ISSN No.: 2454- 2024 (online)

International Journal of Technical Research & Science

HYBRID PHOTOVOLTAIC-THERMAL SYSTEMS USING DIETHYL ETHER FOR EXTREME WINTER CONDITIONS

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Abstract-Water with a comfortable temperature for domestic applications is an acute problem for the people residing in the extreme cold weather conditions or areas with a mild amount of sunlight or insolation. This research deals with generating warm water for these conditions using improvised photovoltaic (PV) panels. PV panels have the ability of concentrating the heat due to the incident solar insolation thereby increasing its temperature much above the ambient temperature. The efficiency of PV panels is also a function of temperature with an optimum performance temperature limited to 25°C. Efficiency decreases by 0.5%/K after 25ºC.The surface temperature of the PV panel increases due to concentration of heat, attaining 50-60°C above 25°C. This research articulates modelling of integrated hybrid Photovoltaic-Thermal (PV-T) system utilizing diethyl ether for generating warm water with simultaneous cooling of PV panels thereby increasing its efficiency. This objective was addressed with a heat exchanger in a cubical enclosure made of aluminium with solar cells occupying its top surface and acting as a heat input. The enclosure consist of ether as a heat storage and transmitting medium with circulating water inside the pipes as heat absorber. Ether was selected due to its boiling point of 34°C which would be able to transfer heat to the water until water attains a temperature of 34°C. Ether proved to be a viable option with 4.9°C reduction in surface temperature of the panels and also generating warm water at 34°C.

Keywords: Photovoltaic (PV), Photovoltaic-Phase Change Material (PV-PCM), Photovoltaic-Thermal (PV-T), Hybrid Photovoltaic-Thermal, Photovoltaic cooling.

Table-1 List of Symbols and Abbreviations

PV-T: Photovoltaic/Thermal	φ :Tilt angle measured from horizontal
PCM: Phase change material	h_{free} :Natural heat transfer coefficient
V_{oc} /OCV: Open Circuit Voltage	g :Gravity
I_{sc} /SSC: Short Circuit Current	$\eta_{electrical}$:Electrical Efficiency
FF :Fill Factor	ρ_{air} :Density of air
α :Angle of elevation	h_{forced} : Forced heat transfer coefficient
P_{out} :Power produced by panel	S_{module} :Net solar radiation on the panel
T_{amb} :Ambient temperature	Gr :Grashoff number
Re : Reynolds number	Nu : Nusselt number
T_{panel} :Surface temperature of panel	σ :Stephen-Boltzmann constant
α_P :Absorptivity of the panel	$S_{incident}$:Solar radiation incident on the panel
A:Area of the panel	ε =Emissivity of the panel

1. INTRODUCTION

PV panels are suffering from design limitation of 12–15% conversion efficiency. The remaining energy is converted into heat thus overheating the panel. This is due to the limitation of P-N junctions in solar cells capable of accepting only a particular band of sunlight. Silicon PV modules exhibit a power loss with the rise in temperature above 25°C, with a temperature coefficient of -0.5%/K [4, 11]. Phase Change Material (PCM) as a heat transfer medium is widely used in various domestic and industrial applications due to its efficient heat storage and dissipation. In this research, ether is used in the hybrid PV-T system to serve the dual aspects of generating warm water and producing power. The research available till date focused on the cooling of PV panels using PCM. Very few researches were devoted to the hybrid PV-T part. However, the review of both PV cooling and PV-T systems provided with the checks and balances to be opted during design of the systems. A rectangular enclosure made of aluminium, copper or sometimes transparent material like acrylic was fabricated at the rear part for most of the PV panels either for cooling or PV-T systems. Most prominent PCM medium of heat sink was Rubitherm(RT) series [7,10,16] and paraffinic hydrocarbons[12] broadly adopted by researchers in the cooling of PV panels. Critical point plays a vital role in the design of volume of container which houses the coolant [13]. Simulation was also adopted by researchers to predict the variance in parameters enabling a designer for modification for optimum performance [2] .The effects of convection, velocity of wind, angle of inclination of PV panel and environmental temperature in the design of the system was also justified by researchers thereby strengthening the design [9]. Researchers from various locations around the globe obtained variable results with the same conditions of PCM and panel capacity thereby concluding that the research at any particular location on the earth cannot be generalized where a hot climate requires a high PCM melting temperature and a cool climate favors a low PCM melting temperature [15]. Certain nontraditional PCM's such as Vaselinum flavum [8], petroleum jelly[6],ZnO/water nanofluid[14], MgO water nanofluid[5], Paraffin infused graphite[1] were also used by various researchers and the objective of PV cooling was achieved.

