Hybrid PV/T Panel	300W, Collector area 1.44m^2
Battery	Amaron; 12V, 100Ah
Pump	Metro; 165-250Volts, Power: 12 W H_{max} = 1.5-2.8 m of water
Flow meter	Capacity:- 0-2 LPM
Data logger	E&E, 8 channel datalogger
Infrared Thermometer	HTC; MT4 Range: -50 to 550 °C
Heat Exchanger	Air cooled fin type
Thermocouple	Range 0 to 500 °C Nickel-Chromium (K type)/Metal wire
Solarimeter	Tenmars electronics; TM 206
Solar Simulator	Halonix; 49 Halogens of 150 watts each
Charge Controller	Sukam; MPPT Charge controller

Table.1 shows the components of experimental setup

Material	**Properties**			
	Specific Heat (J/Kg-K)	**Density (Kg/m^3)**	**Thermal Conductivity (W/m-K)**	**Particle size**

Zinc Powder	376.81	7140	1.16	240
Ethylene Glycol	337	1110	0.285	-
Propylene Glycol	323	1051	0.147	-

Table.2 Shows the Material specifications

METHODOLOGY

- By the two-step process nanofluids were prepared.
- Zinc nano powder of APS 50 nm was bought from Sisco Research Lab Pvt Ltd.
- 3 different solutions of concentration 0.3% by volume was prepared with Zn nanoparticles in 3 different base fluids; Water, Water (75%) with Ethylene Glycol (25%) and Water (75%) and propylene Glycol (25%).
- In each case sonication was performed in an Ultra sonic bath for 2 hrs. to produce colloidal solutions.
- A closed circuit for the flow of nanofluid was established with the heat exchanger and a pump in between as shown in figure 1.
- Thermocouples are attached at different points to measure the temperature.
- Setup was then run at a constant flow rate of 2 lpm (0.03kg/s) and the readings were taken at intervals of 30 min.
- Intensity of radiation was varied after every half an hour, starting from 700W/$m^2$to 900 W/m^2 to simulate the outdoor conditions.

Governing Equations

After taking all the readings, thermal and electrical efficiencies of the hybrid PV/T system would be evaluated to investigate the effect of nanofluids.

Applying Energy balance and assuming steady state:-

$$E_{in} = E_{out}$$

which implies,

$$E_{in}^{\cdot} = E_{el}^{\cdot} + E_{th}^{\cdot} + E_{loss}^{\cdot} \quad (1)$$

where **E_{el}** the output electrical power,

E_{in} is solar irradiation the incident,

E_{loss} is the energy loss for the control volume.

E_{th} the useful thermal energy gained from the collector

E_{th} can be evaluated through a simple analysis of energy as:-

$$E_{th} = m_f . C_{p,f} . (T_{f,out} - T_{f,in}) \quad (2)$$

where: -

$T_{f,in}$ and **$T_{f,out}$** represent the inlet temperature and outlet temperature of fluid from the collector

C_{pf} is the specific heat of fluid,

m_f is mass flow rate of the fluid through the collector, respectively.

Following empirical relations are used to evaluate the thermo physical properties of nanofluids:

- For Density of the mixture:

$$\rho_{nf} = \varphi\rho_n + (1 - \varphi)\rho_{bf} \quad (3)$$

And

$$\rho_{bf} = \emptyset\rho_{f1} + (1 - \emptyset)\rho_{f2} \quad (4)$$

- For the Specific Heat Capacity of the mixture:

$$C_{p,nf} = \frac{\varphi.(\rho_n.C_{p,n})+(1-\varphi).(\rho_{bf}.C_{p,bf})}{\rho_{nf}} \quad (5)$$

And

$$C_{p,bf} = \frac{\emptyset.(\rho_{f1}.C_{p,f1})+(1-\emptyset).(\rho_{f2}.C_{f2})}{\rho_{bf}} \quad (6)$$

where n, bf and nf signify subscripts, nanoparticles, base fluid, and nanofluid correspondingly and ρ is the density [8].

