Effect of Gravity Assisted Heat Pipe Cooling on Photovoltaic Panels

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Abstract: **Photovoltaics is one of the useful ways of harnessing solar energy, as electrical energy can be directly generated from the conversion of solar energy through it. Depending on the type of technology and the environmental parameters, a photovoltaic module can convert only 6-17% of the incoming solar irradiance into electricity with remaining part of energy falling on its surfaces is either convected and radiated to the surroundings or absorbed by the solar panel. This absorbed solar radiation energy along with ambient temperature elevates the temperature of the photovoltaic cells. The increase in the temperature of the cells has an adverse effect on their performance, decreasing the conversion efficiency and the power output of the solar panel significantly.It becomes necessary to maintain the operating temperature of the solar panels within safe values, to achieve better efficiency and output from it. To keep the working temperature of the photovoltaic panels within the prescribed limits of the manufacturer, which is also known as nominal operating cell temperature (NOCT), various cooling techniques have been employed. Currently researchers have suggested and also studied many cooling methods worldwide. One of them being the thermosyphon heat pipe cooling technology in which the flow of condensate takes place under the influence of gravity. This gravity assisted heat pipe based cooling technique is a low cost, passive and a promising cooling solution for photovoltaic modules. The current paper describes the effect of gravity assisted heat pipe cooling on the performance of solar photovoltaic modules, investigated in various studies.**

Keywords: ***solar cell, solar panel, solar radiation, heat pipe, thermosyphon, cooling***

1. INTRODUCTION

One of the current global issues is the energy crisis. The use of non conventional energy sources in terms of sustainability and environmental factors is becoming widespread as renewable and clean energy nowadays. Solar energy is the most important of them, as the other sources of energy are also dependent on it. Energy conversion devices, which by using the photoelectric effect convert the sunlight into electricity, are called photovoltaic cells or solar cells [1].The core component of a photovoltaic power generation system is the solar cell. The solar cell has a conversion efficiency of only 6-15% [2].

The use of photovoltaic cells and modules for electricity generation through solar energy; is very common today [3]. It is a fact that photovoltaic cells convert less than 20% of the solar radiation energy into electrical energy. The remaining amount of the radiation is partly convected and radiated to the atmosphere and partly converted into thermal heat energy and accumulated within the solar cell. This accumulated heat energy in the cell raises it's temperature much above the cell temperature limits specified by its manufacturer [4]. The higher operating cell temperature and the ambient temperature, which is one of the environmental factors, have an adverse effect on the photovoltaic conversion efficiency of the solar cells. Actually with the increase in the operating temperature, there is a linear decrease in the power output and the conversion efficiency of a solar panel [5]. The range of efficiency decrease per degree Celsius typically varies from 0.25% to 0.5% [6]. According to Weng et al [7] also, the range of efficiency reduction is 0.2% to 0.5% with an increase of 1K in solar cell temperature. Hence the heat accumulation in the solar cell, which causes the increase in temperature of the solar cell, is a highly undesirable phenomena as far as the efficiency and power output are concerned. Also the service life of the solar cell gets reduced due to its long-term high temperature usage. Therefore it is of prime importance to cool the solar cells and hence the solar panels. Figure 1 shows the variation of efficiency with cell temperature.

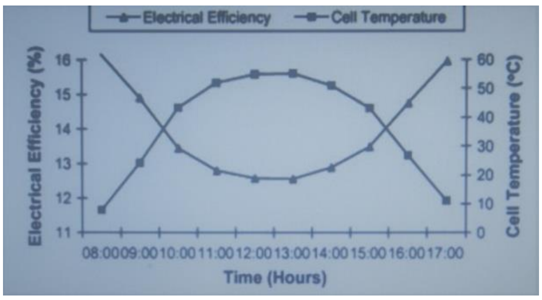

Fig.1. Variation of Cell Efficiency with Cell Temperature [25]

Thus innovative solutions for potential cooling of the photovoltaic panels are required to control the module operating temperature. Various cooling techniques are employed to cool photovoltaic panels that contribute in reducing their operating temperature and hence help to improve its efficiency and power output. Heat pipe-based cooling of photovoltaic panels is deemed to be a potential cooling method [8]. Normally the contact between the flat

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solar panel and the heat pipe is not proper and hence reduces the heat transfer between two. This problem can be resolved by using flat shape novel heat pipes, which results in better contact between the panel and the heat pipes, thereby enhancing heat transfer efficiency. It also helps to maintain a uniform temperature distribution across the panel [9].