The research available till date focused on the cooling of PV panels using solid-liquid PCM.As solid-liquid PCM's exist in the lower range of transition temperature, it cannot satisfy the objective of an integration of thermal system. Liquid-gas PCM offers the flexibility of existing at various range of transition temperature to suit ones requirements. Thus in this research, ether in the liquid-gas segment would satisfy the objective of the hybrid PV-T system.

2. EXPERIMENTAL SET-UP

An aluminium enclosure was fabricated underneath a solar cells of 16 Watts acting as store house for PCM. A designed network of copper pipes for carrying water was fabricated inside the aluminium box.

Fig. 2.1 Copper Pipes Layout

The container was to be filled with ether through a valve provided at the top of the box. Ether would be absorbing the heat from the PV cells during its operation and transmitting it to the water inside the pipes. The properties of diethyl-ether are shown in Table 2.1.

Table-2.1 Thermo-Physical Properties of Diethyl-Ether

S. No.	Properties	Value
1	Molecular Formula	$C_4H_{10}O$
2	Molecular Weight (g/mol)	74.123
3	Boiling Temperature (^oC)	34.6
4	Thermal Conductivity (W/m k)	0.203 at 303K
5	Density (kg/m^3)	.713
6	Specific heat (kJ/kg K) Liquid	2.21
7	Specific heat (kJ/kg K) gas	1.95
8	Specific heat (kJ/kg K) gas (Cp)	0.48
9	Specific heat (kJ/kg K) gas (Cv)	0.47
10	Viscosity (mPa.s)	0.2100 (303K)
11	Enthalphy of evaporation (kJ/kg)	377

ISSN No.: 2454- 2024 (online)

International Journal of Technical Research & Science

The flow of water would be regulated through a sensor controlled valves allowing only the water with a temperature below 34°C to be retained inside the pipes. Three K-type thermocouples were reposed at three distinct points to measure the variation in the temperature of ether inside the box. The header of copper pipes at the entrance was connected to the water tank. The warm water gets collected in an insulated tank placed at datum as shown in Fig. 2.2.

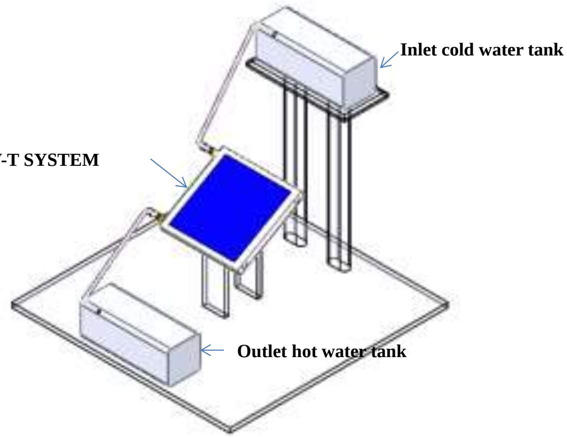

Fig. 2.2 Model of Experimental Set-Up

3. MATHEMATICAL MODELING

The mathematical modelling of the above system was confined to the conservation of energy in the system. The approach of design using conservation of energy has been established by few researchers [3, 9] in design of the systems.

3.1 Applying Conservation of Energy

$$Q_{absorbed} = Q_{radiative\ loss} + Q_{convection\,loss-air} + P_{out} + Q_{Ether} + Q_{water} \tag{1}$$

3.2 Heat Received As Insolation From Sun

The incident insolation S_{module} in Wm^{-2} from the sun was measured using pyranometer from 0900 hours to 1700 hours on half-hourly basis. This forms the total heat in the analysis of conservation of energy.

$$Q_{absorbed} = \alpha_P S_{\text{module}} A \tag{2}$$

Where a denotes the area of the panel in meters

3.3 Heat Loss Through Radiation From the Front Surface of Panel (Radiative Loss)

The loss of heat through radiation from the surface of the panel depends upon emissivity of the panel and is given by (3).

$$Q_{radiative\ loss} = \varepsilon\sigma A({T^4}_{panel} - {T^4}_{amb}) \tag{3}$$

Where A denotes the area of the panel and ε denotes the emissivity of the panel.

