-Shamani et al. [17] investigated a PVT collector using several nanofluids (SiO2, TiO2, and SiC). The maximum thermal and electrical efficiencies while using a SiC nanofluid were 81.73 percent and 13.52 percent, respectively. Much research on the heat transfer properties of nanofluids has been conducted; however, the accuracy with which the trend of heat transfer enhancement can be predicted is limited. There are also several uncertainties in the use of nanofluids, necessitating more theoretical and experimental research [18]. Al-Shamani et al. [17] experimented with several nanofluids at different flow rates. According to the results, SiC had the highest electrical performance of roughly 13.52 percent and the highest total efficiency of 78.24 percent.
carried out exploratory work in a hybrid system using water nanofluid. It was discovered that total enactment and power generation increased by 3.13 percent and 52.4 percent, respectively. The authors also demonstrated that SiO₂ improved total performance and power output by 3.29 percent and 43.36 percent, respectively. Al-Waeli et al. [20] used collectors to explore three types of water-based nanofluids. In which water-based nanofluid collectors had attained better overall performances than water PVT collectors. Sardarabadi et al. [21] experimented with PVT systems utilizing water as a base fluid and SiO₂ nanofluid at varied concentrations. They determined that overall performance was achieved at 3.6 percent for 1 wt percent and 7.9 percent for 3 wt percent compared to PVT water alone. Ghadiri et al. [22] employed an indoor PVT system to analyze different mixes of water and ferrofluid. The overall efficiency was 45 percent as compared to a hybrid system. Sardarabadi and Passandideh-Fard [23] used deionized water to dissolve three types of nanoparticles (Al₂O₃, TiO₂, and ZnO). Chol and Estman [24] pioneered nanofluids as a cooling system in PVT systems, which aroused considerable attention due to their superior thermophysical properties compared to normal fluids. Nanofluids are solid-liquid synthesized nanoparticles in companies with sizes generally ranging from 1 to 100 nm floating in water [25].

According to the cited literature, many of the articles presented thermal and electrical performance along with fewer volume flow rates in hybrid collector technology with meagre negligence. In this research article, four types of volume flow rates were investigated, as well as a comparative study on various parameters such as solar radiation, inlet and outlet water temperature differences, and water and nanofluid behaviour and characteristics. Furthermore, the goal of this study is to improve the efficiency of a hybrid collector by using two distinct types of cooling medium, namely water and water-based Al₂O₃ nanofluid, as the working fluid with four different volume flow rates. The working fluid is critical in increasing the efficiency of the Al₂O₃ nanoparticles.

2. Experimental Details

2.1. Description of PVT Collector. The PVT collector comprises a solar panel, a copper tube, a manual data recorder, a pump, a storage tank, a nanofluid tank, and other components. The suggested approach was built, produced, and
tested to determine the efficiency of a nanofluid PVT system, which was then compared to a liquid PVT system. Water and nanofluids were used as coolants or working fluids with varying flow rates in the PVT system, and varied concentrations and flow rates were tested in the PVT collector. The intended study was to be conducted at Avadi, near Chennai. Figure 1 shows an experimental photograph of a PVT collector.

The PVT collector features a multisilicon glass panel with dimensions \((l \times b \times h)\) of 164 cm \(\times\) 99.2 cm \(\times\) 0.35 cm. Because of the platform’s insulating effect, a 0.04 cm copper sheet was used for heat absorption on the back of the solar panel. Furthermore, the copper tube with diameters of 1.0 cm outer and 0.8 cm inner diameters is used as a heat absorber from the solar panel’s backside. Table 1 shows the performance of the solar panel under the standard test conditions. The photovoltaic thermal collector was installed at a 13° angle to the southern hemisphere. Every day, between 8 a.m. and 5 p.m., fifteen-minute readings were obtained for all weather conditions and output power. Figure 2 depicts the copper tube on the Tedlar side of the solar panel. Figure 3 depicts the heat transmission processes in a cross-sectional view of the channel.

2.2. Details of Nanofluid. Aluminium oxide is utilised in this research investigation. All of the chemicals employed in the study were of analytical quality and were not further refined. In this work, the nanofluids were created using the two-step approach, which disperses nanoparticles in a fluid. According to Li et al. [26], the thermal conductivity of nanofluids diminishes beyond a particular concentration of surfactant. As a result, the thermal conductivity of nanofluids with varying surfactant concentrations is examined. Figure 4 depicts the laboratory synthesis of nanoparticles and nanofluid. Further, Figure 5 shows an SEM picture of an \(\text{Al}_2\text{O}_3\) nanoparticle.