This paper summarizes the outcomes of various studies that have been conducted to investigate the gravity assisted heat pipes as potential cooling solution for photovoltaic panels. The effect of different heat pipe parameters on its performance and hence on the performance of the solar photovoltaic module, to which they are attached for cooling purpose, have been studied thoroughly by different researchers.

1.1 Photovoltaic Panel Construction

A photovoltaic panel consists of solar cells which are generally wafers of polycrystalline silicon. In order to provide strength to these wafers, they have been encapsulated in a layer of EVA (Ethylene Vinyl Acetate) [10]. A tedlar layer of approximately 0.0001m thickness, which is nothing but polyvinyl fluoride film, is provided at bottom of the encapsulation to support it. Further a glass sheet of 0.032m thickness is covered on the top of the wafer encapsulation. A layer of anti reflective coating (ARC) is applied below the glass sheet, this glass sheet is in contact with the wafers. This coating reduces the reflection, and hence enables solar cells to absorb more solar radiation. Figure 2 shows the construction of a typical photovoltaic panel.

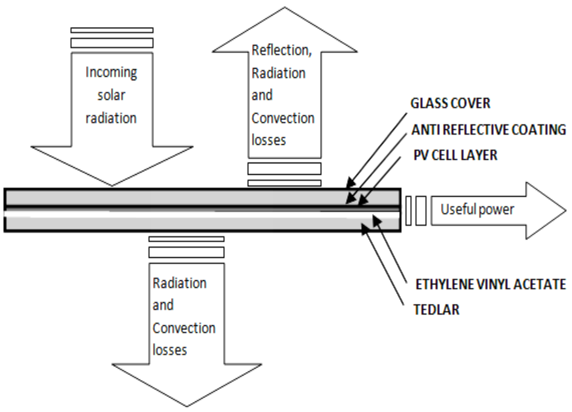

Fig. 2. Construction of a photovoltaic panel [26]

1.2 Photoelectric Conversion Efficiency

Basically the conversion efficiency of a photovoltaic cell is dependent on its working temperature and nature of its material apart from other parameters. M. Mattei et al. [11] studied about photovoltaic cell performance and proposed an expression for the photovoltaic cell's efficiency as given below:

$$\eta = \eta_r \,[\, 1 - \beta \times (T_c - T_r) + \lambda \times \log(\Phi) \,]$$

In this equation η_r is the efficiency of the reference module at its reference temperature T_r, which is 25 °C for the reference solar radiation I_{ref} equal to 1000 W/m^{2}K,. β is 0.0045 K^{-1} and λ is 0.12, which are known as temperature coefficient and solar irradiation coefficient respectively. T_c is the cell temperature and Φ is solar radiation actual intensity.

1.3 Photovoltaic Hybrid System

The efficiency of a photovoltaic thermal (PV/T) hybrid system is considered to be significantly more as compared to photovoltaic panel efficiency or thermal collector efficiency when considered separately. Here, in hybrid technology both systems are combined together to generate electricity and thermal heat simultaneously from a single unit. Solar panel converts the solar radiation into electricity and the thermal system attached to the PV module transforms excess solar radiation energy from the PV module into useful thermal heat energy. And because of these dual features the overall efficiency of the system increases significantly [12]. Figure 3 shows a water cooled hybrid photovoltaic system. Here the water is pumped through different tubes mounted at back side of the panel, in order to extract heat from it. Because of heat removal the temperature of the panel reduces, thereby improving its performance. At the same time the heated water inside the tubes can be used for different heating applications. Therefore the overall efficiency of the system increases significantly as solar radiation energy is being utilised to generate electricity and thermal heat energy as well.

