Thermal performance evaluation of using aluminium oxide water-based nano fluids as coolant in hybrid collector

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Abstract

This research article deals with the thermal performance evaluation of using aluminium oxide water based nano fluids as a coolant in hybrid collector. There are two kinds of system can be designed and fabricated in this study. First one is standalone pv system which was performed electricity generation alone. This system can act as a reference of hybrid collector. Second one is water cum aluminium oxide nano fluid which can be generated both electricity and hot water production. Two types of volume flow rate were carried out in this article. Further, aluminium oxide with 0.05 % concentration acted along with water as a base fluid.The study results, which were analyzed from electrical and thermal viewpoints, have shown and revealed that the aluminium oxide-water nanofluid presented a better performance in terms of photovoltaic energetic conversion compared to standalone pv system. While aluminium oxide-water nanofluid revealed the highest thermal energetic efficiency. Moreover adding thermal unit to photovoltaic module (PV) enhanced the total energetic efficiency by 48.3 % for water, 57.2% for aluminium oxide-water.

Keywords: mass flow rate, aluminium oxide, standalone pv system, hybrid collector, electrical and thermal efficiency.

1. Introduction

Energy demand has increased globally, causing fossil fuel reserves to diminish. In today's world, sustainable energy creation is one of the most pressing issues. Sunlight energy is one of the finest renewable energy sources, and it has a minimum environmental impact. PV/thermal (SPV/T) systems consist of PV modules connected with a heat exchanger that uses either water or air to cool. Both thermal and electrical energy are produced concurrently by the SPV/T system As a PV system's operational temperature rises, its electrical efficiency decreases. Kim et.al [1] analyzed the performance of heating system combined with PVT collectors of 1.5kWp that were integrated on a building roof as a heating system. The experimental results showed that the total heat gain from the collector was 9.7 kWh, while the average thermal and electrical efficiency levels of the system were 30% and 17%, respectively. Alzaabi et.al [2] proposed a design to improve the electrical efficiency of PV panels using Water Hybrid Photovoltaic Thermal (PV/T) system. Experimental results showed that the electrical power output and thermal efficiency of the PV/T system increased by 15 to 20 %,60-70% as compared to the PV panel.

Choudhary et.al [3] investigated the stability analysis of Al_2O_3/water nanofluid with the help of zeta potential and visual inspection methods and the effects of pH and sonication time for the stability of nano fluids in detail. The stability was also analysed by using sodium dodecylsulphate,as a surfactant.Khanjari et.al [4] studied to evaluate the effects of utilizing nanofluid on the performance of PV/T system using pure water,Ag-water nanofluid and Alumina-water nanofluid. The maximum increase percentage of heat transfer coefficient versus volume fraction for alumina-water and Ag-water nanofluid were 12% and 43%, respectively. Increasing the inlet fluid velocity improved the heat transfer coefficient by 8-10%than pure water.

Sharma et.al [5] worked on the thermo physical properties of three different TiO_2, $Al_2O_3$and SiO_2 nano particles with vegetable oil-water emulsion at room temperature in different volumetric concentrations. The results revealed that increase of nanoparticle concentration in base fluid increased its thermal conductivity, viscosity and decreases its specific heat. Further noticed that Al_2O_3 nano fluid exhibited better thermal properties among all three nanofluids.Kumar et. al [6] studied and explored, the impacts of volume fraction on thermo-physical properties CuO, Al_2O_3,TiO_2,Fe_3O_4 with water and ethylene glycol based nano fluids .Finally, it was inferred from this study that the thermo-physical properties should be considered as important parameters with the use of nano fluids for high-temperature applications.

Sardarabadi et.al [7] investigated experimentally and numerically, the use of Al_2O_3,TiO_2,ZnO all dispersed in de ionized water as base fluid, with 0.2% (wt%) as coolants in photo voltaic thermal unit. An uncertainty analysis was performed for the experimental data and t-statistic indicator was used to verify the results of the numerical model. The electrical efficiency for the PVT system was calculated based on the measured temperature of the photovoltaic surface and the fluid outlet. Sekhar et. al [8]studied, the specific heat capacity and viscosity properties of Al_2O_3 water-based Nanofluids of 47 nm average particle diameter at 0.01%–1% concentrations. The results indicated a nonlinear increase of viscosity with particle concentration due to aggregation of particles. The estimated specific heat capacity of the nanofluid decreased with the increase of particle concentration due to increase in thermal diffusivity.