3. Analytical Methodology

3.1. Thermal Performance. The collected heat was computed using an equation to determine the thermal efficiency of the PVT collector (1).

The equation of mass flow rate of air is expressed by

\[ \dot{m} = \rho A \frac{\text{mod}}{v}, \]  

\[ A = \text{mod} \times 1.012, \]  

\[ \dot{Q}_t = \dot{m} C_p (T_o - T_i). \]  

The primary criteria utilised to define thermal efficiency are collected heat, collector area, and solar radiation in the following equations.

\[ \eta_{th} = \frac{\dot{Q}_t}{A_{\text{mod}} I_a}, \]  

\[ \eta_{th} = \eta_o - \alpha \frac{(T_i - T_o)}{I_a}, \]  

where \(\dot{Q}_t\) is heat energy generation in kJ, \(A_{\text{mod}}\) is the length and breadth of the module, \(I_a\) is solar radiation of the particular location, \(\eta_o\) is the collector performance when the transformation between the temperature of input \((T_i)\) and the temperature of air \((T_o)\) is considered an ambient air temperature, and \(\alpha\) is the heat loss coefficient.

4. Results and Discussions

This experimental investigation used water and water-based \(\text{Al}_2\text{O}_3\) nanofluid at four different flow rates, namely, 0.5 LPM, 1.0 LPM, 1.5 LPM, and 2.0 LPM. Measurements were taken every 30 seconds between 8:00 and 17:00 on an average day of the experimental day. The temperature gradient panels grew throughout the day as sun irradiation increased, according to the findings.

4.1. Weather Data Analysis. The weather information comprises the ambient temperature, wind speed, and solar radiation of the average days of the experimental day. Moreover, this research was carried out throughout the months between May and July of 2021. Table 2 shows the range of solar radiation and wind speed on the experimental days.
Table 3 also shows the temperature ranges of ambient, input, and output temperatures.

The average experimental day of meteorological data is depicted in Figure 6. The solar radiation, wind speed, and ambient temperature appear to exist a canopy structure from 8 hrs to 17 hrs, as depicted in Figure 6. It gives real-world data from a specific location where the system’s projected performance, such as energy gain, the temperature differential between intake and output, thermal efficiency, and other relevant metrics, may be determined. The diurnal average incoming solar radiation dispersion for the experiment period is a megaphone shape, with the largest value at noon being 937.07 W/m², and the smallest value was 72.18 W/m² at 7 a.m. 218.58 W/m² at 5 p.m., according to this graph. The average daily air temperature climbs from 29.36°C at 9:00 a.m. to 34.23°C at 5:00 p.m. Similar findings have been absorbed from other journals such as [27, 28].

4.2. Performance Analysis of Water as a Coolant in Hybrid Collector. Each coolant has upsides and downsides; water is utilised as a coolant in this study due to its heat-carrying capability and natural availability. Water as a coolant in a hybrid collector is investigated in terms of energy obtained by the system, difference in intake and exit temperature of the channel and mass flow rate of the fluid, specific heat capacity of the fluid, solar intensity, and panel area.
Figure 7 displays the energy obtained by the system for each of the four water flow rates. The difference in air temperature between the working fluid channel’s output and input is directly proportional to the amount of heat generated ($Q_u$). The mass flow rate of the fluid ($\dot{m}$), the specific heat of fluid ($C_p$), and the difference in exit and intake air temperature ($T$) were used to calculate heat energy generation. Equation (3) aided in determining the energy gained by the system at each of the four flow rates. The energy gained by the system climbed as the flow rate climbed from 0.5 LPM to 2.0 LPM in the experimental study. Furthermore, the difference in fluid intake and exit temperatures arose when flow rates grew, increasing thermal efficiency.

![Figure 8: Difference in temperature of all the four flow rates of water.](image)

![Figure 9: Thermal efficiency of all the four flow rates of water.](image)

**Table 4: Various performances of the PVT collector with water as a cooling medium.**

<table>
<thead>
<tr>
<th>Flow rate (litres per minute)</th>
<th>Energy gained (J)</th>
<th>$\Delta T$ (°C)</th>
<th>Thermal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 LPM</td>
<td>221.9</td>
<td>6.4</td>
<td>13.9</td>
</tr>
<tr>
<td>1.0 LPM</td>
<td>467.9</td>
<td>6.7</td>
<td>29.2</td>
</tr>
<tr>
<td>1.5 LPM</td>
<td>708.6</td>
<td>6.8</td>
<td>44.3</td>
</tr>
<tr>
<td>2.0 LPM</td>
<td>971.5</td>
<td>7.1</td>
<td>60.7</td>
</tr>
</tbody>
</table>
According to the above animation, the system gains 145.5 J, 306.7 J, 464.4 J, and 636.8 J at flow rates of 0.5, 1.0, 1.5, and 2.0 LPM. Similar results have been reported in other journals, such as [29, 30].