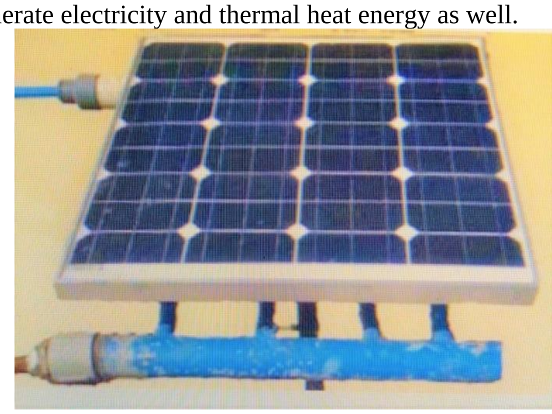

Fig. 3. A Typical PV Hybrid System [12]

2. ACTIVE AND PASSIVE COOLING METHODS

In general the active cooling methods involve additional power requirements whereas the passive cooling techniques may involve initial and manufacturing costs, but no running cost is involved in passive cooling techniques. There are two options in both active and passive cooling techniques. In the first case only cooling of the PV module is focused. The second case falls under the PV/T category. In this case the waste heat generated after cooling is recovered through some mechanism for further utilization in certain heating applications [13].

In their research Maleki et al., [14] divided the PV cooling approaches into two main categories as active method and passive method. They classified the heat pipes and phase change material (PCM) as passive methods for cooling photovoltaic panels. There are other cooling methods also which can be categorized as passive cooling methods like heat sink cooling, nanofluid cooling, thermoelectric cooling and evaporative cooling etc [15].

Tonui et al. [16] used both active and passive methods to extract heat from photovoltaic panel. In fact they used air as the cooling medium for the panel. In their PV/T system, i.e. photovoltaic/thermal system they studied the effect of both forced and natural circulation of air. This solar preheated air could be used for agricultural and industrial applications. For heat transfer augmentation in their system, they used fins on the back side of the air duct. Due to this arrangement, the overall performance of the PV/T system improved significantly.

Mutombo [17] used a rectangular shape channel for thermosyphon application, using water as working fluid. In his study he presented the behavior of gravity assisted hybrid photovoltaic thermal PV/T system. In this simulation study, the results show a considerable increase in the overall efficiency of the PV/T module. In comparison to an efficiency of 14.6% for a standard PV module, they were able to achieve an efficiency of 38.7%. Also the temperature of the water in the storage tank reached to a value of 37.1ºC. These results are quite encouraging in the field of photovoltaic thermal applications.

William et al. [18] published a research paper which establishes heat pipes as viable cooling solution for solar cells. Heat pipes can receive high heat flux from the concentrating photovoltaic cells and passively remove it by natural convection.

In one of the studies based on passive cooling method the heat generated in the module is partly absorbed by the phase change material[19], while in an another study again based on passive cooling technique, the air was made to flow across the sheet fins at the bottom of the panel due to buoyancy effects[20]. Both these passive cooling methods resulted in higher power outputs and conversion efficiencies.

3. GRAVITY ASSISTED HEAT PIPES

Heat pipes are categorized as passive cooling devices. A typical heat pipe consists of an evaporation section, an adiabatic section and a condenser section. They are used to transmit heat from a hotter region to a low temperature region by continuous evaporation and condensation of the working fluid. Heat is absorbed in the evaporation region and released in the condenser region, where the working fluid gets condensed and transformed into liquid form .The condensed fluid called as condensate is then returned back to the evaporator region and the cycle continues. Usually a wick is used to transport liquid from the condenser region to the evaporator region due to the capillary effects. In gravity assisted heat pipes which are also called thermosyphon heat pipes, the wick is not present and the condensate from the condenser section comes down to the evaporator section under the influence of gravity. Hence named as gravity assisted heat pipes.

