# EXPERIMENTAL INVESTIGATION AND COMPARATIVE STUDY OF PV THERMAL WATER- ETHYLENE GLYCOL COLLECTOR AND PV SYSTEM


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**Abstract— Photovoltaic power generation is a method of producing electricity using solar cells. A solar cell converts solar energy directly into electricity. PV cells can absorb upto 80% of the incident solar radiation available in solar spectrum, however only a certain percentage of absorbed incident energy in the range of 6 to 15% is converted into electricity and rest of the energy is dissipated as heat. Excess heat build up behind PV panels is a problem. For every 1℃ above 25℃, electrical output reduces by 0.4 to 0.5%, which may cause degradation and thereby shortening the life time of cells. Hence, cooling of PV modules is very important for maintaining operating temperatures and improving electrical efficiency. Methodology used is cooling the panel by circulating water or water-ethylene glycol mixture at the rear side. The proposed prototype uses unglazed PVT collector having sheet and tube design with serpentine flow arrangement. In terms of electrical energy efficiency and energy calculations, unglazed PVT collector is better than glazed PVT collectors.**



**Index Terms— PVT technology, serpentine flow, sheet and tube design, unglazed PVT collector.**


## I. INTRODUCTION

The energy required by world is estimated to increase by 50% from 2005-2030 due to population growth and economic development [1].Rapid intensive utilisation of fossil fuels results in shortage of their resources and increasing energy cost and environmental pollution[2].Renewable energy technologies in current use supply approximately 13.3% of worlds energy demands. Solar energy is a renewable, ecofriendly, freely available energy resource on earth. Among all the available renewable options, solar energy seems to be promising and considered as energy of future. Solar radiation can be converted into thermal energy and electrical energy [1].Based on solar energy conversion systems, they can be classified as solar thermal collectors and photovoltaic collectors. Solar radiation can be converted into thermal energy by using solar thermal collectors in the thermal systems such as solar water heaters, air heaters, cookers, dryers and distillation devices. Solar thermal collectors may be of flat plate and concentrating solar power.

Solar photovoltaics power generation has long been seen as a clean sustainable energy technology which draws upon planets most plentiful and widely distributed renewable energy source. It is direct conversion of sunlight to electricity occurring without any moving parts or environmental emissions during operation. Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit photovoltaic effect. Electricity generated indirectly using solar photovoltaics with Si-Ge arsenide cells has efficiency of 6.5% to 18% depending on quality of material and for this energy production,0.4 to 1 micro meter wavelength radiations may be used. Monocrystalline technology is reported to have more efficiency (10 to 15%) as compared to polycrystalline (9 to 12%) technology.

However, a new topology has emerged to improve the overall system efficiency of PV system. The topology is called hybrid Photovoltaic Thermal (PVT) technology which integrates PV and thermal technologies to produce heat and electricity simultaneously.PVT modules can generate more energy per unit surface area than side by side PV panels and solar thermal collectors, at a lower production and installation cost. Moreover, it is highly efficient per unit surface area, and is well suited for applications with both heat and power demand and with limited roof space.

## II. BASIC CONCEPTS ABOUT PVT TECHNOLOGY

PVT technology produces simultaneously electrical as well as thermal energy through direct conversion of solar radiation. Solar cells convert solar radiation to electricity with maximum efficiency in the range of 6-15% and for every 1 ℃ rise in temperature, for monocrystalline and polycrystalline silicon PV cells electrical efficiency reduces by 0.5%. PV cells an absorb upto 80% of the incident solar radiation available in solar spectrum. Most of the solar radiation that is absorbed is not converted into electricity. PV cells utilise a small fraction of incident solar radiation to produce electricity and rest is turned into waste heat within solar cells, increasing PV cell temperature, hence efficiency of module drops. This increase in temperature is due to loss of heat (convection and radiation) that is unutilised in energy conversion.

