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Experimental Performance Study of Titanium Dioxide Nano Fluid as a Coolant in Solar Photovoltaic / Thermal System

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Keywords: SPV/T, TiO_2 Nano fluid, Heat transfer characteristics, Serpentine flow copper tube, Thermal efficiency.

ABSTRACT

In the present work, an experimental study was conducted on a Solar Photovoltaic/Thermal System (SPV/T) to determine the effect of different concentrations of Titanium dioxide (TiO_2) nanoparticles of φ = 0.1 % and 0.2 %, mixed in milli-Q water as base fluid (BF) on heat transfer characteristics through a serpentine flow copper tube heat exchanger and compared with water. The experimental setup consists of a solar photovoltaic/ thermal system (SPV/T) of 100 W capacity with a collector area of 0.91 m^2. For the flow supplied by the pump, to the Solar photovoltaic/Thermal System (SPV/T) for the nano fluids with φ = 0.1 %, 0.2 % and water at mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s, the Electrical (PV) efficiency for water as 10.82 % to 11.06 %, TiO_2 0.1 % as 11.60 % to 12.46 % and TiO_2 0.2 % as 11.87 % to 12.81 % were investigated and obtained. The thermal efficiency for water resulted as 53.61 % to 54.07 %, TiO_2 0.1 % 67.46 % to 67.82 % and TiO_2 0.2 % 68.87 % to 69.05 % to respectively.

INTRODUCTION

Sustainable energy generation is one of the most important challenges in the society today. Solar energy is one of the best sources of renewable energy with minimal environmental impact which offers a solution. The shortage of fossil fuels and environmental considerations motivated the researchers to use alternative energy sources such as solar energy. Solar photovoltaic/thermal (SPV/T) system consists of PV modules coupled with heat exchanger with water or air as its cooling medium. SPV/T system produces both thermal energy and electrical energy simultaneously. The electrical efficiency of a PV system drops as its operating temperature increases. SPV/T system aims in reducing the operating temperature of PV modules thereby to keep the electrical efficiency at sufficient level. Nano particles suspended in base fluids results in nano fluids.

For the past decades, nano fluids were studied for its superior thermal properties hence been applied in many engineering systems that require cooling systems. Utilizing nano fluids as an advanced kind of liquid mixture with a small concentration of nanometer-sized solid particles in suspension is a relatively new field, which is less than two decades old. The need to improve the efficiency of coolants undeniably becomes one of the concerns in cooling systems technologies nowadays. Traditional heat transfer fluids such as water, engineering oil and ethylene glycol have been widely used in various industrial fields including chemical production, automobile manufacturing, aeronautics and astronautics. Various techniques have been applied to enhance heat transfer in heating and cooling systems; but the efficiency of these working fluids, in the heat transfer applications, is low. Nano fluid as a coolant provides better option for users due to augmentation in properties. The heat transfer augmentation using nano particles mainly depends on the type and the size of the nano particle and its concentration in the base fluid.

Literature survey

Jin-Hee Kim et al. (2016) analyzed the performance of heating system combined with PVT collectors of 1.5 kWp 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%,

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respectively, and the heating energy for the house reduced by 47%. Niccolo Aste et al. (2016) presented the design of a covered PVT, to evaluate the performance of covered PVT water collectors. The results showed an annual primary efficiency of the PV module equal to 13.4 %, while the electrical efficiency of 13.2 %, thermal efficiency of 28.8 % and average annual efficiency around 40 % respectively.

Amna A. Alzaabi et al. (2014) proposed a design to improve the electrical efficiency of PV panels using Water Hybrid Photovoltaic Thermal (PV/T) system. The results showed that the electrical power output of the PV/T system increased by 15 to 20 % as compared to the PV panel. The thermal efficiency of 60 % - 70 % were achieved the system. Rohit Tripathi et al. (2017) designed and fabricated, an experimental set up of a single unit of fully covered concentrated photovoltaic thermal (CPVT) collector is to achieve thermal as well as electrical gain. Fixed position, manual maximum power point tracking technique case are considered based on the of receiver rotation according to sun movement, to study the annual behaviour of present system. It was found that latter case was is dominating in overall thermal energy as well as exergy gain. The annual net thermal energy and exergy, obtained were 1.25 and 1.19 times higher than the former case.

Abdul Hamid et al. (2014) experimentally investigated heat transfer on TiO_2 dispersed in water and ethylene glycol mixture for 0.5 %, 1.0 % and 1.5 % by wt for 600 Azmi et al. (2014) conducted experiments to determine heat transfer coefficients and friction factor of TiO_2/water nano fluid for flow in tubes and with tapes of different twist ratios, the heat transfer coefficient increases with the decrease in twist ratio for water and nano fluid with the use of twisted tapes. Rohit. S. Khedkar et al. (2014) studied the heat-transfer characteristics of TiO_2–water nano fluid as a coolant in concentric tube heat exchanger. It was observed that the average heat transfer rates for nano fluid as a cooling media are higher than those for the water and increases with concentration of nano fluid composition. Maouassi et al. (2017) illustrated a numerical study of nano fluid laminar forced convection, permanent and stationary (TiO_2), in a solar flat plate collectors to simulate its heat transfer modification properties, for (1 %, 3 %, 5 % and 10%) volume concentrations. Finally, it was concluded that heat transfer increases with increasing both nanoparticles concentration and Reynolds number.

Hossein Chaji et al. (2013) fabricated a flat plate solar collector (FPSC) and tested the effects of different nano particle concentrations of TiO_2 in water as base fluid, mass flow rates of 36, 72 and 108 lit/m^{2}h and particles concentration ratios of 0, 0.1 %, 0.2 % and 0.3 % wt were investigated.

The index of the collector total efficiency for mass flow rates of 72 and 108 lit/m^{2}hr rates has increased by 6.7 % and 15.7 % respectively in comparison with 36 lit/m^{2}hr mass flow rate. Madhuri. G. Chatur et al. (2015) carried out an experimental study to investigate the thermal performance of solar collector water heater with pure water, nano fluid and concluded that the thermal performance efficiency is higher by using 3 % nano fluid followed by pure water, the outlet temperature increases with low mass flow rate for both fluid as pure water and nano fluid and the same working fluid efficiency slightly increases as mass flow rate increases.

Anuj Kumar Sharma et al. (2016) prepared vegetable oil-water with TiO_2, SiO_2 and Al_2O_3 nanoparticles 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, and it was also noticed that Al_2O_3 nano fluid exhibits better thermal properties among all three nano fluids. Rahman et al. (2014) studied by introducing water based Cu, Al_2O_3, and TiO_2 nano fluids inside the enclosure of a corrugated bottom triangular solar collector. It was also found that heat transfer increased by 24.28% from the heated surface as volume fraction. Faizal et al. (2013) estimated economically that 10,239 kg, 8625 kg, 8857 kg and 8618 kg total weight for 1000 units of solar collectors can be saved for CuO, SiO_2, TiO_2 and Al_2O_3 nano fluid respectively.