Anderson et al. [21] used heat pipes for cooling of solar modules, which resulted in panel working temperature of 40 ºC under atmospheric temperature of 34 ºC. Here the evaporator zone of the heat pipe is attached on the rear surface of photovoltaic modules and the condensation section of the heat pipe extends beyond the solar module and is not in contact of the module. In the normal heat pipes a wick is used to transfer the liquid from condenser section to the evaporator section due to capillary effects. Whereas in gravity assisted heat pipes or thermosyphon heat pipes, the liquid flows due to gravity effects.Akbarzadeh A. &Wadowski T. [22] have tested this method of gravity assisted heat pipe cooling of solar modules and reported improvement in the performance of photovoltaic panels. Since the thermal contact between the heat pipe and the rear surface of the solar panel is not good, there is poor heat transfer between them.S. Kalogirou and Y. Tripanagnostopoulos [23] Performed and reported the results of experimental studies. In their studies they used both water cooling and air cooling methods on the condenser sides of the heat pipes in an array of micro heat pipes.

Since the operating pressure and nature of the liquid inside the closed thermosyphon decide the boiling point of the working fluid, selection of proper thermosyphon fluid and operating pressure both are important. The thermosyphon temperature and hence the panel temperature are dependent on these two thermosyphon parameters. In general the panel temperature is a function of the ambient temperature, solar radiation intensity and wind velocity. Hence the panel cooling requirements should be adopted accordingly.

In their studyAkbarzadeh A. &Wadowski T.[22] have used gravity assisted heat pipes for cooling photovoltaic cells. They increased the solar illumination on solar cells 20 times by using a concentrator. In this study they were successful to maintain the solar cell temperature below 46 ºC, which can be considered as a great achievement.

3.1 Working of Thermosyphon Heat Pipes

Basically a normal heat pipe has three parts, i.e. evaporator zone, adiabatic zone and a condenser zone. It has a wick material inside it for transport of the working fluid. A gravity assisted heat pipe has no such wick medium; instead the transport of the working medium takes place due to the effect of gravity. In this case the heat is received by the working fluid in the evaporator region and as a result it gets vaporized. Vapor thus formed rises to the condenser region. Now this vapor in the condenser releases its heat to a cooling medium on the condenser side and transforms into liquid. This liquid in the form of a film descends along the pipe surface and reaches to the evaporator section under gravitational effects in a thermosyphonic manner, as shown in figure 4. Again this liquid accumulated in the evaporator zone receives heat, vaporises reaches to condenser region, liquifies and then comes back again to the evaporator section and thus the cycle keeps on repeating in a closed loop [24].

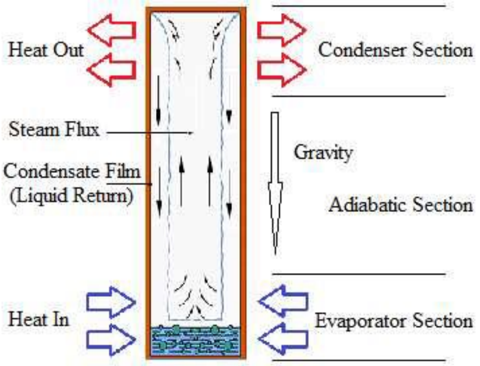

Fig. 4. Thermosyphon Heat Pipe Working [25]

4. SOLAR PANEL COOLING BY THERMOSYPHON HEAT PIPES

Various studies have been conducted to explore the effect of thermosyphon heat pipe cooling on the performance of photovoltaic panels. In spite of being an effective technology, exhaustive research on this topic is still awaited. However, some significant works have been performed in this area, which establish it as one of the promising, viable and a potential cooling solution for photovoltaic panels. The effect of different heat pipe parameters on its working has been studied in various studies, in order to analyse, their influence on the cooling of the photovoltaic panels. In the following section, some highlighted works on this topic have been discussed, which shows the importance of this emerging and novel technology as far as the cooling of solar photovoltaic panels is concerned.

4.1 Effect of Working Fluid

Engin Ozbas & Gaziza Datkayeva [25], used three identical photovoltaic modules. One of them was used as the reference panel, whereas passive cooling was applied to the remaining two panels. The performance of these two panels was compared with the reference panel and the effect of passive cooling was studied. Table 1 shows the specifications of these three identical modules used in this study, at STC of 1000 W/m^{2}and 25 ^{o}C for solar radiation intensity and ambient temperature respectively.