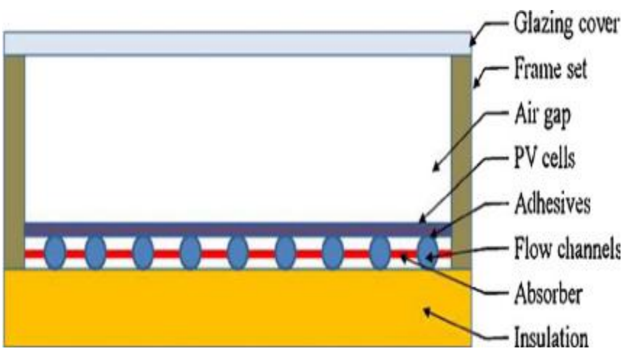


Fig. 1: cross section of typical PV/T module [3]

Temperature rise is due to unutilised energy which mainly comes from high energy photons (>band gap energy ($E_g$)).This shows temperature rise is much higher in top region of solar cell where most of the high energy photons are absorbed in region near junction.Therefore cooling either by natural or forced circulation reduces PV cell temperature. Cooling of PV module maintains electrical efficiency at satisfactory level.

A typical PV/T module is a sandwiched structure comprising several layers, namely from the top to bottom, a flat-plate thermally clear covering as the top layer; a layer of photovoltaic cells or a commercial PV lamination laid beneath the cover with a small air gap; tubes or flowing channels through the absorber and closely adhered to the PV cell layer; a thermally insulated layer located right below the flow channels. All the layers are fixed into a framed module using the adequate clamps and connections.Fig.1 is a schematic of a typical PV/T module structure. A PVT module is basically derived from combined functions of thermal collector and photovoltaic panel. Overall efficiency is sum of electrical and thermal efficiencies [3].

$$\eta_o = \eta_e + \eta_{th} \tag{1}$$

Thermal efficiency is the ratio of useful thermal energy $Q_u$ to the overall incident radiation, $G$ .

$$\eta_{th} = \frac{Q_u}{G} \tag{2}$$

where, $Q_u$ is the heat collected by PVT collector could either be given as product of mass flow rate, specific heat capacity of fluid used and difference of outlet and inlet temperatures .

$$Q_u = mC_p(T_0 - T_i) \tag{3}$$

Where, $m$ is the mass flow rate in kg/s, $C_p$ is the specific heat capacity in J/Kg$^0$C, $T_0$ and $T_i$ are the outlet and inlet temperatures respectively.

Electrical efficiency of PVT system is given by,

$$\eta_e = \frac{P_{max}}{A_c \times G} \tag{4}$$

Where $P_{max}$ is the maximum power obtained , $A_c$ is the area of the collector, $G$ is the solar insolation in W/m$^2$.

## III. DESIGN CONSIDERATIONS AND MODELLING OF PVT COLLECTOR

The proposed prototype works on the principle of thermosyphon and consists of PV module, absorption unit, wooden box and insulation, storage tank. For the construction of PVT module a solar panel is selected by taking into consideration of both durability and cost criteria and selected a 60 watt capacity panel with following specifications as shown in table 1.

Table 1: 60 W panel specifications

| | |
|---|---|
| Power($P_{max}$) | 63.4 W |
| Open circuit voltage ($V_{oc}$) | 21.9 V |
| Short circuit current ($I_{sc}$) | 3.836 A |
| Current at maximum power ($I_{mp}$) | 3.591 A |
| Voltage at maximum power ($V_{mp}$) | 17.7 V |
| Fill factor(FF) | 0.754 |
| Cell efficiency (%) | 15.68 |
| Module efficiency (%) | 12.69 |

In order to recover the heat absorbed by solar panel, metal sheet has been attached to backside tedlar layer of panel. Since the solar panel is to be electrically isolated we can't braze or weld the sheet metal to panel. By taking the dimensions of backside of solar panel, the aluminium absorber plate has been fabricated and attached to the solar panel by using thermally conductive silicone adhesive sealant. Further in order to transfer the heat recovered from panel to water, an intricate network of cooling tubes have been attached to the other side of sheet metal. Different configurations or designs are available among which serpentine shaped tubings are preferred as more surface area is available and more no. of turns per unit area increases heat removal efficiency.