φ is the ratio (volumetric) of nanoparticles in a solution of suspension of the fluid (base) that can be considered as follows:

$$\varphi = \frac{m_n/\rho_n}{m_n/\rho_n + m_{bf}/\rho_{bf}} \quad (7)$$

where m_f and m_n are the mass of the fluid and nanoparticles respectively.

$\emptyset$ is the ratio (volumetric) of fluids in the fluid (base) solution which might be evaluated by:

$$\emptyset = \frac{m_{f1}/\rho_{f1}}{m_{f1}/\rho_{f1} + m_{f2}/\rho_{f2}} \quad (8)$$

where m_{f1} and m_{f2} are the masses of the fluids, used to prepare the base fluid.

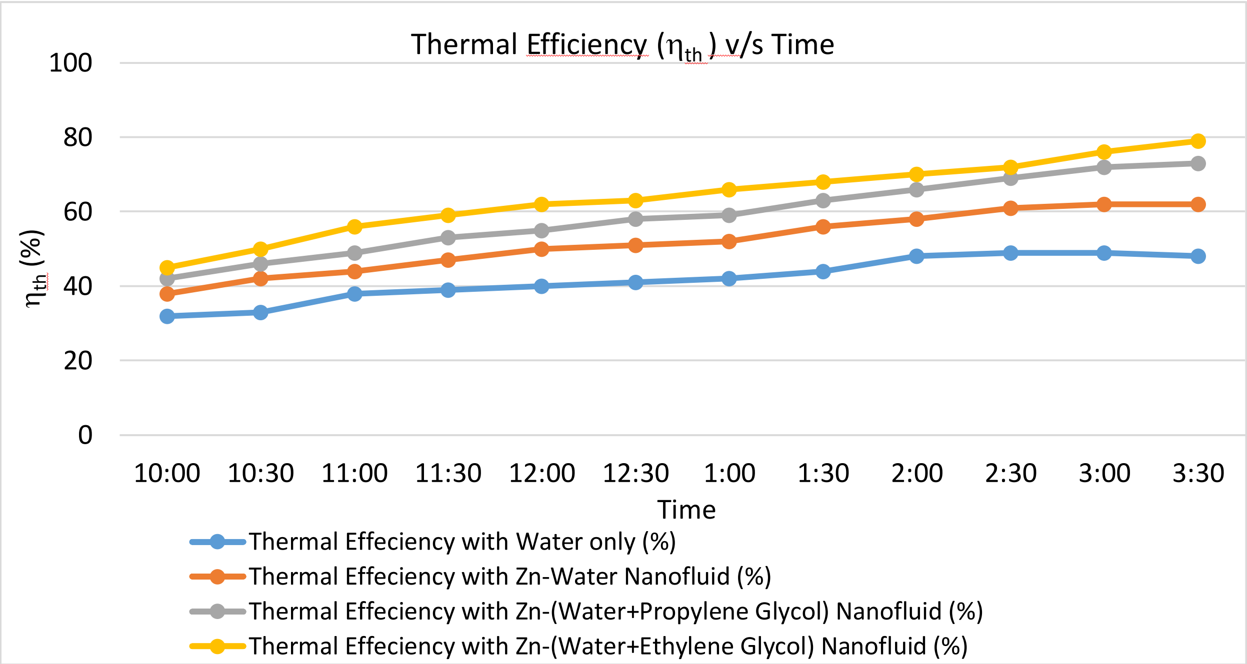
- Thus thermal efficiency can be expressed as:

$$\eta_{th} = \frac{\dot{E_{th}}}{\dot{E_{in}}} \quad (9)$$

- The electrical efficiency might be stated as:-

$$\eta_{el} \equiv \frac{\dot{E_{el}}}{\dot{E_{in}}} = \frac{V_{oc}\times I_{sc}\times FF}{\dot{G_{eff}}\times A_c} \quad (10)$$

Where,



- Short circuit current $\mathbf{I_{sc}}$.
- Open circuit voltage $\mathbf{V_{oc}}$.
- **FF** is fill factor (for polycrystalline PV panels the value of fill factor is **0.89**).
- $\mathbf{G_{eff}}$ is the mean of the radiation incident evaluated from solar power meter.
- $\boldsymbol{A_c}$ is the area of collector.