Table 1. Electrical Specifications of Panels [25]

Maximum Power	P_{max}	10 W
Voltage at Maximum Power	V_{pmax}	17.5 V
Current at Maximum Power	I_{pmax}	5.7 A
Open Circuit Voltage	V_{oc}	22 V
Short Circuit Current	I_{sc}	6.2 A

For the passive cooling of the two modules, six identical gravity assisted type heat pipes, i.e. closed thermosyphons were manufactured. Pure water is used as the working liquid in three of these six heat pipes, whereas in the remaining three heat pipes pure ethanol is used as the working liquid. Now the set of three water filled heat pipes was used in one of the PV test panels, while the ethanol filled three heat pipes were used to cool the other test panel. The performance of both of these panels was compared with the reference test PV panel, one without heat pipes.The heat pipe cooled panels along with the reference panel used in this study are shown in figure 5.

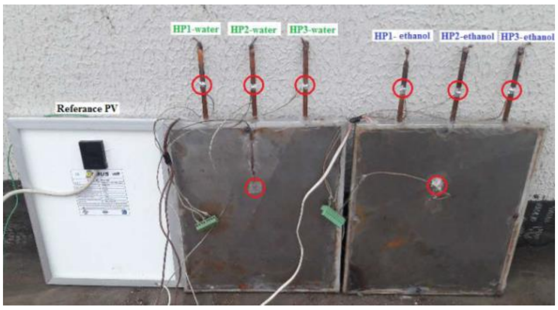

Fig. 5. Gravity Assisted Heat Pipes on the Back of Panels [25]

Back surfaces of the heat pipe cooled panels were covered with metal plate and filled with water as shown in the figure, in order to maintain uniform temperature and a uniform heat transfer to the evaporator sections of the heat pipes adhering to photovoltaic panels on the back side.

In this study Engin Ozbas & Gaziza Datkayeva [25], used K type thermocouples for temperature measurements on different photovoltaic systems. They used a UDL100 type data logger for collecting temperature data from various systems. A CHY 21 - LCR Multimeter was used for measuring the values of open voltage and short circuit currents. Moreover they collected the solar radiation, ambient temperature and wind speed data from meteorological station in Yesilyurt DC Vocational School.

This experimental study was made in the months of autumn. The GPS coordinates used for experimentation were taken as 41^o 41' N and 36^o 26' E (Samsun, Turkey). The inclination angle of the system was kept as 41^o in order to get more radiation from the sun and get more benefits.

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The experiments were performed between 9:40 and 16:30 hours on 28 September 2020.

Table 2 shows the hourly values of power generated in different photovoltaic (PV) panels used in this study.

Table 2. The Amount of Power Generated in the PVs [25]

	Reference PV	Water HP-PV	Ethanol HP-PV
Time	Power	Power	Power
Hr	Watt	Watt	Watt
09:40	5.80	5.75	5.75
10:40	8.35	8.37	8.36
11:40	10.10	9.97	9.96
12:40	10.49	10.56	10.56
13:40	9.88	9.94	9.94
14:40	8.31	8.32	8.31
15:40	5.89	6.09	5.89

In this experimental study, the authors used gravity assisted heat pipes for cooling the PV panels. Further they compared the cooling performance by using pure water and pure ethanol as working fluids in two different thermosyphons. From Table 2, it can be mathematically analysed that the average power output from the reference, water heat pipe and ethanol heat pipe solar panels are 8.25 W, 8.32 W and 8.27 W respectively. From these results, it can be clearly observed that the heat pipe cooling improves the performance of photovoltaic panels.

Further , the authors have suggested to investigate the effect of increasing the heat pipe condenser section length, increasing the number of heat pipes and using the nano-fluids in heat pipes on the passive cooling of photovoltaic panels and hence on their performance.

Moreover, since this experimental study has been performed in the autumn season, the effect of passive cooling can be investigated in summer or hotter regions as well, as recommended by authors.