Sekhara Reddy et al. (2013) conducted experiments on ethylene glycol–water and TiO_2 nano particles and characterized thermal conductivity as a function of temperature and volume concentration of nanoparticles. Based on the experimental results, it was observed that the thermal conductivity of TiO_2 nano fluids increases with increase in percentage of volume concentration of TiO_2 and also with temperature. Silambarasan et al. (2012) carried out experiments on the preparation of dispersions of sub-micron TiO_2 particles in water by stirred bead milling, for potential use as coolants. The results indicated that the ultrasonication can be utilized to tailor the transport properties of the sub-micron dispersions produced by stirred bead milling. These dispersions possess higher thermal conductivity than water and can also be utilized as coolants.

Mohammad Sardarabadi et al. (2016) investigated experimentally and numerically the use of the TiO_2, ZnO and Al_2O_3/water nano fluid with 0.2 % by weight (wt %) as coolants in photovoltaic thermal system. To investigate the reliability of the measurements, an uncertainty analysis was performed for the experimental data. The t-statistic indicator was used to verify whether the results of the numerical model were statistically significant. The energy balance equations for various parts of the PVT system are solved using numerical simulations. Both numerical and experimental results showed that the TiO_2 and

ZnO nano fluids presented a better performance in terms of the electrical efficiency compared to that of the Al_2O_3 and de ionized water.

In terms of the thermal performance of the system, the ZnO nano fluid was found to have the highest thermal efficiency compared to de ionized water and the other two nano fluids. Lastly the numerical model was used to investigate the effect of nano particles mass fraction, range from0.05 to 10 wt%, on electrical and thermal performance of the PVT system. Navid Bozorgan et al. (2015) reviewed an article that provides comprehensive information for the design of a solar thermal system utilizing nano fluid as an absorber fluid working at the optimum conditions. Murshed et al. (2005) prepared TiO_2 nano fluids in rod-shapes of dia10 nm×40 nm (diameter by length) and in spherical shapes of diameter 15 nm in deionized water. The experimental results showed that the thermal conductivity increases with an increase of particle volume fraction. Abdul Hamid et al. (2014) provided an experimental investigation on TiO_2 dispersed in water and ethylene glycol mixture The Nusselt number of the nano fluid increases with the increase of Reynolds number at 1.5 % concentration, slightly higher than based fluid.

Abbasian Arani et al. (2013) performed an experimental study to investigate the convection heat transfer characteristics in fully developed turbulent flow of TiO_2–water nano fluid to analyse the effect of mean diameter of nanoparticles on the convective heat transfer and pressure drop on nanoparticle volume concentrations in a horizontal double tube counter-flow heat exchanger. It was found that the Nusselt number does not increases by decreasing the diameter of nanoparticles. Salma Parvin et al. (2014) work investigated the entropy generation and heat transfer performance by forced convection through a direct absorption solar collector for Cu water nano fluid. The results show that both the mean Nusselt number and entropy generation increased as the volume fraction of Cu nanoparticles and Reynolds number increases.

Saida et al. (2014) theoretically analysed the entropy generation, heat transfer enhancement capabilities and pressure drop for a flat-plate solar collector operated with single wall carbon nano tubes (SWCNTs).Vikrant et al. (2012) attempted to introduce the idea of harvesting solar radiant energy through usage of nano fluid-based concentrating parabolic solar collectors (NCPSC). It was observed that while maintaining the same external conditions, the NCPSC was about 5–10 % higher efficiency as compared to the conventional parabolic solar collector. Omid Mahian et al. (2013) reviewed the effects of nano fluids on the performance of solar collectors and solar water heaters from the efficiency, economic and environmental considerations viewpoints.

Elmira et al. (2012) studied a numerical simulation, for the cooling of a solar cell by forced convection in the presence of Al_2O_3-Water nano fluid. Gabriela Huminic et al. (2011) presented the heat transfer characteristics of two-phase closed thermo syphon (TPCT) with iron oxide-nano fluids. Prasad Arvind Wale et al. (2015) reviewed the synthesis, properties and applications of TiO_2 nano fluid in various fields. Jian et al. (2010) performed experimental investigation on the thermal performance of an oscillating heat pipe (OHP) charged with base water and spherical Al_2O_3 particles. Noie et al. (2009) developed a two-phase closed thermo syphon (TPCT) device for heat transmission with aqueous Al_2O_3 nano particle suspensions in various volume concentrations. Experimental results showed that, the efficiency of the TPCT increases up to 14.7 % than that of pure water for different input powers.

Nada et al. (2004) investigated experimentally, a two-phase closed thermo syphon flat-plate solar collector with a shell and tube heat exchanger under the field conditions of Cairo, Egypt. The experimental results indicated that the number of the thermo syphon tubes has a significant effect on the collector efficiency. Wei Yu et al. (2009) measured the thermal transport properties of Ethylene glycol (EG) based ZnO nano fluids. Xing Zhang et al. (2007) measured the effective thermal conductivity and thermal diffusivity of Au/toluene, Al_2O_3/water, TiO_2/water, CuO/water and CNT/water nano fluids using the transient short-hot-wire technique.

With reference to the above cited literatures, it can be seen that majority of earlier works focused on thermo physical properties of the nano fluids on solar photovoltaic system. However, very few studies have concentrated on the energy efficiency analysis of Photovoltaic system. Moreover, further exploration on experimental performance enhancement of Solar Photovoltaic/thermal system with different nano fluid concentrations is required. Hence, the purpose of this work is to conduct an experimental energy efficiency analysis on two different concentration with φ=0.1 % and 0.2 % of TiO_2 nano fluid with varying three mass flow rates of fluid (0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s) respectively.

METHODOLOGY

This study contains the analysis of electrical and thermal efficiency for the designed solar photovoltaic/thermal system (SPV/T) for water, TiO_2, with φ 0.1 % and 0.2 % concentration for the mass flow rate of 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s.

The following assumptions are made for the analysis of solar photovoltaic/thermal system:

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 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.

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:

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

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)

$$\dot{S} = G N_s N_m A_{mod} \quad (2)$$

Where,
G = solar radiation (W/m^2)
N_s = number of strings
N_m = number of modules
A_{mod} = PV module area (m^2)

$$A_{mod} = L_1 L_2 \quad (3)$$

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

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

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)

Thermal efficiency

Hottel and Woertz (1942) as reported by Duffie and Beckman (2013) first investigated thermal performance of solar flat plate collector. Bliss (1959) introduced the collector heat removal factor, FR, 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 Equation (5).

$$Q_u = F_R A_{\text{mod}} [G(\tau\alpha) - U_L (T_f - T_a)] \quad (5)$$

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)
$\dot{m}$ = mass flow rate of fluid (kg/s)
Cp= specific heat of fluid (kJ/kg K)
TO= outlet air temperature (°C)
T_o= inlet air temperature (°C)
T_i = inlet air temperature (°C)

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

F_R= heat removal factor,
$\dot{m}$ = mass flow rate of fluid (kg/s)
Cp= specific heat of fluid (kJ/kg K)
TO= outlet fluid temperature (°C)
Ti= 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, FR as given in the Equation (9). This relation is known as Hottel-Whillier Bliss Equation (9).