The copper tubing is brazed to the copper plate and two ends of the tubes were taken out on both sides for external connection to the storage tank. The copper plates and tubes are blackened in order to the increase the extent of absorption of heat. The copper tubing is arranged in serpentine shape to create a thermosyphon action in the water flowing through it. The whole absorber plate along with copper tubes is attached to solar PV panel. All the parts comprising of solar PV panel, absorber plate with copper tubing will be encapsulated in an wooden box with suitable inclination of 15 $^{0}$S with respect to ground. Fig.2 shows the schematic diagram of the experimental set up.

The water storage tank of 5 litre capacity (fluid tank) has been placed at a height 50 cm higher than the plain of solar panel to provide a good pressure difference for the flow of water.

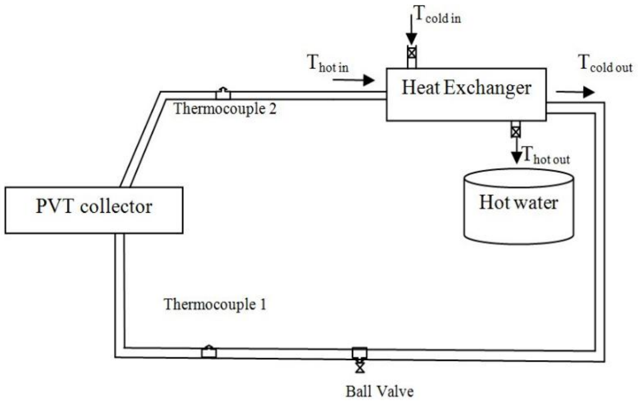


Fig.2: Schematic diagram of experimental set up

Fluid tank is immersed in a cooling tank. The heat from the hot fluid in the fluid tank gets transferred to cooling tank, maintaining fluid within fluid tank as always cold and fluid in the cooling tank as hot i.e, it acts as a heat exchanger.

Once the unit is installed the water from storage tank is made to flow into the panel by throttling the valve provided at the inlet. Due to the heat absorbed by the tubes from the plate the water gets heated up and due to thermosyphon action water starts raises up and gets collected at the top portion of storage tank. Meanwhile in the process of removal of heat from the absorber plate, it decreases the temperature of solar PV panel thereby maintaining the power output of the panel at its maximum even under high solar insolation condition.

The absorber collector tubes is designed in a serpentine tube arrangement. The sheet and tube at plate is generally made of aluminium and copper respectively, which presents advantages such as ease of manufacturing, high conductivity (about 204 W=mK) and low specific heat capacity of the material.Fig.3 shows serpentine tube arrangement of PVT collector modelled.

The parameters required for modelling PVT collector is shown in table 2. The $U_L$ value, material property, thickness and optical losses is important in designing the collector. The higher value of $U_L$ means the greater heat loss of the collector [4]. In other words, the thermal efficiency will decrease linearly with the increase of overall heat losses and is given by ,

$$\eta_{th} = F_R(\tau\alpha)_{PV} - F_R U_L \frac{(T_i - T_a)}{G} \tag{5}$$

Where, $(\tau\alpha)_{PV}$ is the transmissivity absorptivity product of PV system. Heat removal factor $F_R$ is given by,

$$F_R = \frac{mc_p}{A_C U_L}\left(1 - e^{\frac{-A_c U_L F'}{mc_p}}\right) \tag{6}$$