RESULTS

Figure.2 Thermal Efficiency (η_{th}) v/s Time graph

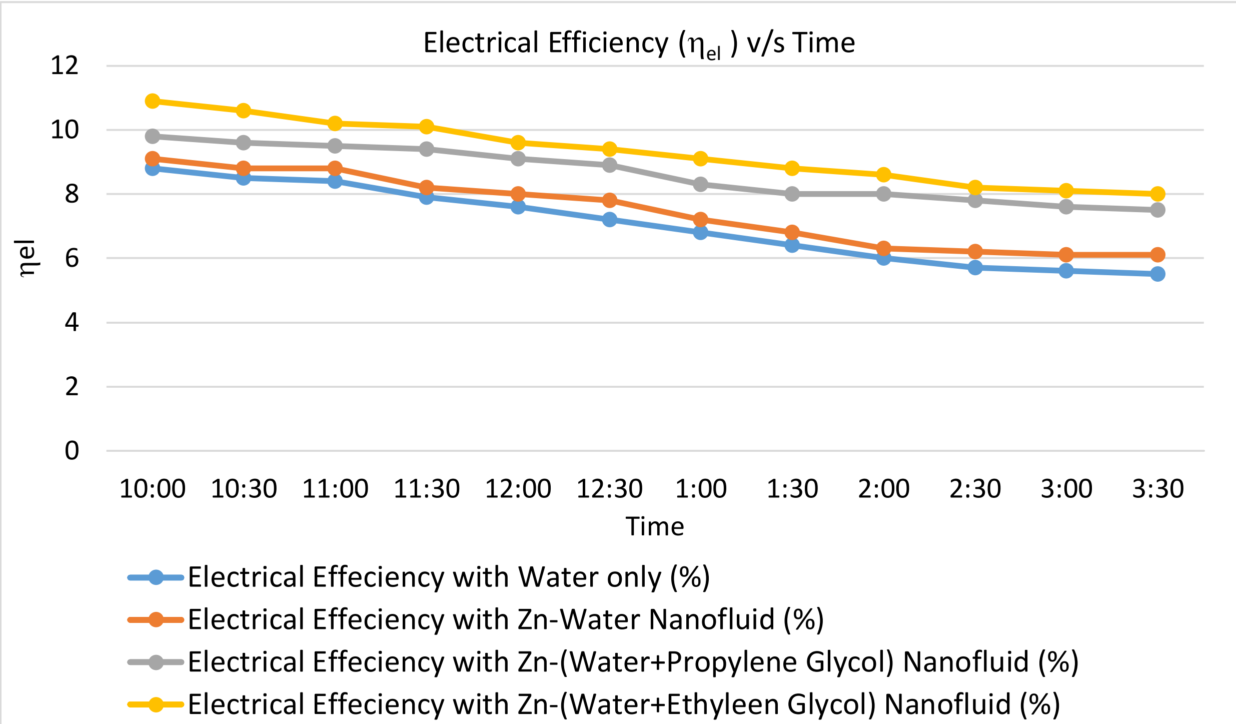


Figure.3 Electrical Efficiency (η_{el}) v/s Time

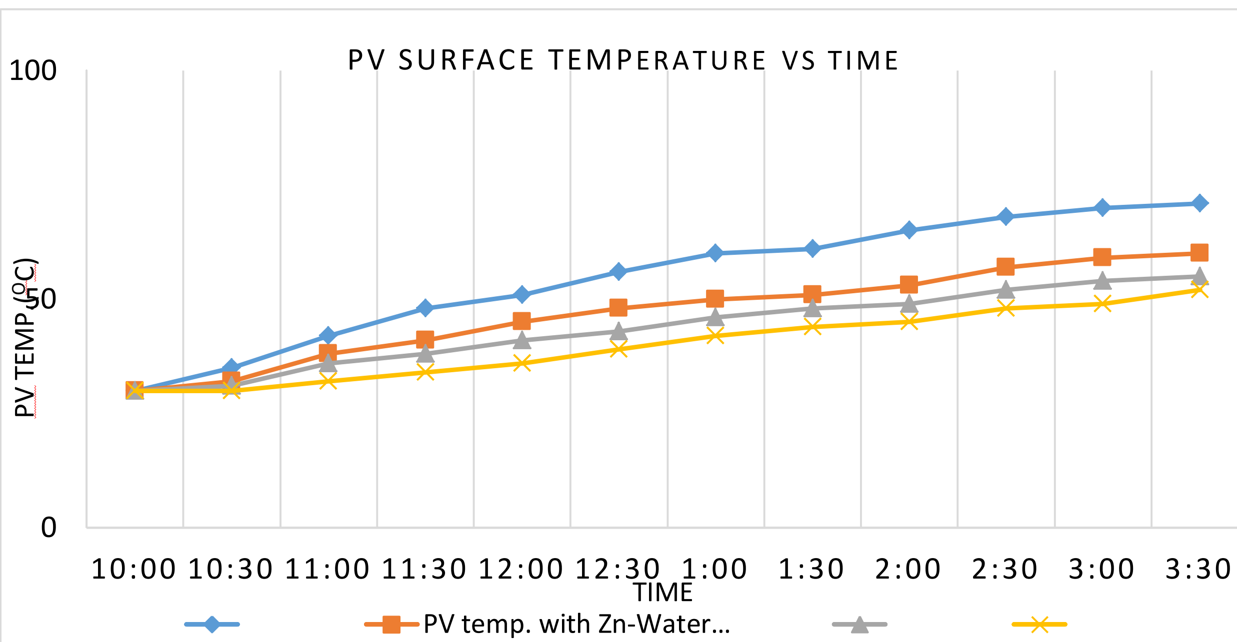


Figure.4 Variation of PV surface temperature with Time

ERROR INVESTIGATION

For both electrical and thermal efficiencies an Error investigation is executed. Table 3 signified the uncertainties related with the measuring equipment of the experimental operation.

If R is related to 'n' independent linear parameters as

$R = R\ (v_1, v_2, v_3 \ldots v_n)$, the ambiguity of function R might be evaluated as:

$$\delta R = \sqrt{\left(\frac{\delta R}{\delta v_1}\delta v_1\right)^2 + \left(\frac{\delta R}{\delta v_2}\delta v_2\right)^2 + \cdots + \left(\frac{\delta R}{\delta v_n}\delta v_n\right)^2} \quad (11)$$

Where δR show the ambiguity of function R, δv_i signified ambiguity of parameter v_i, and $\delta R/\delta v_i$ is the partial derivative of R with respect to the parameter V_1 [7].

Equipment and model	**Measurement section**	**Accuracy**
Current multimeter	Current	±(0.8%+1)A
Voltage multimeter	Voltage	±(0.5%+1)V
Rotameter	Mass flow rate	± 1kg/hr
Infrared thermometer	surface temperature of PV	0.14°C
Thermocouple	Fluid temperatures	±0.15-0.25°C
Mercury thermometer	Temperature (Ambient)	±0.5°C
Power meter (Solar)	Solar radiation Incident	±10 W/m^2

Table.3 shows accuracy of various components

Using the above equation (11) and recalling Eq (10), from the table solar input and the electrical/ thermal outputs fractional uncertainties are considered, by considering the maximum uncertainties for each parameter based on the following equation the maximum fractional uncertainty of the electrical efficiency can be calculated as:

$$\eta_{el} = f(G, P_{el}) = \frac{\delta\eta_{el}}{\eta_{el}} = \pm\sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2 + \left(\frac{-\delta G}{G}\right)^2} = \pm 0.019$$