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

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)

Nusselt number

The Nusselt number equation for both base fluid and nanofluids is as:

$$Nu = \frac{hL}{k} \qquad (10)$$

Where,
h= convection heat transfer coefficient W/m2K
K =thermal conductivity W/m K
L= Characteristic length m
Heat transfer Coefficient

$$h = \frac{q}{\Delta T} \qquad (11)$$

Where,
h= heat transfer coefficient in W/m^{2}K
q=local heat flux density (W/m^2)
ΔT=temperature difference (K)
Reynolds No

$$\mathrm{Re} = \frac{\rho V D}{\mu} \qquad (12)$$

Where,
ρ = Density of the fluid, g/cm3
V = Velocity of the fluid, cm/s
D = Diameter of the tube, m
μ = Viscosity of the fluid, kg/ms

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 these parameters, the equations used to calculate the uncertainty and error analysis given as: [Holman JP].

$$S_x = \left[\frac{1}{N-1} \sum (X_i - \bar{X})^2 \right]^{1/2} \qquad (13)$$

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= $N - 1 = 7$ degrees 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:

$$P_X = tS_X \qquad (14)$$

Where,
P_X=PrecisionLimit
S_X =Precision Index

EXPERIMENTAL DESCRIPTION

Nano fluid Preparation

The TiO_2 nanoparticles were supplied by Across Organics and used without any further purification .The physical characteristics of Titanium (iv) Oxide (TiO_2) are <25 nm (TEM), with purity: 98.0-100.5%, surface area: 45m^2 /gm. Two types of sample nano fluids were prepared by dispersing TiO_2 nano particles with different φ of 0.1 % and 0.2 % in milli-Q water, as the BF. An Ultra sonic processor was used for 2 hrs to ensure the proper mixtures of different φ TiO_2 nano particles into the BF. The nano fluid was found to be stable and no sedimentation was observed at low flow rates during the experiments and even in the stationary condition. Lower values of the volume fractions of nano particles are considered in the study of nano fluids to minimize the enhancement effect of viscosity. Nano fluid thermo physical properties are listed in Table 1and are influenced by several factors such as nanoparticle volume fraction as well as the thermal conductivity of a base fluid and nanoparticle.

Table 1 Water and Nanoparticle properties:

Name	c_p(J/kgk)	K (W/mk)	ρ (Kg/m^3)
Water	4182	0.60	1000
TiO_2	692	8.4	4230

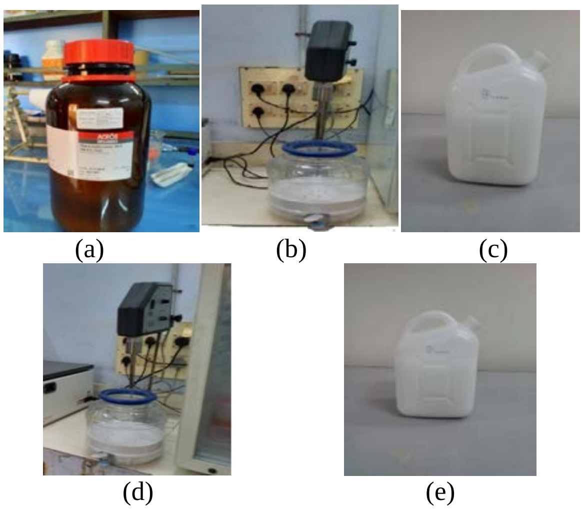

Fig. 1 (a) Represents the photographic view of TiO_2 nanoparticle, (b) nano fluid TiO_2 0.1% in ultrasonic processor, (c) prepared TiO_2 0.1% nano fluid, (d) nano fluid TiO_2 0.2% in ultrasonic processor and (e) prepared TiO_2 0.2% nano fluid

Experimental set up description

The Solar Photovoltaic panel was placed at an inclination angle of 13° on a rooftop of the building on a horizontal surface facing south. The experiments were conducted at Chennai, India, and the latitude and longitude of the test location is 13.08 °N and 80.27 °E, respectively. The experimental setup consists of a solar panel, SFCT heat exchanger, working fluid inlet tank, working fluid outlet tank, working fluid cooling tank, a flow meter, boosting pumps, valves, thermocouples and a data acquisition system.

The Photographic view of the experimental system and Serpentine flow copper tube heat exchanger and the schematic diagram of the experimental setup are shown in Figs. 2(a), (b) and 3 respectively. The solar photovoltaic panel with 100 W capacity with a PV module area of 0.91 m^2 was attached with the SFCT heat exchanger. The fluid (water/titanium dioxide of 0.1 % and 0.2 %) from the working fluid inlet tank entered through a valve to the booster pump 1 thereby indicating the fluid inlet temperature T_1 by the thermocouple inserted into the pipe connections and passed through the flow meter. The flow rate of the fluid was measured using a rotameter. The working fluid then entered into the lower end bottom of the heat exchanger and flowed along the SFCT heat exchanger, receiving the tedlar heat absorbed at the bottom of the solar photovoltaic panel, thereby the inlet working fluid got heated up and its temperature increased.

Fig. 2 (a) Photographic view of the SPV/T experimental system (b) Serpentine flow copper tube heat exchanger

The hot working fluid entered into the fluid collecting tank from the upper end bottom of the heat exchanger, by indicating the fluid outlet temperature T_2 by the inserted thermocouple. The hot working fluid then entered into a working fluid cooling tank and got gradually cooled when passed along a SFCT that was fluid with normal running water through booster pump 2. At this stage heat from the hot working fluid is transferred to the normal running water kept in the collecting tank. The normal running water used for cooling purpose after regular intervals are discharged out now and then. Then the cooled working fluid reached the inlet fluid tank for the recirculation along the solar PV/T system. This cycle is repeated so that the solar photovoltaic panel is cooled continuously thereby increasing the system efficiency. The glazing and tedlar temperatures were recorded by the thermocouples that were on and beneath the solar photovoltaic panel. All temperature values were tracked by a data logger in short step times (10 sec) during the experiment period. The solar radiation was measured using a digital solar power meter by placing it over the PV panel. Experimental data were collected and recorded at a regular time interval of 30 min.