Usri et. al [9] presented the thermal conductivity of water and ethylene glycol (EG) based Al_2O_3 nanofluid with volume ratio of 40:60, 50:50 and 60:40 using a two-step method. The measurement data of the nanofluids gave maximum enhancement of thermal conductivity at condition 2.0 % volume concentration, temperature of 70 °C and for all base fluid.Sudarmadji et. al [10]investigated the convective heat transfer and pressure drop of nanofluid, using alumina-water nanofluid for 0.15%, 0.25% and 0.5% under laminar flow regime. Experiment showed that the convection heat transfer increases remarkably with the increase of the nano particles concentration under various values of Reynolds number. The Nusselt number and pressure increased about 40.5% and slightly compared to pure water under 0.5% volume concentration.

Mahian et.al [11] performed an analytical study on the entropy generation and heat transfer due to Al_2O_3/water nanofluid at volume concentrations up to 4%. It was observed that the uncertainties in thermo physical models and tube roughness have considerable effects on the values of heat transfer coefficient and Nusselt number. The analysis of entropy generation concluded that the entropy generation decreased with increase in nanofluid concentration. Omid et.al [12] performed an analytical analysis to evaluate the performance of a mini channel based solar collector using Cu/water, Al_2O_3/water, TiO_2/water, and SiO_2/water. Analysis of the first law of thermodynamics revealed that Al_2O_3 nanofluids showed the highest heat transfer coefficient in the tubes while the lowest value belongs to SiO2 nanofluids. The highest outlet temperature was provided by Cu/water nanofluids among the other three. The results of second law analysis elucidate that Cu/water nanofluid produces the lowest entropy generation among the nanofluids. It is found that the entropy generation of TiO_2 was lower than Al_2O_3.

Aly et. al [13]carried out a computational fluid dynamics (CFD) study on heat transfer and pressure drop characteristics of water-based Al_2O_3 nanofluid flowing inside coiled tube-in-tube heat exchangers. The results revealed that, when compared at the same Reynolds number, the heat transfer coefficient increased by increasing the coil diameter and nanoparticles volume concentration. Kolhe et. al [14] investigated a research on the effect of Al_2O_3 and CuO on the thermal efficiency enhancement of a heat pipe on the different operating state. Results showed that by, thermal performance was enhanced by reducing the thermal resistance and wall temperature difference.

Albadr et. al [15]studied and investigated experimentally the forced convective heat transfer and flow characteristics of Al_2O_3nanofluid (0.3–2)% flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions are. The heat transfer coefficient of the nanofluid increased with increase in the mass flow rate and increase of volume concentration of the nanofluid, thereby resulted in increase of viscosity and friction factor. Hashim et. al[16] added n0.1, 0.2, 0.3 a 0.4wt.% to pure water as energy storage in different industrial applications 0.3 wt.% gave greater temperature gradient than pure water than other three wt.%.

Mukeshkumara et. Al [17]studied the heat transfer coefficients of shell and helically coiled tube heat exchanger using Al_2O_3 / water nanofluid. This study was done by changing the parallel flow configuration into counter flow configuration under laminar flow regime. It was found that the overall heat transfer coefficient of counter flow was 4-8% higher than that of parallel flow at 0.4% nanofluid. The overall heat transfer coefficient was found to be 5-9% higher than that of parallel flow at 0.8% nanofluid. Moreover the thermal performance of 0.8% nanofluid was higher than 0.4% nanofluid.

Hezaveh et. Al [18] studied and developed a new model for predicting effective thermal conductivity for Al_2O_3nanoparticles dispersed in ethylene glycol (EG) and water regarding the shape factor and volume fraction of nanoparticles. Finally it was concluded that the shape factor value applied for Al_2O_3–Water system cannot be used for Al_2O_3/ EG system. Yousefi et.al [19] presented experimentally an investigated work on the effect of Al_2O_3 - H_2O nano fluid, with and without Triton X-100 as surfactant, on the efficiency of a flat-plate solar collector. The weight fraction of nano particles were 0.2% and 0.4%and the particles dimension was 15 nm and mass flow rate of 1 to 3 Lit/min.The results showed that for 0.2 wt% the increased efficiency was 28.3%.