3.4 Heat Loss Through Convection of Air From The Surface of Panel

As heat transfer occurs in the mixed convection regime due to the intermittent flow of air, Nusselt number has to be evaluated for calculation of convective heat transfer coefficient. The free and forced convective heat transfer coefficients are to be calculated for assessing the heat loss due to free and forced convection.

$$Nu^m = (Nu_{forced})^m \pm (Nu_{free})^m \tag{4}$$

$$h_{air} = \frac{Nu^m k_{air}}{L} \tag{5}$$

Nu_{forced} and Nu_{free} denotes the Nusselt numbers for forced and free convection respectively. Heat lost through free convection of air

$$Q_{freeconvection} = h_{free} A(T_{PV} - T_{amb}) \tag{6}$$

Heat loss through forced convection of air

$$Q_{forcedconvection} = h_{forced} A(T_{PV} - T_{amb}) \tag{7}$$

3.5 Power Produced By Panel

The ideal rated power is 16 Watts, as specified by the manufacturer but the rated power is calculated under ideal laboratory conditions under insolation of $1000 Wm^{-2}$.The actual power obtained is at much variance to the specifications provided by the manufacturer.

$$P_{out} = V_{oc} I_{sc} FF \tag{8}$$

$$\eta = \frac{V_{oc} I_{sc} FF}{Q_{absorbed}} \tag{9}$$

$$FF = \frac{V_{oc} - \ln(V_{oc} + 0.72)}{V_{oc} + 1} \tag{10}$$

3.6 Heat Transfer Through the Panel To the Ether

The thermal resistance between solar insolation and ether consists of PV panel, EVA sheet and Aluminium sheet as shown in Fig. 2.3.The temperature of the bulk of the fluids on two sides of the wall are T_0 and T_1 $(T_0 > T_1)$.

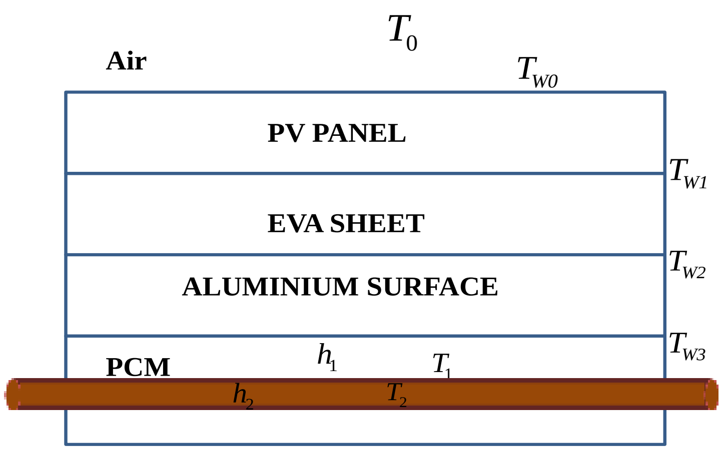

Fig. 2.3 Representation of Thermal Resistances of Hybrid PV-T System

$$Q = UA(T_0 - T_1) \tag{11}$$

Where U is the overall heat transfer coefficient considering the effects of PV panel, EVA sheet and Aluminium layer.

3.6 Heat Transfer From Ether to Water

Experimental heat transfer from Ether to water flowing in the pipes is given by (12).

$$UA\Delta T = mc\Delta T \tag{12}$$

4. RESULTS AND DISCUSSION

Experimentation was conducted on the roof of Mechanical Engineering Department at NIT Jalandhar campus on December 2017 throughout a week. Due to flow of winds from Mediterranean, north India witnesses a cold winters during the month of December and January compared to the rest of the country with temperatures hovering around single degrees. Though the ambient temperature remains remained low but the temperature on the surface of panel increases due to concentration of heat. The maximum ambient temperature during the day time reached 18°C.Wind velocity remained between $1\text{-}1.5 ms^{-1}$.The environments was conducive for the experimentation to be carried out as it simulated the extreme winter conditions.