Figure 8 depicts the difference in temperature of all the four flow rates of water. For all four flow rates, the fluid inlet temperature was linearly followed by the ambient air temperature. The difference in $T$ (difference in outlet and inlet air temperatures) was caused by the shape of the channels and the fluid’s mass flow rate. As flow rates go up, temperature differences elevate, resulting in better system performance at high fluid flow rates. The accompanying graphic shows that from 8 a.m. to 11 a.m., as well as 3 p.m. to 5 p.m., all flow rates are linearly traversed, whereas those from 11 a.m. to 3 p.m. were accomplished spectacularly. The greatest temperature difference reached in this research investigation was determined to be 6.4°C, 6.7°C, 6.8°C, and 7.0°C for flow rates of 0.5, 1.0, 1.5, and 2.0 LPM, respectively.

Figure 9 depicts the thermal efficiency of all the four flow rates of water. Equations (1)–(5) can be assisted to produce the thermal efficiency of the hybrid collector. As the working fluid temperature increased after receiving solar intensity for a longer time duration of the experimental day, the heat loss to the ambient air was also greatly increased. Thermal efficiency ($\eta_{th}$) was determined based on the measured
parameters such as difference in outlet and inlet air temperature ($\Delta T$), mass flow rate of air ($m$), specific heat of the fluid ($C_p$), area of the solar panel ($A_{mod}$), and solar radiation ($I_a$). The thermal performance increased with an increase in fluid flow rate from 0.5 LPM to 2.0 LPM. Various performances of the hybrid collector with water as a cooling medium are shown in Table 4, as per the above illustration that maximum thermal efficiency was attained at 13.9%, 29.2%, 44.3%, and 60.7% for the flow rates of water 0.5, 1.0, 1.5, and 2.0 LPM, respectively. Similar performance was found namely in [30–32].

4.3. Performance Analysis of Water Based Al$_2$O$_3$ as a Coolant in the Hybrid Collector. Even though water has a higher heat carrying capacity, it has its own set of obstacles, such as leaks, poor performance, and other associated concerns. In this experimental investigation, water-based nanofluid demonstrated superior performance in all categories. Further, to improve the performance of the hybrid collector, an efficiency analysis was done using an Al$_2$O$_3$ nanofluid as the working fluid. In addition, confirming the efficiency improvement of the hybrid collector using an Al$_2$O$_3$ nanofluid as the working fluid, the liquid hybrid collector was employed as a reference.

Figure 10 displays the energy obtained by the system for each of the four Al$_2$O$_3$ flow rates. In the experimental investigation, the energy gained by the system increased as the flow rate increased from 0.5 LPM to 2.0 LPM. Additionally, the differential in fluid intake and exit temperatures increased when flow rates increased, resulting in greater thermal efficiency.

The system acquires 165.8 J, 362.9 J, 559.4 J, and 779.1 J at flow rates of 0.5, 1.0, 1.5, and 2.0 LPM, respectively, according to the animation above. From the morning through the evening hours of the experimental day, the diagrammatic depiction of energy obtained and thermal efficiency of all flow rates has followed the same course.

Figure 11 displays the temperature difference between the four Al$_2$O$_3$ flow rates. The fluid inflow temperature was linearly followed by the ambient air temperature for all four flow rates. The form of the channels and the fluid’s mass flow rate generated the difference in $T$ (difference in exit and inlet air temperatures). Temperature differences increase as flow rates increase, resulting in improved system performance at high fluid flow rates. The accompanying graph indicates that all flow rates are crossed linearly from 8 a.m. to 11 a.m., as well as those from 3 p.m. to 5 p.m., although those from 11 a.m. to 3 p.m. were completed spectacularly. The highest temperature difference measured

Table 5: Various performances of the PVT collector with Al$_2$O$_3$/water as a cooling medium.