Saidur et al. [20] investigated and evaluated the extinction coefficient of water based aluminum nanofluid by varying nanoparticle size and volume fraction. The particle size had minimal influence on the optical properties of nanofluid. The improvement was promising within 1.0% volume fraction and the nanofluid was almost opaque to light wave. Irwansyah et al. [21] examined the laminar convective heat transfer of Al_2O_3-water nano fluids in a square micro channel. A maximum enhancement of 6.9 % and 21 % were realized for 0.6% Al_2O_3-water and 1% Al_2O_3-water nanofluids. Himanshu

Tyagi et al. [22] theoretically investigated the feasibility of using a non concentrating direct absorption solar collector (DAC) and compared its performance with that of a typical flat-plate collector using aluminum and water nano fluid. A 2D heat transfer analysis was developed in which direct sunlight was incident on a thin flowing film of nanofluid. According to the results obtained from the study, under similar operating conditions, the efficiency of a DAC using nanofluid as the working fluid was found to be up to 10% higherthan that of a flat-plate collector.Mintsa et al. [23] presented the effective thermal conductivity measurements of Al_2O_3 and CuO water nanofluids. Readings at ambient temperature as well as over a relatively large temperature range were made for various particle volume fractions up to 9%. Results clearly showed that the predicted overall effect of an increase in the effective thermal conductivity with an increase in particle volume fraction and with a decrease in particle size.

HemmatEsfe et al. [24] investigated experimentally the thermal behavior of Al_2O_3–EGnano fluids. The experimental results exhibited that the thermal conductivity of nano fluids enhanced significantly with the increase in concentration and temperature. Rahmana et al. [25] studied a corrugated bottom triangular solar collector by introducing Cu, Al_2O_3, and TiO_2water based nano fluids inside the enclosure. The corrugated bottom was kept at a constant high temperature whereas the side walls of the triangular enclosure were kept at a low temperature. It was concluded that Grashof number and solid volume fraction had significant influence on the streamlines and isotherms in the enclosure. Mahian et al. [26] reviewed the effects of nano fluids on the performance of solar collectors and solar water heaters from the efficiency, economic and environmental considerations point of view and its applications in thermal energy storage, solar cells, and solar stills.

Darzi et al. [27] studied experimentally the effects of Al_2O_3 nano fluid with a mean diameter of20 nm on heat transfer, pressure drop and thermal performance of a double tubes heat exchanger. The effective viscosity of nano fluid was measured in various temperatures ranging from 27 °C to 55 °C. Experiments were carried out at different Reynolds numbers ranging from 5000 to 20,000 approximately. Faizal et al. [28] evaluated the payback period of 10,239 kg, 8625 kg, 8857 kg and 8618 kg total weight for 1000 units of solar collectors using CuO, SiO_2, TiO_2 and Al_2O_3 nano fluid. Finally, it was observed that the environmental damage cost can also be reduced with the nano fluid based solar collector. Elmira et al. [29] studied the numerical simulation, for the cooling of a solar cell by forced convection in the presence of Al_2O_3-water nano fluid. The finite elements method was used to solve the system of differential equations that was based on the Galerkin method, by considering the effect of solid volume fraction for different values of Reynolds number on the results in the form of isotherms and modified local and average nusselt number.

Moraveji et al. [30] tested the effect of using Al_2O_3 nano fluid on the thermal efficiency enhancement of a heat pipe on the different operatingstate. Yousefi et al. [31] investigated experimentally the effect of Al_2O_3 e-water nano fluid, as working fluid, on the efficiency of a flat-plate solar collector with and without Triton X-100 as surfactant. Chandrasekar et al. [32]experimentally investigated the effective thermal conductivity and viscosity of Al_2O_3/H_2O nano fluid. Theoretical models were also developed to predict thermal conductivity and viscosity of nano fluids without resorting to the well-established Maxwell and Einstein models, respectively. As per the literatures were cited above none of the journal deals with aluminium oxide with the electrical and thermal performance of hybrid collector. This article deals with the performance enhancement of water based nano fluids which can be compared with standalone pv system.