4.1 Effect of Ether as Heat Transfer Medium on The Performance of PV Panel

The objective of this system was to provide warm water of 34°C for domestic applications along with an additional benefit of enhanced efficiency. The purpose of selection of ether in this application is based on its boiling point of 34°C due to the surface temperature attained by the panel. Ether would be absorbing more heat due to its combination of specific heat and latent heat. This leads to rise in temperature of water at a faster rate. The water is held inside the pipes with a sensor controlled valve to for ejection of water upon attainment of temperature of 34°C.

4.2 Surface Temperatures of Standalone PV Panels and PV-T Systems

The surface temperature of the panel kept increasing due to concentration of heat, even during mild insolation hours. As, only a particular range of bandwidth of the solar radiation is converted into electricity, the remaining gets absorbed as heat by the panels thereby increasing its temperature. The average surface temperature of PV-T system was observed to be 32.4°C compared to 34.1°C of simple PV system.

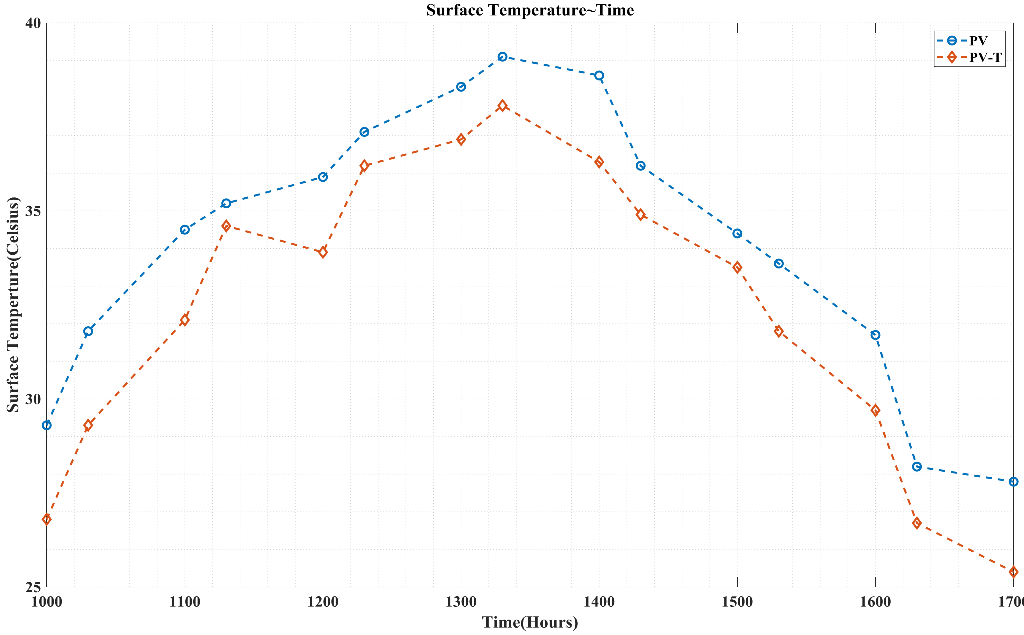

Fig. 4.1 Variation of Surface Temperature With Time

4.3 Open Circuit Voltage of Standalone PV Panels and PV-T Systems

The relation between OCV and surface temperature can be represented by ideal diode equation as a solar cell is a typical P-N junction diode. The magnification factor of OCV was quite less compared to the SSC. OCV is a result of insolation. The rated maximum OCV prescribed by the manufacturer was 2V for the panel. Average OCV measured was approximately 1.8V approximately for both the systems.

