Experimental investigations of hybrid PV/Spiral flow thermal collector system performance using Al$_2$O$_3$/water nanofluid

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Abstract. In this paper, the PV/T (Photovoltaic thermal unit) system is investigated experimentally to examine the thermal, electrical and overall efficiency by circulating Al$_2$O$_3$/water nanofluid of 1wt% and 2wt% with an optimum flow rate of 40L/H. The overall efficiency of PVT system is largely influenced by various factors such as heat due to photovoltaic action; energy radiated at the infrared wavelength of the solar spectrum, solar irradiance, mounting structure, tilt angle, wind speed direction, Ambient temperature and panel material composition. However, the major factor is considered in this study to extract the heat generated in the PV panel by using nanofluid as a coolant to increase the overall system efficiency. Therefore, the result shows that by using 2 wt% Al$_2$O$_3$/water nanofluid the electrical efficiency, thermal efficiency and overall efficiency of the PVT system enhanced by 13%, 45%, and 58% respectively compared with water.

Keywords: PVT system, electrical efficiency, thermal efficiency, Al$_2$O$_3$/water nanofluid,

1. Introduction
Hybrid PVT System absorbs the direct solar radiation and converts into electrical and thermal energy. In this system solar cell, converts sunlight into electrical energy i.e electricity, and the thermal collector captures the remaining energy and removes heat generated by the PV panel. Matin Ghadidri et al., [1] investigated the performance of PVT system using ferrofluid as a heat transfer medium. They reported that the overall system efficiency is about 76% by using ferrofluid of 3wt% as a cooling medium. Michael et al.,[2] analyzed that the copper sheet laminated PV/T system using 0.05 % copper oxide –water nanofluid .the result revealed that the thermal efficiency of 45.76%. Mohammad Sardarabadi et al., [3] investigated experimentally the effect of Silica/water on PV/T system. The result revealed that the thermal efficiency of 7.6% and 12.8% in case of 1wt% and 3wt% and the total exergy efficiency is about 24.31% at 3 wt% of Silica-water nanofluid respectively. Ying-Ying Wu et al., [4] studied the performance of photo electric hybrid system. The result showed that the unglazed PVT gives higher system performance by using nanofluid compared with water. Wei He et al., [5] studied the performance of a thermoelectric cooling and heating system in summer and winter operation modes. The result revealed that the COP of the system reaches 1.7 and the electrical and thermal efficiency increases into 16.7% and 23.5% respectively. Khelifa et al., [6] analyzed the hybrid PV/T system using Computational Fluid Dynamics (CFD). Adnan Ibrahim et al.,
[7] presented the types of flat plate PV/T collector and its performance is evaluated by using water, air and both. Liang et al., [8] used TRNSYS simulation software for Dynamic Simulation of Hybrid Photovoltaic/Thermal Collectors. Tyagi et al., [9] presented the overview of research and development on hybrid PV/T system. Jarimi et al., [10] discussed the theoretical and experimental studies of a bi-fluid PV/T solar collector and 2D steady-state analysis is developed. The simulation result showed that the good agreement.

2. Preparation of nanofluids
The Al$_2$O$_3$ nanoparticle (size of 50nm) at low concentration of 1wt% and 2wt% are dispersed in ionized water. Figure 1 shows that the Ultrasonic probe sonicator device which operates at higher frequency and amplitude may cause heating. Therefore the nanofluid is kept in a separate container surrounded by ice cubes to prevent fluid evaporation at a higher temperature. Finally, the probe is immersed in the nanofluid to disperse the nanoparticle uniformly in the water, and the dispersion characteristics of the nanofluid are studied by a scanned electron microscope. From the SEM image Figure 2 a, b. It is clearly observed that before sonication the particles were not evenly dispersed after sonicing for 1 hour the particles are well dispersed as shown in Figure 2 c, d. The nanoparticle average diameter as measured as less than 50nm and prepared two different mass fractions of nanofluid and it was stable for 13 days without sedimentation as shown in Figure 1 a.b.