2. Methodology

This research study contains the analysis of electrical and thermal efficiency of hybrid collector with a concentration and two kinds of mass flow rates.The following assumptions are made for the analysis of hybrid collector as given below [33 and 34].

1. The system is in a quasi- steady State.
2. The ohmic losses in a solar cell are negligible.
3. The heat capacity of the Solar Photovoltaic/Thermal system is neglected in comparison with the heat capacity of fluid in the storage tank.
4. One dimensional heat conduction is a good approximation
5. There is no temperature stratification in the thermal storage tank due to forced mode of operation.

2.1 Electrical efficiency

The electrical efficiency (η el) of a PV module can be defined as the ratio of actual electrical output of the PV module to the rate of solar energy incident on the module. It is mathematically expressed as:

$$\eta_{el}=\frac{V_{mp}I_{mp}}{\dot{S}}=\frac{\dot{E}_{el}}{\dot{S}} \qquad (1)$$

Where,

I_{mp} = Current at Maximum Power(A)

V_{mp}= Voltage at Maximum Power(V)

$\dot{E}_{el}$ = outlet electrical power, W,

$\dot{S}$ = rate of solar energy incident on the PV surface, W

$$\dot{S}=GN_sN_mA_{\mathrm{mod}} \qquad (2)$$

Where,

G = solar radiation, W/m^2,

Ns = number of strings,

N_m= number of modules,

A_{mod}= PV module area, m^2.

$$A_{\mathrm{mod}}=L_1L_2 \qquad (3)$$

Where,

L_1= length of PV module, m,

L_2= width of PV module, m.

The equation of mass flow rate of fluid is expressed by

$$\dot{m}=\rho A_{\mathrm{mod}}V \qquad (4)$$

Where,

$\dot{m}$ = mass flow rate of fluid, kg/s,

ρ = density, kg/m^3,

V = velocity of fluid, m/s.

A_{mod}= PV module area, m^2,

2.2 Thermal efficiency

Thermal performance of solar flat plate collector was first investigated by Hottel and Woertz as reported by [45]. F_R, is the heat removal factor of collector and defined it as the ratio of actual heat transfer to the maximum possible rate of heat transfer when absorber plate is maintained at inlet fluid temperature.FR, for any given system is calculated using Eq (5).

$$Q_u=F_RA_{\mathrm{mod}}\left[G(\tau\alpha)-U_L\left(T_f-T_a\right)\right] \qquad (5)$$

Where,

F_R= heat removal factor,

A_{mod}= PV module area, m^2,

G = solar radiation, W/m^2,
α = absorptance of the solar cell,
τ = transmittance of the glass cover,
U_L= Overall heat loss coefficient, W/m^2 °C,
T_f= fluid temperature, °C,
T_a= ambient temperature, °C.

$$T_f = \frac{(T_o - T_i)}{2} \quad (6)$$

Where,
T_f= fluid temperature, °C,
T_o= outlet fluid temperature, °C,
T_i= inlet fluid temperature, °C.

The rate of useful energy collected can also be expressed by considering the increase in enthalpy of fluid flowing through the collector as,

$$Q_u = \dot{m} c_p (T_o - T_i) \quad (7)$$

Where,
Q_u= useful heat energy gained, kJ,
ṁ = mass flow rate of fluid, kg/s,
C_p= specific heat of fluid, kJ/kg K,
T_o= outlet air temperature, °C
T_i= inlet air temperature, °C.

$$F_R = \frac{\dot{m} c_p (T_o - T_i)}{A_{mod}\left[G(\tau\alpha) - U_L (T_f - T_a)\right]} \quad (8)$$

Where,
F_R= heat removal factor,
ṁ= mass flow rate of fluid, kg/s,
C_p= specific heat of fluid, kJ/kg K,
T_o= outlet fluid temperature, °C,
T_i= inlet fluid temperature, °C,
G = solar radiation, W/m^2,
A_{mod}= PV module area, m^2,
U_L= Overall heat loss coefficient, W/m^2 °C,
τ = transmittance of the glass cover,
α = absorptance of the solar cell,
T_f= fluid temperature, °C,
T_a= ambient temperature, °C.