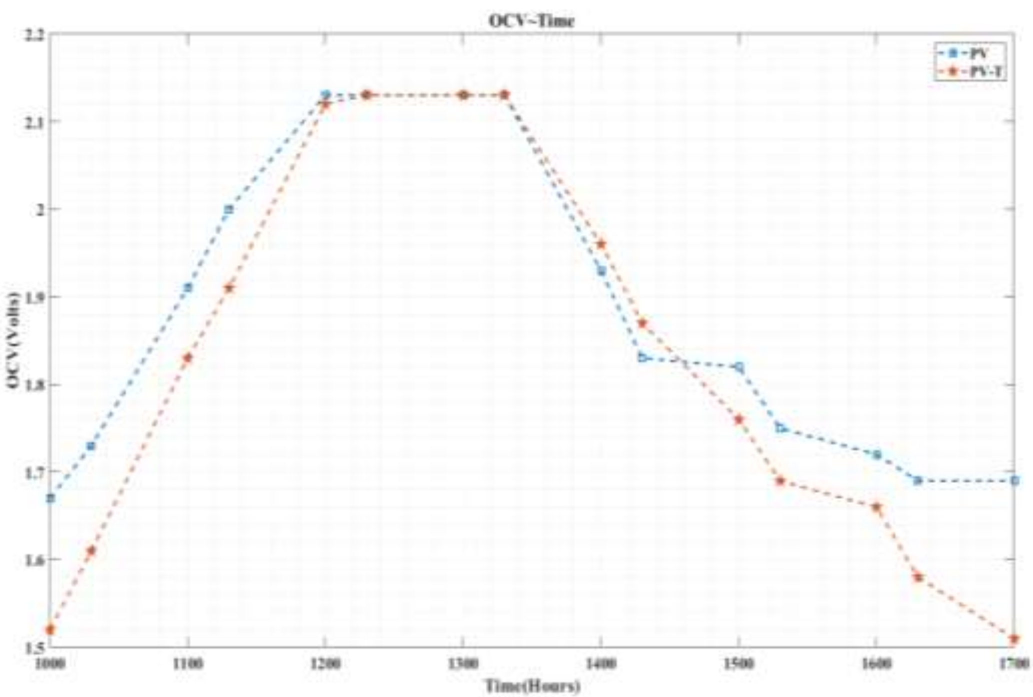

Fig. 4.2 Variation of OCV With Time

4.4 Effect of PCM on Short Circuit Current of Standalone PV Panels and PV-T Systems

Short circuit current first increases and then decreases with the insolation. Average SSC measured in PV-T system was 1.92A compared to 1.87A in simple PV system. The increase in values may seem insignificant but would have a substantial effect on systems with larger capacity.Cooling had a significant impact on short circuit current. There requires a load for the current effect to be felt. Data acquisition machine due to its provision of some resistance for measurement of current was able to measure SSC. But from the V-I characteristic curve of PV cell, it was inferred that maximum current can only be felt at the least possible resistance for the rated power. As least possible resistance in the institute laboratory conditions was one ohm, the maximum possible current was difficult to be evaluated for a resistance below one ohm.