![Figure 1](image_url)

**Figure 1.** Ultrasonic probe sonicator Apparatus,(a),(b) Dispersion stability of prepared Al$_2$O$_3$/water nanofluid of 2% and 1wt%
Figure 2. SEM image of Al$_2$O$_3$/water nanofluid (a, b) 1wt% and 2 wt% before sonication (c,d) 1 wt% and 2wt% after sonication

3. Experimental setup

Figure 3 shows the experimental setup of Spiral flow hybrid PV/T system, which consists of solar panel equipped with a spiral flow thermal collector to collect the generated heat from the PV Panel. The thermal collector made in this study is rectangular spiral type as shown in Figure 4. The PV Panel area is almost covered by the collector design to minimize the heat loss and also to improve the system electrical output. The outlet of the thermal collector is attached to a heat exchanger which is placed in city water supply tank. This transfers the heat to the cold water and then circulated back to the thermal collector. The process will continue to remove the heat generated from the PV panel. The water tank consists of two level sensor and one temperature sensor (RTD) which sense the level of water and its temperature respectively. On the other hand, two RTD is placed to measure the inlet temperature and outlet temperature of the collector for analyzing the thermal efficiency of the system. The flow meter and flow control valve are fixed and controlled to the optimum flow rate of 40LPH. The ON/OFF controller receives the signal from the temperature sensor to maintain the temperature of 60° in city water tank for hot water purpose. The hot water is drained continuously once the temperature reaches the set value. However, nanofluid is constantly circulated to remove the heat from the PV panel to improve the overall system performance. The characteristics of PV panel used in this experiment as shown in Table 1.
Figure 3. Schematic diagram of spiral flow hybrid PV/T system

Figure 4. Spiral flow thermal collector

Table 1: Characteristics of Poly-crystalline PV panel

| Description                  | Specification                  |
|------------------------------|--------------------------------|
| Model                        | Tps107s-50w-poly               |
| Maximum power ($P_{\text{max}}$) | 50W ($\pm 5\%$)               |
| Rated voltage                | 17.2V                          |
| Rated current                | 2.91A                          |
| Open circuit voltage         | 21.5V                          |
| Short circuit current        | 3.25A                          |
| Maximum system voltage       | 1000V                          |
| Test conditions              | Ambient 1.5, 1000w/m$^2$       |
4. Efficiency calculation of PV/T System

Solar radiation is absorbed by the PVT system, and it converts into a useful form of electrical and thermal output. The conversion efficiency of PV/T system depends on many factors which affect the overall system efficiency. The overall efficiency of the system is denoted by $\eta_{pvt}$ is equal to the sum of the electrical and thermal output divided by the total solar radiation incident on the PV panel per unit area [11, 12]. The overall efficiency ($\eta_{pvt}$) of PVT system can be expressed as

$$\eta_{pvt} = \frac{\dot{E}_{\text{Thermal}} + \dot{E}_{\text{Electrical}}}{E_{\text{input}}}$$

(1)

$$\eta_{pvt} = \frac{\int_{t_1}^{t_2} (A_c \dot{E}_{\text{Thermal}} + A_{pv} \dot{E}_{\text{Electrical}}) \, dt}{A_c \int_{t_1}^{t_2} G \, dt}$$

(2)

$$\eta_{pvt} = \left( \frac{E_{\text{Thermal}} + rE_{\text{Electrical}}}{G} \right)$$

(3)

Where, ‘$A_c$’ is the area of thermal collector in mm$^2$, ‘$A_{pv}$’ is the area of PV panel in mm$^2$, ‘$r$’ is the Packaging factor defined as $A_c/A_{pv}$, $E_{\text{thermal}}$ is the the rate of thermal output power per unit area of the collector in Watts, $E_{\text{electrical}}$ is the rate of electrical output power per unit area of the pv panel in watts ‘$G$’ is the effective solar radiation per unit area of PVT system in kW/m$^2$.

$E_{\text{thermal}}$ can be expressed by using Equation (2)

$$\dot{E}_{\text{thermal}} = \left( m_f - c_{pf} \left( T_{in} - T_{fo} \right) \right)$$

(4)

Where, $m_f$ -mass flow rate of the fluid (kg/sec) $C_{pf}$ -specific heat of fluid (J/kg k), $T_{in}$-Inlet temperature of fluid ($^\circ$C), $T_{fo}$ -the outlet temperature of the fluid ($^\circ$C).