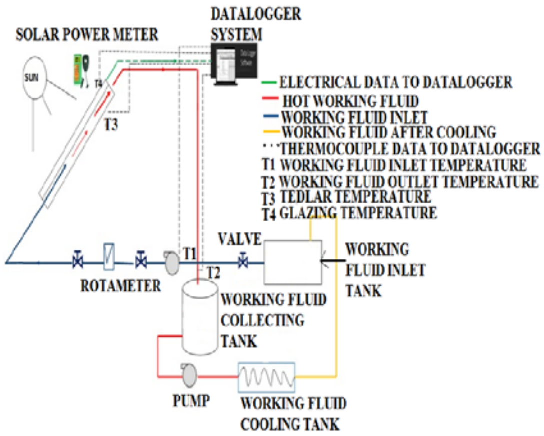

Fig. 3 Schematic diagram of the experimental system

Table 2 Specifications of solar photovoltaic /thermal system

Component Description	Dimensional Value
Tilt Angle of the solar panel	13°
Absorptance of the glass cover, α	0.85
Length of the PV module, L_1	134.9 cm
Width of the PV module, L_2	67.8 cm
PV module area, A_{mod}	0.914622 m^2
Length of Copper Tube, L_C	510mm
Diameter of Copper tube, D_C	15.95mm
Booster Pump 1	60 psi
Booster Pump 2	60 psi
Digital solar power meter	2000 W/m^2
Current at Maximum Power, I_{mp}	5.75 A
Voltage at Maximum Power, V_{mp}	17.40V
Open circuit voltage, V_{OC}	21.40 V
Short circuit current, I_{SC}	6.41 A
Temperature Coefficient	-0.41%/°C
Transmittance of the glass cover, τ	0.95
Operating parameters	
Ambient Temperature, T_a	302-306 K
Solar Radiation, G	700-1200 w/m^2

RESULTS AND DISCUSSIONS

The solar photovoltaic /thermal system (SPV/T) experimental performance analysis were evaluated on days with clear sky condition. The performance assessment of TiO_2 nano fluid with φ = 0.1 %, 0.2 % and mass flow rates 0.015 kg/s, 0.0133 and 0.0117 kg/s were investigated and compared with water. The experiment was carried from 9 am to 4 pm on all experimental days during January to March at Chennai, India. The photographic view of nano fluid and SPV/T system are shown in Figs. 1, and 2 respectively. The typical values of the nano fluid and the system operating parameters used in the present experimental study are shown in Tables 1, 2 respectively.

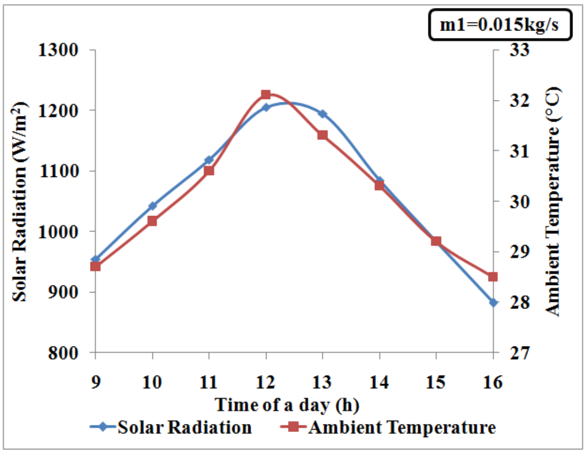

Fig. 4 Average solar radiation and ambient temperature for titanium dioxide nano fluids at mass flow rate 0.015 kg/s during the experiment period.

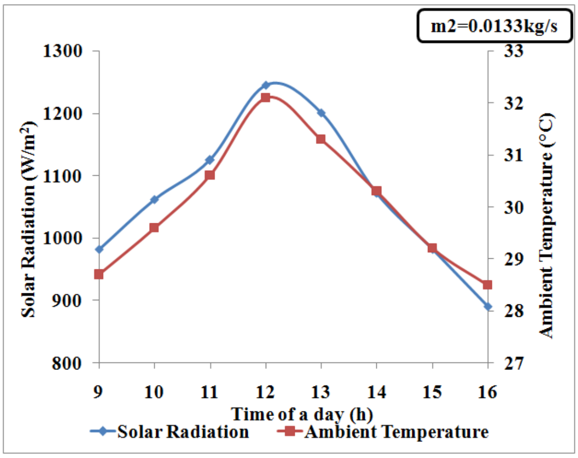

Fig. 5 Average solar radiation and ambient temperature for titanium dioxide nano fluids at mass flow rate 0.0133 kg/s during the experiment period.

Figs. 4, 5 and 6 depicts the average daily variation of the solar radiation and ambient temperature during the experiment period. The maximum solar radiation was found to be 1266 W/m2 at 12 h and minimum solar radiation was found to be 882 W/m2 at 16 h. Similarly, the maximum ambient temperature was found to be 33.4°C at 12 h and minimum ambient temperature as 28.7°C at 9 h and 16 h respectively.

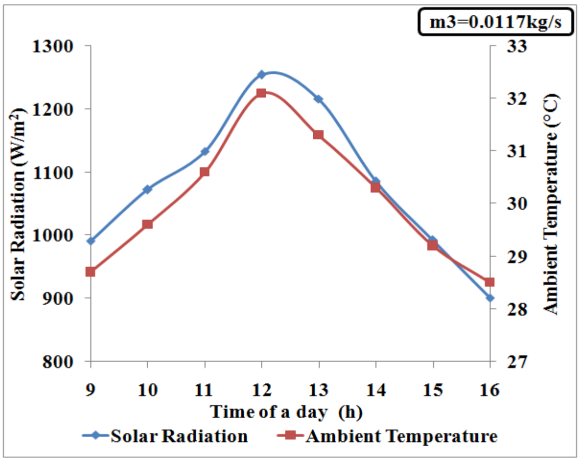

Fig. 6 Average solar radiation and ambient temperature for titanium dioxide nano fluids at mass flow rate 0.0117 kg/s during the experiment period.

Solar radiation was always higher at midday and lower in the morning and evening hours. Evidently, the solar radiation and ambient temperature from 9 h to 16 h represented a dome-shaped structure. It was observed that higher solar radiation was obtained during 11:00 h to 13:00 h. Similarly, the maximum ambient temperature was obtained from 12:00 h to 13:00 h. The inlet temperatures of all the three working fluids were nearly closer to the ambient temperature.

Electrical efficiency (η_{el})

The PV efficiency and PV temperature with the time of a day for the different TiO2 ,with φ = 0.1%, 0.2 % and mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s were compared with water and investigated by using the equations 1,2,3 and are graphically depicted in Figs. 7, 8 and 9 respectively. When the working fluids like water and TiO2 were circulated inside the SFCT heat exchanger the overall temperature of PV panel reduced lead to an enhanced electrical efficiency. The electrical current was dependent on solar radiation intensity, so that the variation of solar radiation intensity and electrical current were qualitatively the same. But the electrical voltage was reversely dependent on solar cells temperature Similarly the solar cells temperature were dependent on solar radiation intensity, so that the variation of solar radiation intensity and solar cells temperature were qualitatively the same.