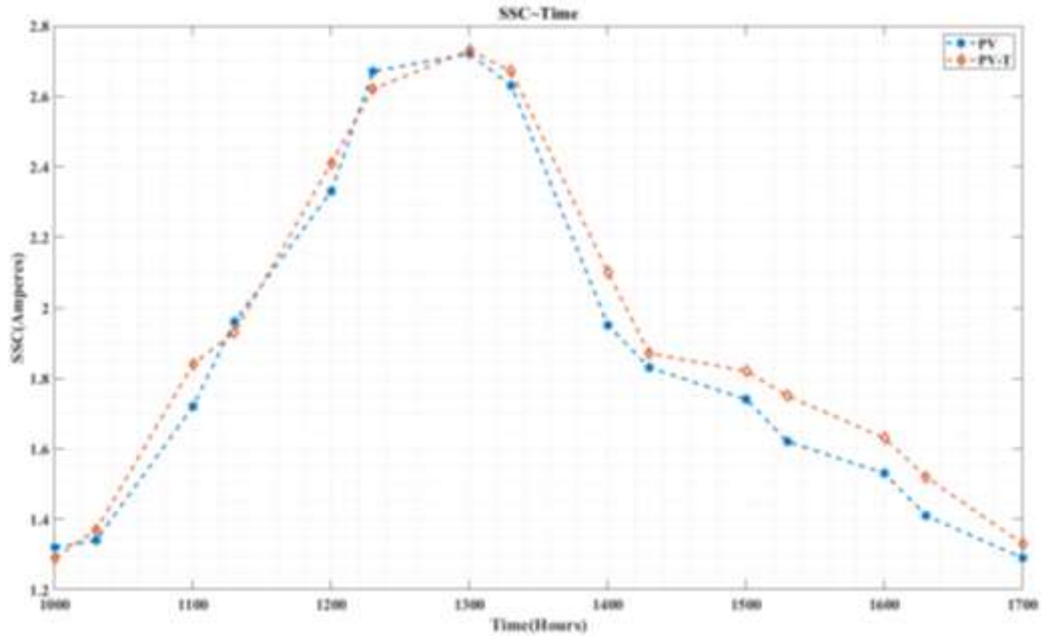

Fig. 4.3 Variation of SSC With Time

4.5 Power Produced By Standalone PV Panels and PV-T Systems

Electrical power produced was less in the morning due to mild insolation and then increased steeply towards mid-day and again decreased in the evening. Average power produced by PV-T systems was 3.65W compared to 3.62W of simple PV-T system .The manufacturers rating on the solar cells are based on ideal insolation of 1000Wm^{-2} and an extremely low resistance, difficult to be attained in the laboratory conditions.

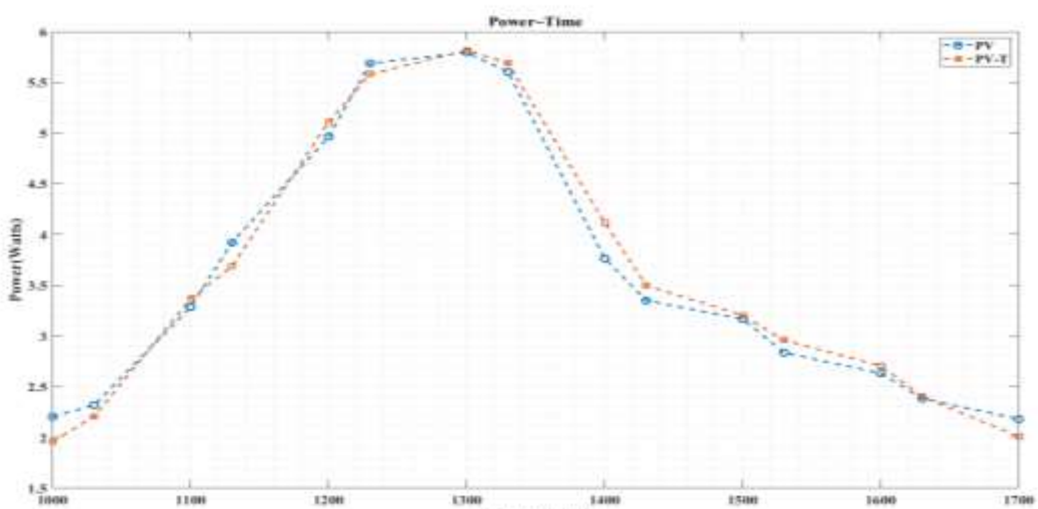

Fig. 4.4 Variation of Power Produced With Time

CONCLUSIONS

A comprehensive research on photovoltaic hot water systems using ether as heat transfer medium was conducted experimentally and its effects were studied on the efficiency of the solar panel. The increase in the parameters from simple PV panel to hybrid PV-T systems may seem insignificant due to its capacity of rated 16 watts. The increase would be substantial if the capacity of the PV panel is increased by manifold.

- Ether due to its ability of transferring maximum heat due to its combination of specific heat and latent heat was a suitable application in this research for the objective of warm water to be attained. Enhanced efficiency of PV panel was an augmented benefit achieved along with hot water. It was concluded by observing the average surface temperature of PV-T system which was less than that of PV panel by 1.72^{o}C.
- Average open circuit voltage of hybrid PV-T system and conventional PV panel was 1.8V due to the relation of OCV with surface temperature.
- Average short circuit current of PV-T system was 1.92A compared to 1.87A of simple PV panel.
- Warm water of 34^{o}C was attained.

The selection of ether proved to be a viable option as a heat transfer medium with simultaneous gain of warm water and enhanced efficiency.

ACKNOWLEDGEMENTS

This work was supported by Dr. B R Ambedkar National Institute of Technology, Jalandhar under TEQIP-III grant NITJ/TEQIP-III/R&D/01/7432, MHRD, Government of India.

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