In the Experiment, 1.9% is the maximum ambiguity of electrical efficiency.

likeways, the maximum uncertainty for thermal efficiency is calculated as:

$$\eta_{th} = f(G, T_{in}, T_{out}, \dot{m}) = \frac{\delta\eta_{th}}{\eta_{th}} = \pm\sqrt{\left(\frac{\delta T}{T}\right)^2 + \left(\frac{\delta\dot{m}}{\dot{m}}\right)^2 + \left(\frac{-\delta G}{G}\right)^2} = \pm 0.029$$

In the experiments the extreme total uncertainty for all parameters is less than 3%. Which confirms the dependability of the data measured.

CONCLUSIONS

- Thermal and Electrical efficiency obtained of the hybrid PV/T system is highest when it's cooled by Zn-(Water+Ethylene Glycol) nanofluid and least in the case when its only cooled by water.
- The maximum change in electrical efficiency observed is **2.6%** and maximum change in thermal efficiency observed is **31%.**
- Electrical efficiency of the Hybrid PV/T system decreases with time, as the operation time of the solar panel increases its resistance increase, current generating capacity decreases and hence its power generation capacity.
- Thermal efficiency of the Hybrid PV/T system increases with time as the operation time of the panel increases because more temperature difference is obtained across the heat exchanger.
- PV Panel surface temperature also is least in case of Zn-(water+Ethylene Glycol) Nanofluid cooled hybrid system and maximum in the case of water cooled system.
- PV surface temperature increase with time in all the 4 cases of cooling because of its continuous operation.
- Zn-(Water+Ethylene Glycol) Nanofluid gives most drop in surface temperature as compared to other 3 liquids/coolants. During our experiment the maximum temperature

difference between water cooled and Zn-(Water+Ethylene Glycol) Nanofluid cooled PV Panel is 19^0C.

REFERENCES

[1] Khanjari, Y., Pourfayaz, F., & Kasaeian, A. B. (2016). Numerical investigation on using of nanofluid in a water-cooled photovoltaic thermal system. Energy Conversion and Management, 122, 263-278.

[2] Al-Shamani, A. N., Sopian, K., Mat, S., Hasan, H. A., Abed, A. M., & Ruslan, M. H. (2016). Experimental studies of rectangular tube absorber photovoltaic thermal collector with various types of nanofluids under the tropical climate conditions. Energy Conversion and Management, 124, 528-542.

[3] Cui, Y., & Zhu, Q. (2012). Study of photovoltaic/thermal systems with MgO-water nanofluids flowing over silicon solar cells. In Power and Energy Engineering Conference (APPEEC), 2012 Asia-Pacific (pp. 1-4). IEEE.

[4] Michael, J. J., & Iniyan, S. (2015). Performance analysis of a copper sheet laminated photovoltaic thermal collector using copper oxide–water nanofluid. Solar Energy, 119, 439-451.

[5] Rejeb, O., Sardarabadi, M., Ménézo, C., Passandideh-Fard, M., Dhaou, M. H., & Jemni, A. (2016). Numerical and model validation of uncovered nanofluid sheet and tube type photovoltaic thermal solar system. Energy Conversion and Management, 110, 367-377.

[6] Sardarabadi, M., Passandideh-Fard, M., & Heris, S. Z. (2014). Experimental investigation of the effects of silica/water nanofluid on PV/T (photovoltaic thermal units). *Energy*, *66*, 264-272.

[7] Taylor JR. An introduction to error analysis: the study of uncertainties in physical measurements. Sausalito: University Science Books; 1997.

[8] Sardarabadi M, Passandideh-Fard M. Experimental and numerical study of metal-oxides/water nanofluids as coolant in photovoltaic thermal systems (PV/T). Solar Energy Materials and Solar Cells. 2016; 157:533-42.