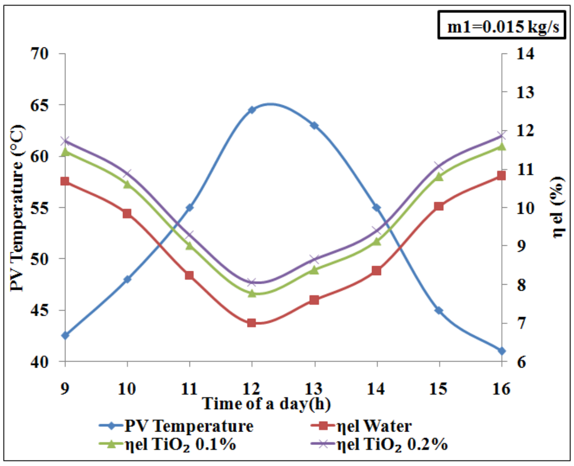

Fig.7 PV-Temperature and η_{el} with the time of a day for mass flow rate at 0.015 kg/s

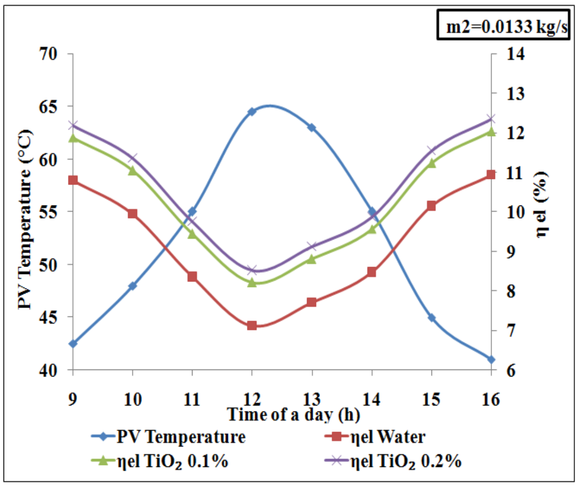

Fig. 8 PV-Temperature and η_{el} with the time of a day for mass flow rate at 0.0133 kg/s

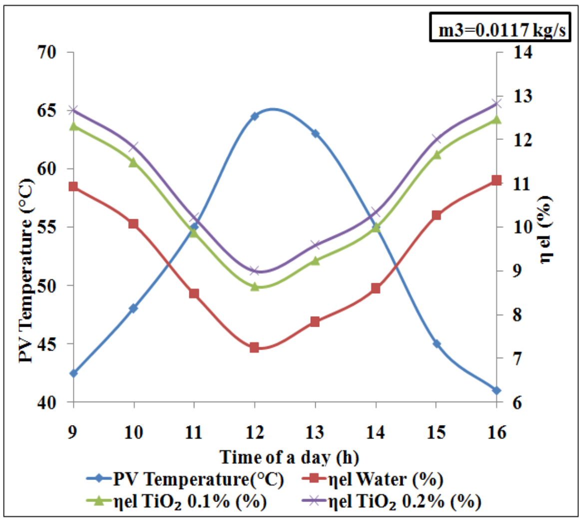

Fig. 9 PV-Temperature and η_{el} with the time of a day for mass flow rate at 0.0117 kg/s

Moreover the PV temperature was high during noon and low during the morning and evening hours respectively. But, in contrast PV efficiency was high during morning and evening hours and low in the noon time. Due to sun movement this difference occurred throughout the day. Based on the results in Table 3, it can be concluded that the electrical efficiency of the SPV/T system was obtained as 10.82 %, 11.60 %, and 11.87 % for water, TiO_2 0.1 % and TiO_2 0.2 % nano fluids respectively at mass flow rate of 0.015 kg/s. 10.94%,12.03%,12.34% for water, TiO_2 0.1 % and TiO_2 0.2 % nano fluids respectively at mass flow rate of 0.0133 kg/s. 11.06%, 12.46%, 12.81% for water, TiO_2 0.1 % and TiO_2 0.2 % nano fluids respectively at mass flow rate of 0.0117 kg/s. TiO_2 nano fluids has more heat absorbing capability than water which considerably decreased its glazing surface temperature. It has been observed that the electrical efficiency (the ratio of maximum power to the incident solar radiation) was increased by 2 % at a mass flow rate of 0.0117 kg/s with TiO_2 0.2 % nano fluids due to decrease in temperature of solar cell of PV module.

It was concluded that TiO_2 nano fluids, has obtained the highest average electrical efficiency. This is because of a more uniform distribution in the surface temperature reduction for TiO_2 0.1 %, 0.2 % nano fluids compared to water. Therefore, increase of nanoparticles concentration slightly reduced the surface temperature, which in turn translated into a slight increase of electrical efficiency. Good thermal conductivity leads to a small temperature difference between the PV cells and the heat transferring fluids in the system and thereby to a minimal PV cell temperature. The maximum enhancement ratio due to heat transfer rate of the working fluids increased with the maximum mass flow rate of 0.0115 kg/s and the heat transfer rate started to decrease at the minimum mass flow rates of 0.0133 kg/s and 0.017 kg/s, because the value of the temperature difference decreases with the increase in mass flow rate.

Electrical efficiency has a relationship with the inlet water temperature at different solar irradiation levels. Hence, due to the necessity in variation of mass flow rates and working fluid inlet temperature, the effect of nano fluids concentrations differs with respect to the performance of the collector. The nanoparticles size has an effect on the efficiency of the SPV/T hybrid system. The electrical energy efficiency of the SPV/T hybrid system using nano fluids increased with raising the concentration of the nanoparticles. The superior thermo-physical properties of titanium dioxide nanoparticles, especially higher thermal conductivity results in higher electrical energy efficiency in comparison with water. Furthermore titanium dioxide nano fluids are more successful than water in decreasing the temperature of absorber plate and thereby increasing the electrical efficiency. These results are in harmony with the result reported earlier by Mohammad (2016), Jin (2016), Niccolo (2015), Amna (2014) and Azmi (2014).

Table 3 Electrical Efficiency (η_{el}) of the SPV/T system

Working Fluid	TiO_2 0.1 %	TiO_2 0.2 %	Water
Mass flow rate kg/s	η_{el} (%)	η_{el} (%)	η_{el} (%)
0.015	11.6	11.87	10.82
0.0133	12.03	12.34	10.94
0.0117	12.46	12.81	11.06

Working fluids outlet temperature

The hourly variation in the difference of working fluid outlet and inlet temperature ΔT (°C) with respect to time for mass flow rate at 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s are depicted in Figs. 10, 11 and 12 respectively. Outlet and inlet working fluid temperature parameter plays a vital role in contributing towards the overall thermal efficiency of the system. Fig. 10 had minimum a temperature difference due to its higher mass flow rate in comparison with the Figs. 11 and 12 at lower mass flow rates. This is mainly due to the velocity rate at which the working fluid flows under the PV panel and different concentrations of TiO_2 nano fluids.

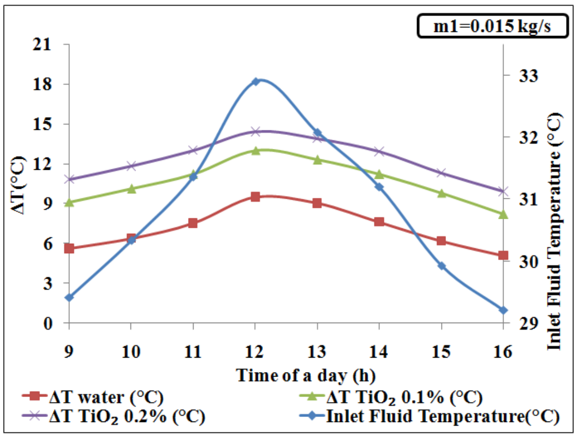

Fig. 10 Working fluids outlet temperature and working fluids inlet temperature with the time of a day for mass flow rate at 0.015 kg/s.