The electrical efficiency of PV system can be expressed by

$$\eta_{\text{electrical}} = \frac{\dot{E}_{\text{Electrical}}}{\dot{E}_{\text{Input}}}$$

(5)

$$\eta_{\text{electrical}} = \frac{V_{oc} * I_{sc} * FF}{A_c G}$$

(6)

where $V_{oc}$-open circuit voltage (V), $I_{sc}$-short circuit current (A), FF-Fill factor. FF can be defined as the quality of semiconductor cell junction and how well the solar cell can collect the carrier generated light from the sun [13].

$$FF = \frac{P_{\text{max}}}{V_{oc} * I_{sc}}$$

(7)
Maximum output power of PV panel is expressed by

\[ P_{\text{max}} = V_m * I_m \]  

(8)

\[ \dot{E}_{\text{Thermal}} = \frac{E_{\text{Electrical}}}{C_f} \]  

(9)

The PV/T system, the \( C_f \) value between 0.35 and 0.40 is reported [14]. The average value of 0.4 is applied in this study to determine the overall efficiency of the PV/T system.

Overall PV/T system efficiency can be modified from equation (3)

\[ \eta_{\text{pv}} = \eta_{\text{thermal}} + r \cdot \eta_{\text{electrical}} \]  

(10)

The thermal efficiency is expressed as

\[ \eta_{\text{th}} = \frac{mC_p\Delta T}{A_pG_T} \]  

(11)

where m- mass flow rate kg/ sec, \( C_p \)-specific heat of the collector cooling medium (J/ kg °C), \( \Delta T \)-Difference between fluid or air outlet temperature (°C), \( A_p \)-Area covered by absorber collector (m²) and \( G_T \)-Total solar radiation.

5. Result and Discussion

The experiment was conducted with latitude, longitude and tilt angle of 12.8, 80.0 and 32 degrees respectively. In a constant solar radiation (800W/m²) a series of experiment was conducted by circulating pure water, Al₂O₃/water with 1wt% and 2 wt% with different flow rate to determine the optimum mass flow rate. From these experiments, the result shows that the highest system efficiency attained at 40L/H as shown in Figure 5.

5.1 Effect of temperature

The variations of PV panel temperature and collector outlet temperature for 1 wt% and 2 wt% is illustrated in Figure 6. The data was measured and collected from 9.30 to 14.30 for some selected days with that the Temperature of the PV and PV/T system was studied. The result shows that the PV panel temperature increased about 70.4 degrees. By circulating nanofluid with 1 wt% and 2 wt% the temperature decreases into 30 degrees and 32 respectively for the mass flow rate of 40L/H.
5.2 Effect of Electrical and Thermal efficiency
The experiment result shows that the electrical efficiency of the system obtained 10% and 12% respectively by circulating water and 1wt% nanofluid. The highest electrical efficiency of 13% was obtained by circulating 2wt% of Al$_2$O$_3$/water nanofluid as shown in Figure 7. The more heat is extracted from the PV panel and hence increases the system electrical output.

The thermal efficiency was also calculated by measuring the temperature at the inlet and outlet of the thermal collector. The experiment result shows that the highest thermal efficiency was obtained of 45% by circulating 2wt% of the nanofluid as shown in Figure 8. The thermal efficiency enhancement also depends on the thermal insulation material used to design a hybrid system. The high insulation
material is the best choice to reduce the heat losses from the thermal collector to increase the overall thermal output.

![Figure 8](image_url)

**Figure 8.** Variation of thermal efficiency in case of water, 1wt% and 2 wt% of Al₂O₃/water nanofluid.

### 6. Conclusion

In this study, the PV/T system was experimentally investigated with water, 1wt% and 2 wt% of Al₂O₃/water nanofluid. The hybrid PV/T system overall performance totally depends on the suspension sustainability of the coolant used. In this study Al₂O₃ nanoparticle is used which possess very good heat transfer characteristics when mixes with water and suspended uniformly by sonication process. The result shows that the PV panel temperature increased up to 70 degrees which may cause the reduction of PV panel life. When circulating the 2 wt% Al₂O₃/water nanofluid the temperature of the PV panel decreased into 36 degrees. The variation of electrical, thermal and overall efficiency also clearly observed. The result shows that by using 2 wt% Al₂O₃/water nanofluid the electrical efficiency, thermal efficiency and overall efficiency of the PVT system enhanced by 13%, 45%, and 58% respectively compared with water and 1wt% of Al₂O₃/water nanofluid.

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