The thermal efficiency of a collector can be obtained using heat removal factor, F_R as given in the, Equation (9). This relation is known as Hottel-Whillier Bliss Equation

$$\eta_{th} = F_R\left[\left(\tau\alpha\right) - U_L\left(\frac{T_f - T_a}{G}\right)\right] \tag{9}$$

Where,
η_{th}= thermal efficiency, %,
τ = transmittance of the glass cover,
α = absorptance of the solar cell,
U_L= Overall heat loss coefficient, W/m^2 °C,
T_f= fluid temperature, °C,
T_a= ambient temperature, °C,
G = solar radiation, W/m^2.

2.3. Uncertainty Analysis

The Solar Photovoltaic /Thermal System (SPV/T) consists of temperature sensors, voltmeter, ammeter, solar meter and pressure gauge etc. During the measurement of theseparameters, the equations used to calculate the uncertainty and error analysis given as below.

$$S_x = \left[\frac{1}{N-1}\sum\left(X_i - \bar{X}\right)^2\right]^{1/2} \tag{10}$$

Where,
S_x= precision index,
N = total no of measured variables,
X_i= individual measurement,
$\bar{X}$ = mean value of the measurement

Using the t-distribution table for v= N – 1 = 7degrees of freedom, at the 95% confidence level, the value obtained was, t= 2.365 . Thus the precision limit was calculated using the following relation as:

$$P_x = tS_x \tag{11}$$

Where,
P_x=Precision Limit
S_x=Precision Index

3. Experimental Procedure

Nano fluid PVT systems has been compared to liquid PVT systems and freestanding PV modules concurrently using the suggested approach to build, produce, and analyse the efficiency of these systems. The PVT system was also used to test water as a cooler with varying flow rates, as well as nano-pcm and nano fluids with varying concentrations and flow rates. The last system is a standalone PV module that operates under normal conditions. The complete experimental set up is shown in Fig. 1. The preparation of Nano fluid and its testing at the Laboratory is found in Fig. 2. The Performance of solar panels at the standard test conditions is displayed in Table 1.

As a starting point for the hybrid collector, we bought a multi-silicon glass panel of 1640mm x 992mm x 35mm in size. Due of the platform's insulating effect, 0.4 mm copper sheet was used to absorb heat on the PV panel's back. The copper tube, which has an exterior diameter of 10 mm and an interior diameter of 8 mm, is also used as a heat absorber on the backside of the solar panel. Solar thermal panels were put at a 13-degree slant to the south to maximise their efficiency. For fifteen minutes each day, between 8 a.m. and 5 p.m., the weather and output power were recorded.

Table 1. Performance of solar panels at the standard test conditions.

Parameter	Value
Rated Maximum Power	260 W
Current at Maximum power	8.42 A
Voltage at Maximum power	30.9 V
Short circuit current	8.89 A
Open circuit voltage	37.7 V
Weight	18.2 Kg

Fig. 1. Experimental Details of PV and PVT systems

Fig. 2.Nano fluid (Al_2O_3) was prepared and tested at Laboratory.

4. Results and Discussion

This study compares the performance of a hybrid collector with a solo pv system at the same climatic location in Chennai, based on the weather data collected.