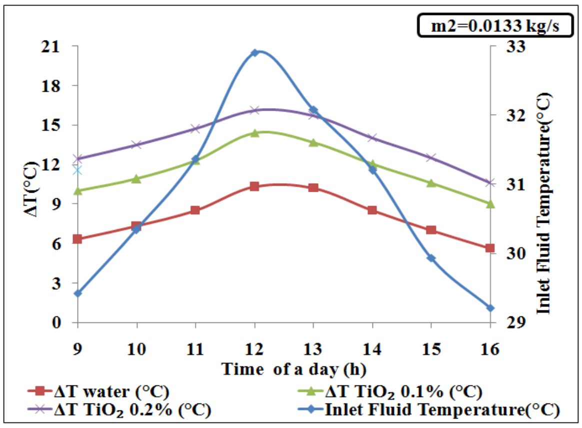

Fig. 11 Working fluids outlet temperature and working fluids Inlet temperature with the time of a day for mass flow rate at 0.0133 kg/s.

The difference between the measured working fluid inlet temperature and that of the collector outlet temperature are 11.1°C, 15.8°C, 17.8°C for water, TiO_2 0.1 % and TiO_2 0.2 % nano fluids respectively at mass flow rate of 0.0117 kg/s. This temperature difference is directly related to the thermal efficiency of the collector. A close inspection of the results showed in Figs. 10, 11 and 12 revealed that the average temperature difference between the SPVT system inlet and outlet was maximum for TiO_2 0.1 %, 0.2 % nano fluids and minimum for water. This, in turn, led to the best thermal performance by TiO_2 nano fluids than water.

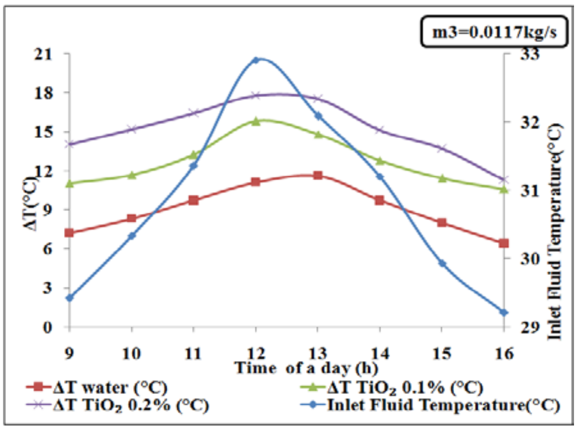

Fig.12 Working fluids outlet temperature and working fluids inlet temperature with the time of a day for mass flow rate at 0.0117 kg/s.

In addition, the working fluids inlet temperature of the collector slightly increased in the experiment duration due to the closed circulation system used for the working fluid. The outlet working fluids temperature strongly depends on the heat capacity of nano fluids, a lower heat capacity at higher outlet temperature. Therefore, TiO_2 nano fluids with lowest heat capacity provide the highest value of outlet temperature, when compared to water. The amount of heat that the working fluids absorbed from PV module was dependent on the solar cells temperature, so the variation of solar cells temperature and outlet temperature of water are qualitatively the same. It is clear that the outlet temperature increased with decrease in the mass flow rate. In addition, at a given mass flow rate, the outlet temperature of nano fluids are higher than water because of the lower heat capacity of nano fluids.

Based on the comparison between the outlet temperature of the solar PV/T system using TiO_2 nano fluids and water, it is apparent that TiO_2 nano fluids have greater effect on the outlet temperature than water as a working fluid. It can be seen that the outlet temperature increased sharply with the higher volume concentration of nanoparticles up to a certain amount which later started to decline. This fact reveals that there is a limiting value of volume concentration after which, no further improvement occurs in the outlet temperature. On the other hand, at a given volume concentration of nanoparticles, the number of nanoparticles decreases with an increase of nanoparticle size. This means that the total contact area between the particles in the suspension is reduced, and hence the local shear stresses in the layers of fluid and consequently the effective viscosity decreases. Then, the nano fluids containing bigger particles provide a more turbulent flow and hence a higher Reynolds number. These results are in harmony with the results reported earlier by Maouassi (2017), Niccolo (2015), Amna (2014).

Thermal efficiency (η_{th})

Figs. 13, 14 and 15 graphically depicted the variation of hourly thermal efficiency for the month of January to March for TiO_2, with φ = 0.1 %, 0.2 % and three mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s respectively. The thermal efficiency TiO_2, with φ = 0.1 %, 0.2 % and three mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s were compared with water and investigated by using the equations 4 to 9 respectively. Various parameters such as mass flow rate of working fluids, specific heat of working fluids, and difference in the working fluids inlet and outlet temperature of the system, solar radiation and area of the PV panel has contributed towards the thermal efficiency of the system. At a constant absorbed radiation and mass flow rate, the outlet temperature and specific heat are the determinative factors in thermal energy efficiency changes. It can be deduced that the thermal energy efficiency is extremely dependent on the inlet and outlet working fluid temperature difference.

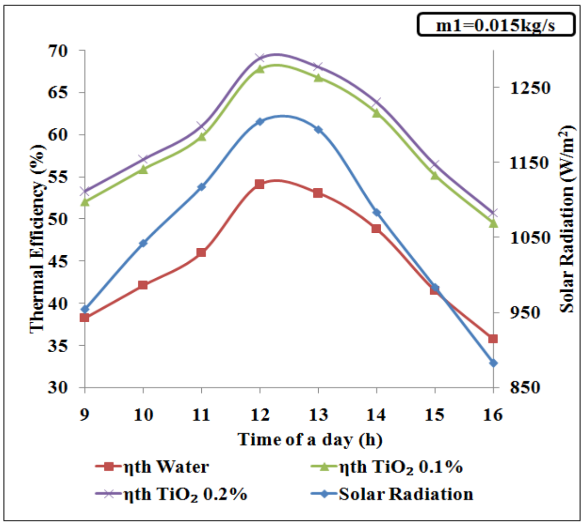

Fig.13 η_{th} and solar radiation with the time of a day for mass flow rate at 0.015 kg/s.

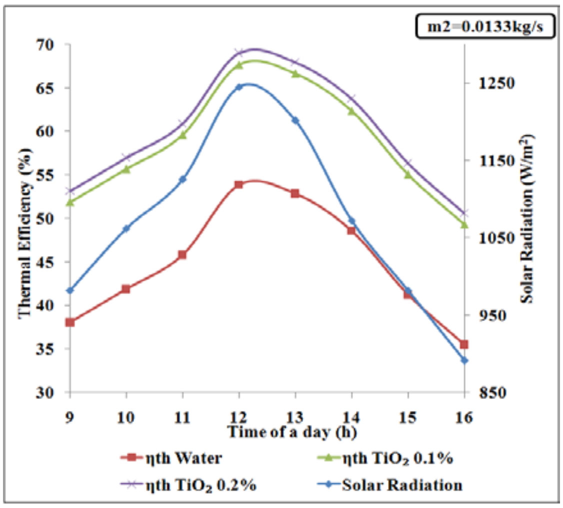

Fig.14 η_{th} and solar radiation with the time of a day for mass flow rate at 0.0133 kg/s.