Fig.3: Serpentine tube segment

An overall heat transfer coefficient from glass to water through solar cell and tedlar is given by,

$$U_{tw} = \frac{(U_{tT} h_T)}{U_T + U_t} \quad (7)$$

Conductive heat transfer coefficient from solar Whillier Model to the Analysis of Combined cell to water through tedlar is,

$$U_T = \frac{K_T}{L_T} \quad (8)$$

An overall heat transfer coefficient from glass to tedlar through solar cell is given by,

$$U_{tT} = \frac{U_t U_T}{U_t + U_T} \quad (9)$$

Conductive heat transfer coefficient from solar cell to ambient through glass cover is given by,

$$U_t = \left(\frac{L_G}{K_G} + \frac{1}{h_0}\right)^{-1} \quad (10)$$

Heat transfer coefficient from glass to ambient is given by,

$$h_0 = 5.7 + 3.8\upsilon \quad (11)$$

Overall heat transfer coefficient from water to ambient is given by,

$$U_b = \left(\frac{L_i}{K_i} + \frac{1}{h_0}\right)^{-1} \quad (12)$$

Overall heat loss coefficient, $U_L$ is given by,

$$U_L = U_{tw} + U_b \quad (13)$$

Fin efficiency factor, $F'$ is given by,

$$F' = \frac{\frac{1}{U_L}}{W\left(\frac{1}{U_L(D + (W - D)F)}\right) + \frac{1}{Wh_{ca}} + \frac{1}{\prod D h_{fi}}} \quad (14)$$

Table 2: Parameters for modelling of PVT collector

| | | |
|---|---|---|
| Length of one serpentine segment | L | 1 m |
| Distance between tubes (Tube spacing) | W | 0.06 m |
| Number of segments | N | 7 |
| Absorber plate thickness | $L_{abs}$ | 0.0025 m |
| Tube outside diameter | $D_0$ | 0.015 m |
| Tube inside diameter | $D_i$ | 0.013 m |
| Specific heat capacity | $C_p$ | 4190 J/Kg K |
| Mass flow rate | m | 0.008 Kg/s |
| Thermal conductivity of copper | $K_{abs}$ | 385 W/m K |
| Fluid to heat transfer coefficient | $h_{fi}$ | 300 W/m$^2$K |
| Heat transfer coefficient from glass to ambient | $h_0$ | 9.5 W/m$^2$K |
| Conduction heat transfer through Tedlar | $h_T$ | 500 W/m$^2$K |
| Conductivity of glass | $K_G$ | 1 W/m K |
| Conduction of insulator (glass wool) | $K_i$ | 0.04 W/m K |
| Conduction of Tedlar | $K_T$ | 0.033 W/m K |
| Thickness of glass | $L_G$ | 0.003m |
| Insulation thickness | $L_i$ | 0.02m |
| Thickness of Tedlar | $L_T$ | 0.0005m |
| Overall heat transfer coefficient from water to ambient | $U_b$ | 0.737 W/m$^2$K |
| Overall heat loss coefficient | $U_L$ | 8.712 W/m$^2$K |
| Conductive heat transfer coefficient from solar cell to water through Tedlar | $U_T$ | 66 W/m$^2$K |
| Overall heat transfer coefficient from glass to Tedlar through solar cell | $U_{tT}$ | 8.10 W/m$^2$K |
| Conductivity of absorber plate | $K_{abs}$ | 204 W/m K |
| Wind velocity | $\upsilon$ | 1 m/s |

Fin efficiency, F is given by,

$$F = \tanh\left(\frac{m\left(\frac{W-D}{2}\right)}{m\left(\frac{W-D}{2}\right)}\right) \quad (15)$$

Where,

$$m = \sqrt{\frac{U_L}{K_{abs}L_T}} \quad (16)$$

## IV. EXPERIMENTAL SET UP AND RESULTS OBTAINED

In order to quantify the efficiency of the PV panels, testing was conducted on the roof top of the building at Amal Jyothi College of Engineering, Kottayam. The test was conducted on 29 May 2015 and 1st June 2015. 60W and 40W capacity panels were used for testing and per wattage of both panels were compared. The specification of 40W capacity panel used for comparison with 60W PVT system is given below.