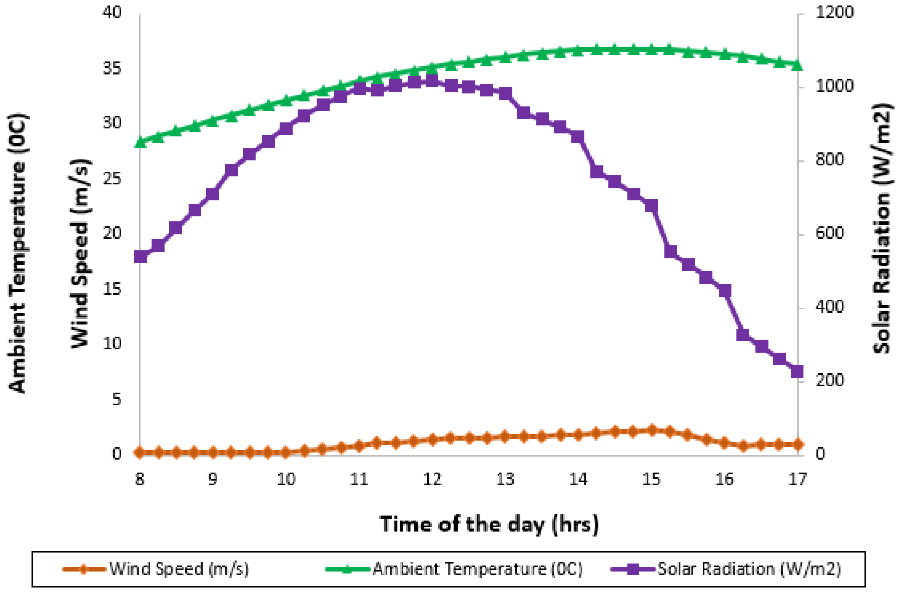

Fig. 3. Average results of the solar radiation, ambient temperature and wind speed at the experimental set up.

FIG. 3 shows the experiment days' climatic characteristics, solar intensity, and ambient temperature. There was a bell-shaped distribution of solar radiation during the experiment, with 1007.07 W/m^2 at 12:00 pm and 307.18 W/m^2 at 7:00 am, as well as 229.29 at 17:00 pm, according to this graph. There is a daily average temperature increase from 29.36 ^{0}C in the morning to 34 ^{0}C in the evening, with the highest temperature at 17:00 p.m. Electrical power impacts on water and nanofluid flow rates are demonstrated in Figure 4. Due to the increasing intensity of the light, electrical power increased until 12 p.m., but subsequently dropped. With 0.5 and 1 LPM water flow, the average electrical output was 46.43 W and 50.34 W, respectively. For water-based aluminium oxide nano fluids, the average electrical power was 51.81 W and 53.28 W, respectively. As the flow rate of the hybrid collector rose, so did the electrical power of the PV panels.

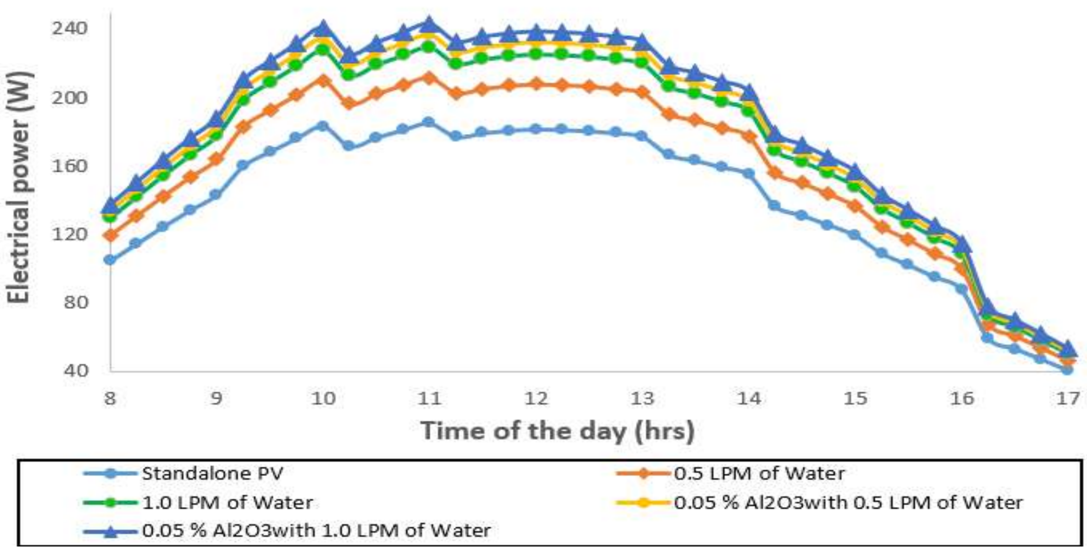

Fig. 4. Electrical power generation of the water and nanofluid with different flow rates.