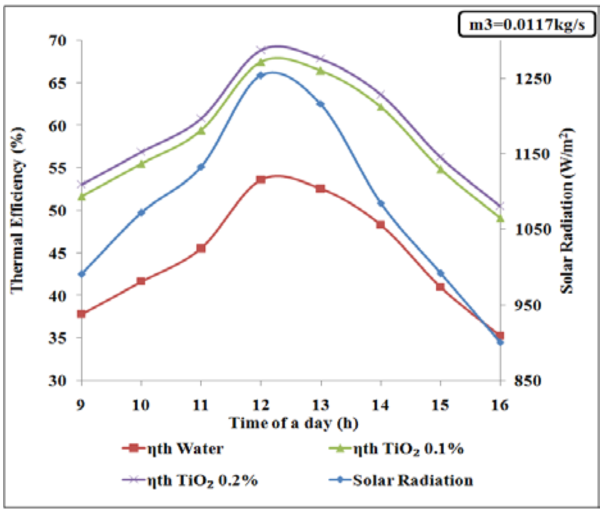

Fig.15 η_{th} and solar radiation with the time of a day for mass flow rate at 0.0117 kg/s.

Each working fluid has unique thermo physical properties as shown in Table 1 and based on it the turbulences, thermal efficiency also varied. In the SPV/T systems, the generation and removal of heat has taken place in different locations in the module. Moreover, it was analysed that the thermal energy production was related to the aperture area of the collector. The results revealed that the effect of nano fluids on system thermal efficiency is less for mass flow rate of 0.0117 kg/s when compared to 0.015 kg/s and 0.0133 kg/s. Based on the results and Table 4, the thermal efficiency has been found to vary between 53.61 % and 69.05 %.

However, for Tio_2 0.1 % and 0.2 % nano fluids at higher temperature differences, the heat loss decreased in comparison with water. The main effect of increased nano fluid concentrations was on the thermal performance of the system. Additionally, the system thermal efficiency was also influenced by the solar radiation. As the solar radiation from 11.00 h to 13.00 h is considerably high, it has reflected in higher thermal efficiency of different mass flow rates of fluids. Whereas the solar radiation at 9.00 h and 16.00 h were comparatively lower resulting in lesser thermal efficiency of the SPV/T system.

Thermal conductivity of TiO_2 nano fluids was higher than water, so considerable amount of heat energy had been absorbed from the solar panel to cool the system. Hence, its performance was much better than water as a working fluid. Solar radiation was the prime factor in increasing the thermal efficiency of the system as more heat is extracted from the tedlar side of the SPV/T system during high solar radiation hours and vice versa. It was inferred that the, solar radiation is considered as one of the significant factors in contributing towards the thermal efficiency of the SPV/T system.

Moreover, the difference of inlet and outlet fluid temperature of different concentrations also remarkably contributed towards the enhancement in thermal efficiency of the system. The thermal balance of the working fluids in the absorber was determined by considering the sum of the thermal energy coming out of the collector and the energy accumulated by the working fluids in the channels is equal to the energy transferred from the PV absorber to the working fluids. Using nano fluids instead of the base fluid and by increasing the mass flow rate were the methods for increasing the system thermal efficiency factor (Duffi & Beckman, 1991).

The thermal performance of nano fluids with different concentrations at higher mass flow rate was better than water. The more heat energy extracted from the tedlar side generated better performance of the system. The overall heat transfer coefficient starts to decrease at lower mass flow rate because the value of the temperature difference decreases with the increase in mass flow rate. Overall heat transfer coefficient for TiO_2 nano fluids increases at the highest mass flow rate of 0.015 kg/s than water. The reason is that the thermal conductivity of nanoparticles increases thereby a large energy exchange process is resulted from the chaotic movement of the nanoparticles.

Thermal conductivity of TiO_2 nano fluids is higher than water, which indicates that considerable amount of heat energy has been absorbed from the solar panel to cool the system. Hence, its performance was much better than water as a working fluid. Thermal efficiency of TiO_2 nano fluids at mass flow rate of 0.015 kg/s was observed to be higher than water at the same mass flow rate. This trend cannot be observed in lower mass flow rates, because the values of Reynolds numbers are very high. Eventually, the thermal efficiency of TiO_2 nano fluids, are higher than water. Similar observations have been reported earlier [Jin (2016), Mohammad (2016), Niccolo (2015), Madhuri (2015), Amna (2014), and Hossein (2013)].

Table 4 Thermal Efficiency η_{th} of the SPV/T system

Working Fluid	TiO_2 0.1%	TiO_2 0.2%	Water
Mass flow rate kg/s	η_{th} (%)	η_{th} (%)	η_{th} (%)
0.015	67.82	69.05	54.07
0.0133	67.64	68.96	53.84
0.0117	67.46	68.87	53.61

Effect of Nusselt Number

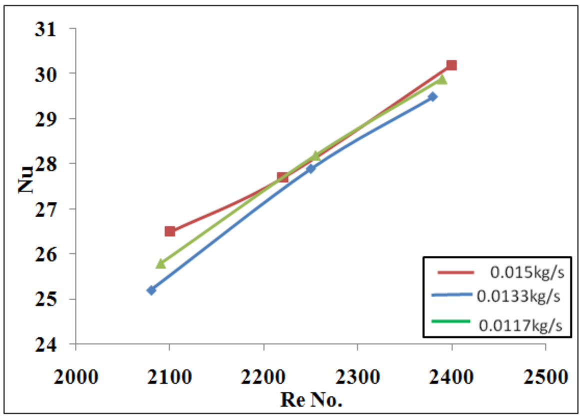

Fig. 16 Nusselt number variations of working fluids at different mass flow rates (0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s) as a function of Reynolds number

Fig. 16 represents the Nusselt number for distilled water as well as for different concentrations of TiO_2/water nano fluids in relation to the Reynolds numbers at three mass flow rates of 0.015 kg/s, 0.0133 kg/s, 0.0117 kg/s respectively. Nusselt numbers of the nano fluids are higher than the base fluid, and the numbers are increasing with the increase in Reynolds number as well as the particle volume concentration. The maximum value can be obtained at the maximum Reynolds number and at the volume concentration of 0.2 % of titanium dioxide nano fluids. As the mass flow rates of the working fluids increases the Nu number also increased in all the concentrations and consequently Re number. Heat transfer efficiency is directly related with the concentration of nanoparticles. Whenever the concentration is increased heat transfer coefficient also increased. In addition of 0.1 % and 0.2 % of TiO_2 nanoparticles into the pure water, an increase in heat transfer coefficient than water was recorded.

Figs. 17, 18 and 19 shows the increase in overall heat transfer coefficient for a given mass flow rate. The heat transfer rate of water and TiO_2 nano fluids increased with the increase in mass flow rate. The same results are shown in Jaafar et al. (2013) and Bhimani et al. (2013). The addition of development for overall heat transfer rate using distilled water as working fluid. This is because thermal conductivity resulted in an increase of heat transfer performance and viscosity of the thickness.