4.2 Effect of Phase Change Temperature

In this study, Zakariya Kaneesamkandi[26], modelled and simulated thermosyphon heat pipe cooled photovoltaic panel. In the study, he tested the performance of photovoltaic module by using two different phase change temperatures of the working fluid inside the thermosyphon heat pipes.In this simulation study; it is observed that by reducing phase change temperature the cooling effect was significantly increased. In the study he used four rectangular thermosyphon tubes on the back surface of the PV panel. Perfect thermal contact was maintained between the panel and the tubes due to flat surface of the tubes, as shown in figure 6. Evaporation of the thermosyphon liquid takes place once the temperature of the panel reaches above its boiling point. This vapour gets condensed , when it comes in contact with the surface which is exposed to surroundings. As long as the boiling temperature of the liquid is below the temperature of the solar panel the evaporation of the liquid will take place followed by its condensation in the condenser section of heat pipe. Square cross section of thermosyphon tubes was taken to make a better contact between tubes and the panel back surface in order to enhance the heat transfer between the panel and the heat pipe evaporator section, adhering to the panel from behind as shown in the figure.

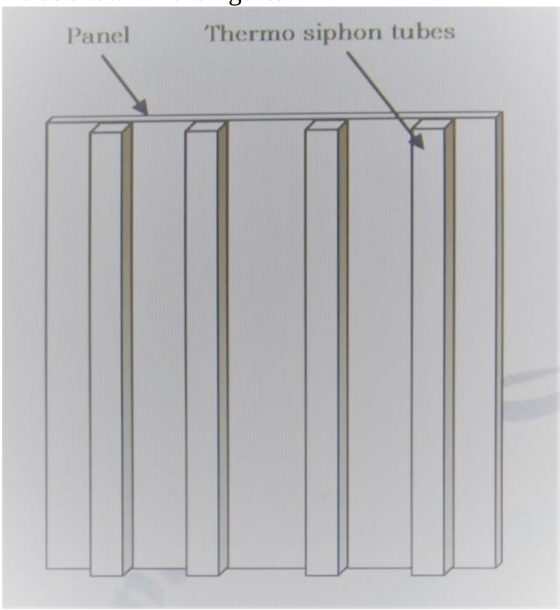

Fig. 6. Rectangular thermosyphon tubes on back of PV panel [26]

In the study the author generated the model by assuming the following points :

1. Steady state conditions
2. The tube temperature is uniform throughout
3. Cooling of vapor is uniform
4. Boiling temperature remains constant during phase change
5. There is perfect thermal contact between tubes and panel

There is a one dimensional conduction of heat(q) which is produced in the cell layer, towards the top and bottom both sides of the panel. It is expressed as [26]:

$$q = K_g(dT/dx)_g + K_t(dT/dx)_t$$

Where K_g and K_t are the thermal conductivities of glass and tedlar layer respectively. Also from the top and bottom surfaces of the panel, heat is dissipated due to convection and radiation, and can be evaluted by the following equation[26] :

$$q = h_t (T - T\infty) + h_b (T - T_g) + \sigma (T^4 - T^4_{sky}) \sigma (T^4 - T^4_g)$$

Where, h_t is the coefficient of heat transfer from top of the panel, h_b is the coefficient of heat transfer from bottom of the panel.   is the Stefan Boltzmann constant.

In his model, he used 30238 nodes and 4740 elements in meshing. He selected medium smoothing and fine mesh for relevance center. Model with meshing is shown in figure 7. The author used ANSYS steady state thermal workbench package to analyze this model.