As shown in Figure 5, electrical efficiency has an influence on water and nanofluid flow rates of 0.5 and 1.0%. Until 12 p.m., when the sun's intensity increases, electrical power drops, and then it increases. 0.5 and 1.0 LPM water flow rates had an average electrical efficiency of 11.95 and 13.06 percent, respectively. A water-based aluminium oxide nano fluid with 0.05 percent concentrations of 0.5 and 1.0 LPM had an electrical efficiency of 13.68 percent and 14.61%, respectively. As coolant flowrate increased, so did electrical efficiency.

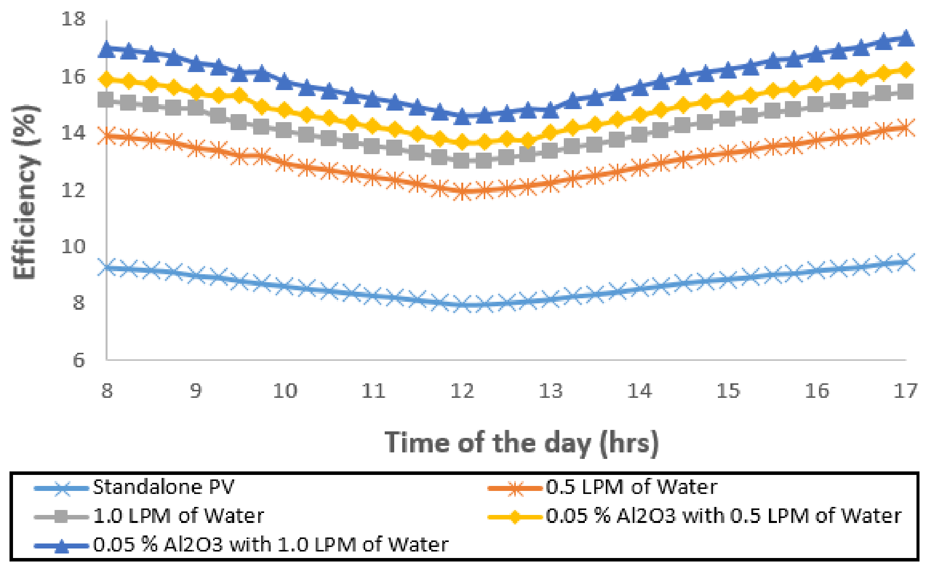

Fig. 5. Electrical efficiency of the water and nanofluid with different flow rates.

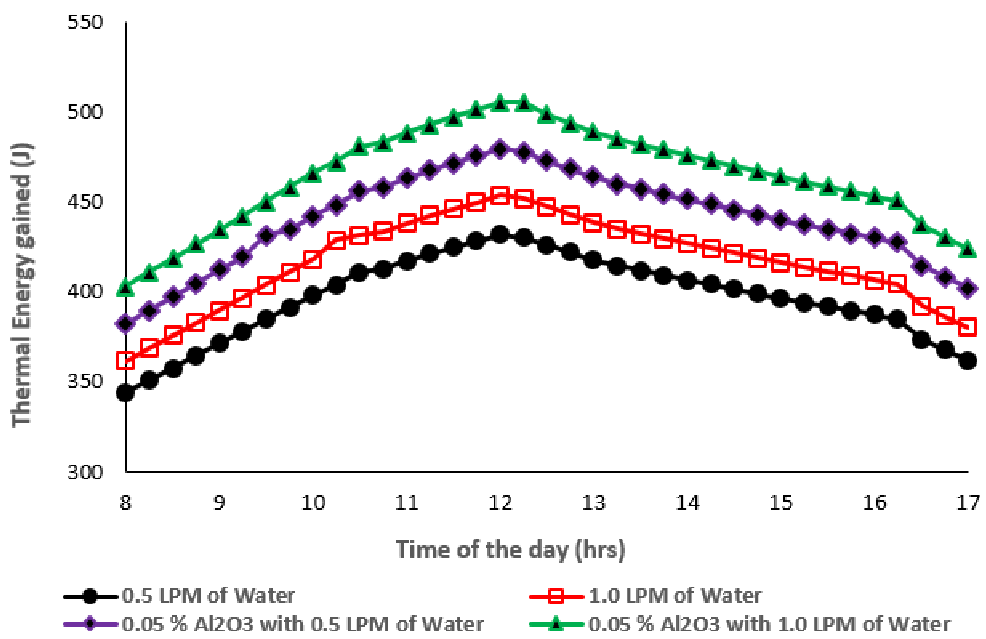

Fig. 6. Electrical efficiency of the water and nanofluid with different flow rates.