<table>
<thead>
<tr>
<th>Flow rate (litres per minute)</th>
<th>Energy gained (J)</th>
<th>$\Delta T$ ($^\circ$C)</th>
<th>Thermal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 LPM</td>
<td>270.5</td>
<td>7.8</td>
<td>16.9</td>
</tr>
<tr>
<td>1.0 LPM</td>
<td>592.1</td>
<td>8.2</td>
<td>37.2</td>
</tr>
<tr>
<td>1.5 LPM</td>
<td>912.5</td>
<td>8.5</td>
<td>57.2</td>
</tr>
<tr>
<td>2.0 LPM</td>
<td>1270.9</td>
<td>8.7</td>
<td>79.4</td>
</tr>
</tbody>
</table>
in this study was 7.8°C, 8.2°C, 8.5°C, and 8.7°C at flow rates of 0.5, 1.0, 1.5, and 2.0 LPM, respectively. In a comparative examination of temperature differences between water and Al2O3 nanofluid, 21.2%, 22.4%, 25.1%, and 24.3% were obtained for flow rates of 0.5, 1.0, 1.5, and 2.0 LPM, respectively. Similar findings were observed in other journals, such as [28–30].

Figure 12 depicts the thermal efficiency of all the four flow rates of Al2O3. The thermal performance increased with an increase in fluid flow rate from 0.5 LPM to 2.0 LPM. Various performances of the hybrid collector with various PVT collector with Al2O3/water as a cooling medium are shown in Table 5. As per the above illustration, maximum thermal efficiency was attained at 16.8%, 37.1%, 57.2%, and 79.4% for water flow rates 0.5, 1.0, 1.5, and 2.0 LPM, respectively. In a comparative examination of temperature differences between water and Al2O3 nanofluid, 22.3%, 27.1%, 29.2%, and 30.8% were obtained for flow rates of 0.5, 1.0, 1.5, and 2.0 LPM, respectively. Similar results have been reported in other journals, such as [27–32].

Figure 13 displays the various studies of thermal efficiency which can be compared with present studies. The inferences of the present studies such as inlet and outlet temperature and solar radiation immensely contribute to the performances of the system. The flow rate of the concern references also performed better which can influence the life span of the solar panel.

5. Conclusion

This study is aimed at investigating the performance of a newly developed hybrid collector for use under typical Chennai weather conditions. Comparative analysis was performed in the following manner. PVT systems based on water and water-based nanofluids were tested in the field. Viscosity, density, thermal conductivity, and fluid stability were among the thermophysical properties investigated.

The performance of a hybrid collector in which water as a cooling agent has been compared with that of Al2O3 nanofluid as the cooling agent. The following findings are summarised as given below.

(i) Thermal efficiency of nanofluid was compared with water. Maximum enhancement in thermal efficiency was 79.4% for the flow rate of 2.0 LPM on Al2O3 nanoparticles which can be compared with water volume flow rates

(ii) Thermal conductivity increased as nanoparticles were added to water, according to the findings. The improvement in thermal conductivity for Al2O3 with 1% volume fractions was 1.98 percent

(iii) The diurnal average thermal efficiencies were 11.4%, 24.9%, 38.4%, and 53.5% for Al2O3 nanoparticles as a cooling medium. Similarly, diurnal average thermal efficiencies were 9.9%, 20.9%, 31.7%, and 43.4% for water as a cooling medium

Nomenclature

\[ A_{\text{mod}}: \] PV module area (m²)

\[ L_1: \] Length of the channel (m)

\[ L_2: \] Width of the channel (m)

\[ I_s: \] Solar intensity (W/m²)

\[ Q_t: \] Energy gained (J)

\[ v: \] Velocity of the fluid (m/s)

\[ \rho: \] Density (kg/m³)

\[ \dot{m}: \] Mass flow rate of the fluid (kg/s)

\[ C_p: \] Specific heat capacity of the fluid (kJ/kg K)

\[ \Delta T: \] Difference in temperature (K)
Data Availability

No data were used to support this study.

Additional Points

Future Recommendations. The solar thermal water PVT system has been emerging research since two decades ago; it has its own merits and demerits. Water and water-based nanofluid has good thermal conductivity, whereas the corrosion-resistant character influences this PVT system that affects the performance of the system. Blending of nanofluids with water is a problem which will be affected the system performances, though it has many challenges which can be utilized in many systems namely domestic, industrial, and other related sectors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors extend their appreciation to King Saud University for funding this work through the Researchers Supporting Project number RSP-2021/164, King Saud University, Riyadh, Saudi Arabia.

References


[23] M. Sardarabadi and M. Passandideh-Fard, "Experimental and numerical study of metal-oxides/water nanofluids as coolant