Table 3: 40 W panel specifications

| | |
|---|---|
| Power($P_{max}$) | 40 W |
| Open circuit voltage ($V_{oc}$) | 21.9 V |
| Short circuit current ($I_{sc}$) | 2.45 A |
| Current at maximum power ($I_{mp}$) | 2.30 A |
| Voltage at maximum power ($V_{mp}$) | 17.4 V |

The inlet/outlet temperature, line voltage and line current, absorber plate temperature and panel surface temperature readings using water and water ethylene glycol mixture as coolants for PV thermal collector were taken on hourly basis and the tables 4 and 7 shows the maximum power obtained on each hour for PV thermal water collector and PV thermal water ethylene glycol collector respectively . According to the tabulations the electrical and thermal efficiencies were calculated as per the equations (4) and (2) respectively.

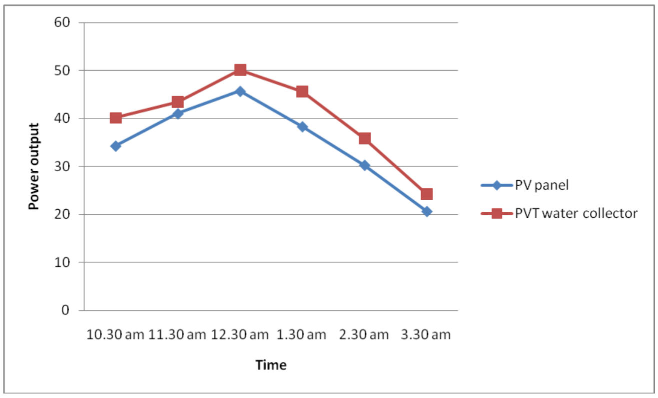


Fig.4: Power v/s time of PV and PVT water collector

Fig.4 and 5 shows the variation of power output with respect to time for PV thermal water collector and PV thermal water-ethylene glycol collector.Power output increases with cooling of PV panel as compared to output obtained without cooling. The power output is observed to be highest at noon with highest solar insolation. Power output is observed to be highest using water cooling.

Table 4: Variation in power output with time and insolation for PV and PVT water collector on 29th May

| Time in hrs | Solar irradiation in W/m$^2$ | Power ($P_{max}$) of PV panel | Power ($P_{max}$) for PVT water collector |
|---|---|---|---|
| 10.30 a.m | 660 | 34.25 | 36.4 |
| 11.30 a.m | 849.98 | 41 | 43.47 |
| 12.30 p.m | 891.45 | 45.68 | 50.13 |
| 1.30 p.m | 853.3 | 38.3 | 45.6 |
| 2.30 p.m | 600 | 30.24 | 35.86 |
| 3.30 p.m | 509.78 | 20.59 | 24.21 |

Table 5: Variation of efficiency with time and insolation for PV and PVT water collector on 29th May

| Time in hrs | Electrical efficiency of PV panel | Efficiency of PVT water collector | |
|---|---|---|---|
| | | Electrical efficiency | Thermal efficiency |
| 10.30 a.m | 10.37 | 11.03 | 35.14 |
| 11.30 a.m | 9.64 | 10.22 | 39.27 |
| 12.30 p.m | 10.24 | 10.8 | 57.98 |
| 1.30 p.m | 8.97 | 10.68 | 54.99 |
| 2.30 p.m | 10.08 | 11.95 | 50.28 |
| 3.30 p.m | 8.07 | 9.49 | 39.45 |

The results shows that the thermal efficiency increases with solar insolation and reaches the peak at noon i.e. at maximum solar insolation period where as the electrical efficiency decremented with the increase in solar radiation and reached the minimum at noon. Hence the panel is in need of some remedy or arrangement to maintain the efficiency of the panel even at noon.