This study investigated the thermal efficiency of a nanofluid PVT collector using water-based nanofluids at various flow rates. For water at 0.5 LPM and 1.0 LPM, maximum thermal efficiency was 54.23 percent and 56.45 percent, respectively, as shown in Figure 6. It was shown that 0.5 LPM and 1.0 LPM aluminium oxide nanofluids with 0.05 percent concentration had similar tendencies, with 65.2 and 68.8 percent, respectively.This is because at greater flow rates, the temperature differential between the input and exit of PV/T system is increased due to the high heat absorption of nanofluid from system.

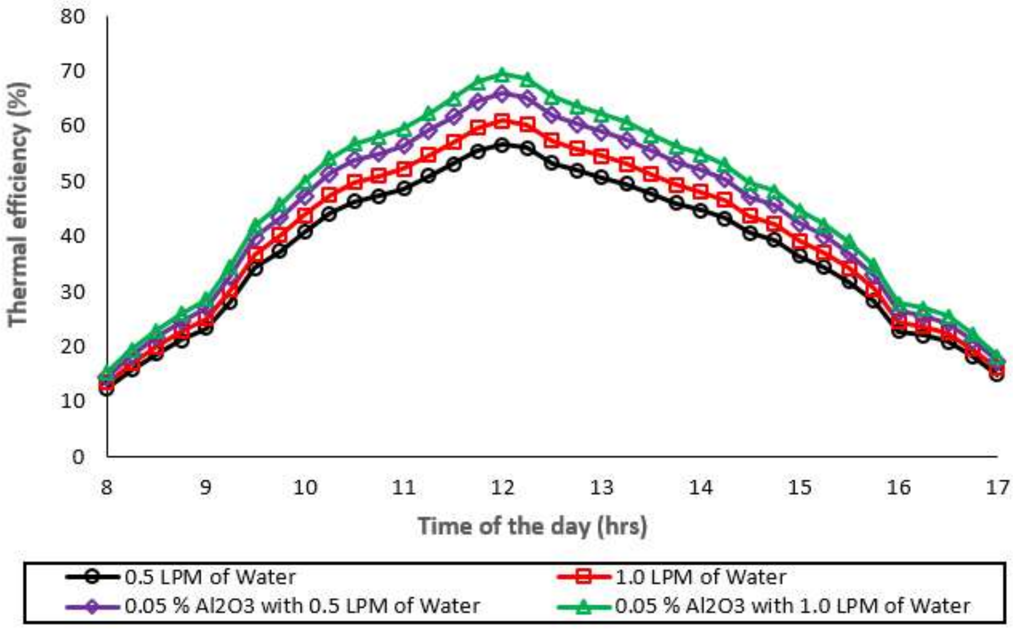

Fig. 7. Thermal efficiency of the water and nanofluid with different flow rates.

5. Conclusion

❖ The following conclusions were finally derived from the system and the performance of a PVT collector conducted by water and aluminium oxide -water nanofluid with a concentration of 0.05 wt percent was evaluated in this experimental research.

❖ Electrical efficiency was attained at standalone pv system, 0.5 lpm, 1.0 lpm and 0.05 % concentration with 0.5 lpm and also 0.05 % concentration with 1.0 lpm of aluminium oxide nano fluid to be 7.97 %, 11.95 %, 13.03%, 13.68% and 14.61 % respectively.

❖ Thermal efficiency was attained at 0.5 lpm, 1.0 lpm and 0.05 % concentration with 0.5 lpm and also 0.05 % concentration with 1.0 lpm of aluminium oxide nano fluid to be 56.7 %, 61.2 %, 66.2 % and 69.5 % respectively.

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