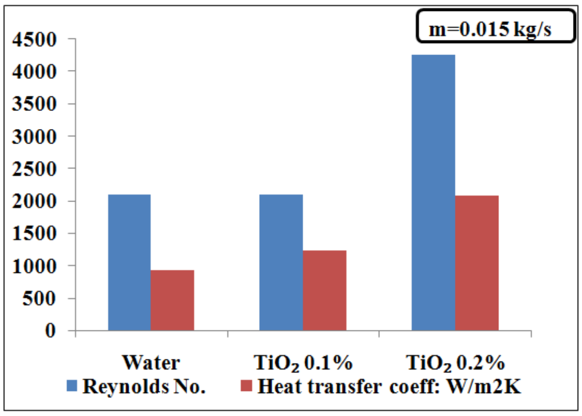

Fig. 17 Overall heat transfer coefficient versus Reynolds number

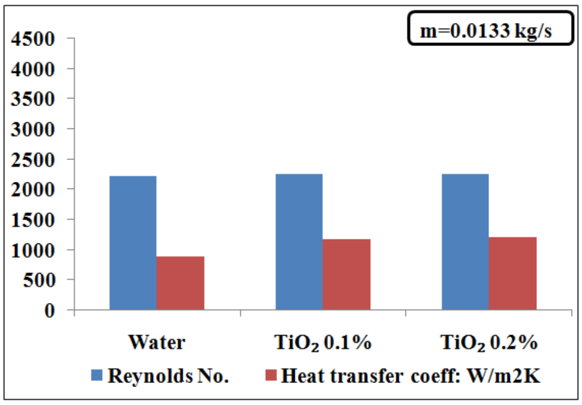

Fig. 18 Overall heat transfer coefficient versus Reynolds number

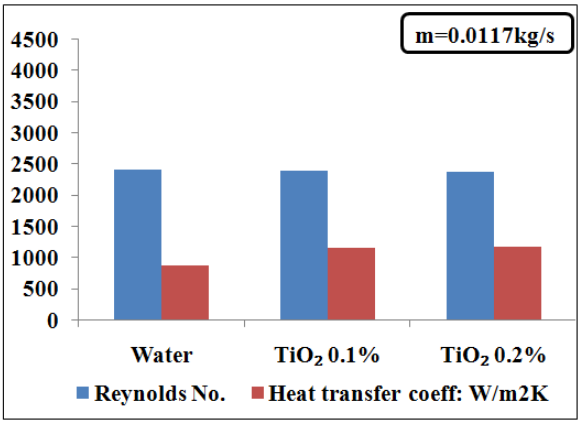

Fig 19 Overall heat transfer coefficient versus Reynolds number

CONCLUSION

A detailed Electrical and Thermal experimental analysis for TiO_2 nano fluids with φ = 0.1 %, 0.2 % and three mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s were investigated and compared with water. Based on the present study, major observations were examined on solar photovoltaic /Thermal system and summarized as below:

1. A line fitted on experimental data of PV temperature and electrical efficiency for each case revealed that as the PV panel was heated more its electrical efficiency decreased, but by passing the working fluids as the coolants below the solar panel, its electrical efficiency increased. The electrical efficiency for water was 10.82 % to 11.06 %, for TiO_2 0.1 % 11.60 % to 12.46 % and TiO_2 0.2 % 11.87 % to 12.81 % respectively. The PV temperature, however, was reduced by only 2% which, in turn, resulted in a slight increase of electrical efficiency by 0.2 % concentration. The SPV/T system overall performance was totally dependent on the suspension sustainability of the coolant used. In this study TiO_2 nano fluids were used which possessed very good heat transfer characteristics when mixed with water and suspended uniformly by sonication process.
2. The experimental performance was significant as the working fluid outlet temperature was higher 11.1°C, 15.8°C, 17.8°C for water, TiO_2 0.1 % and TiO_2 0.2 % at lower mass flow rates 0.0117 kg/s than the other two higher mass flow rates of 0.015 kg/s and 0.0133 kg/s respectively. Therefore, by varying the mass flow rates and different concentration, the heat removal factor (FR) can be increased considerably.
3. A line fitted on the experimental data of solar radiation and thermal efficiency for each case revealed that the thermal efficiency increased with the mass flow rate and nano particle concentrations and due to the change in outlet working fluid temperature. The thermal efficiency for water resulted as 53.61 % to 54.07 %, TiO_2 0.1 % as 67.46 % to 67.82 % and TiO_2 0.2 % as 68.87 % to 69.05 % respectively. Based on this analysis, the TiO_2 nano fluids with φ = 0.2 % at mass flow rates 0.015 kg/s showed a better thermal performance compared to other working fluids. The results showed that while the thermal performance of the SPV/T system was highly dependent on the concentration of the nano fluid with its minimal mass flow rate.
4. At higher mass flow rate minimum heat was absorbed by the working fluids leading to lower working fluid outlet temperature with maximum thermal efficiency. Therefore, the achieved efficiency of the SPV/T system was remarkably dependent on the solar radiation and thermo physical properties of the working fluids As a result using Titanium dioxide nano fluids with a high concentration will considerably improve the thermal performance of the system.
5. The results showed that TiO_2 nano fluids with φ = 0.1 %, 0.2 % and three mass flow rates 0.015 kg/s, 0.0133 kg/s and 0.0117 kg/s had greater

effect on the heat transfer performance and efficiencies than those of water as a coolant. In addition, the results presented in this paper are found to be promising. Even though this work has been carried out for a specific application, it has the potential that SPV/T system can be used in a variety of other applications, where both the electrical and thermal energy are required, particularly when there is a further price decrease of solar cells. Further work is needed to identify and design an advanced predictive control strategies for SPV/T system.

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NOMENCLATURE

A_{mod}	PV module area (m^2)
BF	Base Fluid
C_p	Specific heat of fluid (kJ/kg.K)
D_c	Diameter of Copper tube (mm)
$\dot{E}_{el}$	Outlet electrical power (W)
F_R	Heat removal factor
G	Solar radiation (W/m^2)
I_{mp}	Current at Maximum Power (A)
k	Thermal Conductivity (W/m.k)
L_1	Length of the PV module (cm)
L_2	Width of the PV module (cm)
L_c	Length of Copper Tube (mm)
$\dot{m}$	Mass flow rate of working fluid (kg/s)
m	Mass (kg)
N_m	Number of modules
N_s	Number of strings
Q_u	Useful heat energy gained (kJ)
SFCT	Serpentine flow copper tube
SPV/T	Solar Photovoltaic /Thermal
$\dot{S}$	Rate of solar energy incident on the PV surface (W)
TiO_2	Titanium Oxide
TEM	Transmission Electron Microscope
T	Temperature (°C)
T_a	Ambient Temperature (°C)
T_f	Fluid temperature (°C)
T_i	Inlet working fluid temperature (°C)
T_o	Outlet working fluid temperature (°C)
U_L	Overall heat loss coefficient (W/m^2 °C)
V	Volume (m^3)
V_{mp}	Voltage at Maximum Power (V)
v	Velocity of working fluid (m/s)

Greek symbols

φ	Concentration in %(w/V)
τ	Transmittance of the glass cover
α	Absorptance of the solar cell
ρ	Density(kg/m^3)
η_{el}	Electrical efficiency (%)
η_{th}	Thermal efficiency (%)