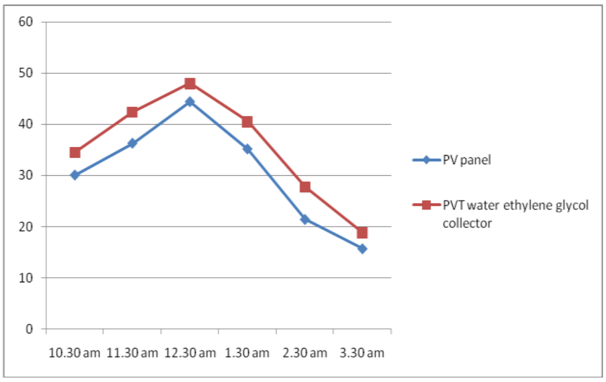


Fig.5: Power v/s time of PV and PVT water ethylene glycol collector

Table 5 and 6 shows the comparison of efficiency of PV thermal water collector and PV thermal water ethylene glycol collector with PV system. From the observations of tabulated data, pure water is a better coolant than water-ethylene glycol mixture with a higher specific heat capacity. The average thermal and electrical efficiencies obtained using pure water as coolant is better than water-ethylene glycol mixture.

Table 6: Variation in power output with time and insolation for PV and PVT water ethylene glycol collector on 1st June

| **Time in hrs** | **Electrical efficiency of PV panel** | **Efficiency of PVT water ethylene glycol collector** | |
|---|---|---|---|
| | | **Electrical efficiency** | **Thermal efficiency** |
| 10.30 a.m | 10.46 | 11.32 | 19.13 |
| 11.30 a.m | 10.22 | 11.13 | 19.87 |
| 12.30 p.m | 9.62 | 10.5 | 22.92 |
| 1.30 p.m | 9.47 | 11.24 | 20.74 |
| 2.30 p.m | 9.52 | 11.36 | 15.67 |
| 3.30 p.m | 10.41 | 11.84 | 9.34 |

Table 7: Variation in power output with time and insolation for PV and PVT water ethylene glycol collector on 1st June

| **Time in hrs** | **Solar irradiation in W/m$^2$** | **Power ($P_{max}$) of PV panel** | **Power ($P_{max}$) for PVT water ethylene glycol collector** |
|---|---|---|---|
| 10.30 a.m | 575 | 30.1 | 34.5 |
| 11.30 a.m | 710 | 36.3 | 42.4 |
| 12.30 p.m | 800 | 44.4 | 48 |
| 1.30 p.m | 680 | 35.186 | 40.52 |
| 2.30 p.m | 450 | 21.44 | 27.74 |
| 3.30 p.m | 302 | 15.73 | 18.78 |

## V CONCLUSION

In this paper experimental investigation of PV thermal Collector using water and water ethylene glycol mixture as coolants is done and found that average electrical efficiency without cooling is found to be 9.56% and with water and water-ethylene glycol cooling is 10.69% and 11.23% respectively. Average thermal efficiency of the panel is found to be 46.18% and 17.94% using water and water-ethylene glycol respectively.

## REFERENCES

[1] V. E. Paret, M. P. Pareto, The Urban Component of the Energy Crisis http://ssrn.com/abstract=1221622, Dec 12, 2008.

[2] A. Ibrahim, M.Y.Othman, M. H. Ruslan, S. Mat, K. Sopian, "Recent Advances in Flat Plate Photovoltaic/thermal (PV/T) Solar Collectors", Renewable and Sustainable Energy review, vol.15, no. 1, pp.352-365,2011.

[3] X. Zhang, X. Zhaoa, S. Smitha, J. Xub, X. Yuc, "Review Of R & D Progress And Practical Application of the Solar Photovoltaic/Thermal (PV/T) Technologies", Renewable Sustainable Energy, vol.16, pp.599-617, 2012.

[4] M.A.M. Rosli, K. Sopian,S. Mat, M. Yusof Sulaiman and E. Salleh,"Heat Removal Factor of an Unglazed Photovoltaic Thermal Collector with a Serpentine Tube", Middle-East Journal of Scientific Research, vol.21, no.12, pp.2359-2362, 2014.