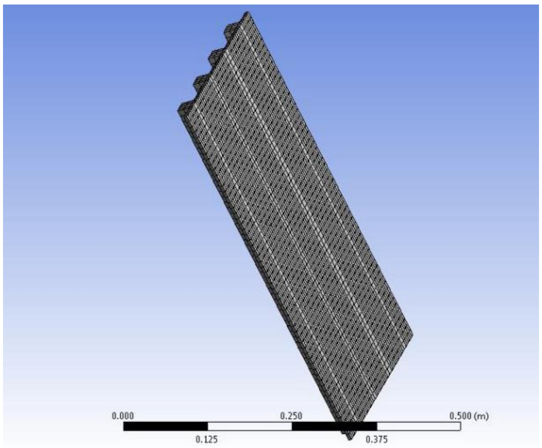

Fig. 7. Meshed Model [26]

In this simulation study the two phase change temperatures used by author inside thermosyphon heat pipe are 40 °C and 50 °C respectively for the analysis. He used the following empirical relation [27] for calculating the heat transfer coefficient.

$$h_t = 2.8 + 3.8 V$$

Where h_t is the coefficient of heat transfer on top side of panel, V is the wind speed. Now if we consider the value of wind velocity as 5 m/s, the heat transfer comes out to be 21.8 W/m^{2}K. In this study the panel surface area was 0.32 m^2. The thermosyphon tube is square shaped with a cross section area of 0.05 m^2. The solar radiation was assumed as 800 W/m^2.

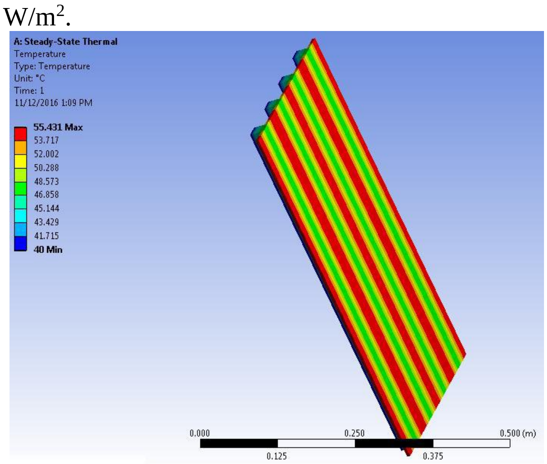

Fig. 8. Simulation results at 40 °C [26]

It is concluded from the analysis that when the phase change temperature of 40 °C was used in the thermosyphon heat pipe, the maximum and minimum temperature values across the panel were recorded as 55.43 °C and 48.57 °C as shown in figure 8. Similarly when the phase change temperature was used as 50 °C, the maximum and minimum temperature values in the panel were seen as 64.33 °C and 57.96 °C. Thus a direct relation was observed between the average panel temperature and the phase change temperature maintained in the thermosyphon. Through mathematical analysis, it can be deduced that by reducing the phase change temperature of the thermosyphon liquid by 20%, a reduction of 13.8% in the maximum panel temperature is obtained. It is also observed that the difference between the maximum and minimum temperature values of solar module is large, which is approximately 7 °C in both the cases. This is due to the poor thermal conductivity of the glass material covered on solar cells layer. There is significant enhancement in the cooling of the panel with the reduction of the phase change temperature in the thermosyphon, which is the main outcome of the present study. It has been suggested that solar panel temperature can be lowered further, if number of tubes or size of the tubes is increased. But it would be economical and justified only if the ambient temperature is high or the solar radiation intensity is high, as reported by the author.

4.3 Effect of Condenser Cooling Medium

Tang et al. [28] performed an experimental study on silicon solar panel. It has a maximum power of 10 W under standard conditions of 25 °C ambient temperature and 1000 W/m^2 solar intensity. For cooling this panel an array of micro heat pipes has been involved. The natural circulation of air and water has been used to cool down the condensers of the heat pipes in the array. That means the heat from the panel is finally transferred to air or water through the heat pipe condenser section, which causes the reduction in the temperature of the solar module and thus enhances its performance.

In the air cooled solar panel, the evaporator section having length 283 mm is attached at the back side of the solar module. The condenser section with its length of 200 mm was exposed to the atmospheric air. In the water cooled solar module also, the evaporator section of length 283 mm is attached to the back surface of the solar module. The condenser section with its length of 40 mm is attached to a water flume. A water tank was also used for the availability of water to the water flume. The specifications of the water flume and water tank are respectively 40x25x385 mm and 280x280x280 mm. There is a distance of 170 mm between them.

In this study, the authors [28] measured efficiency, power, and the temperatures of the solar panel. For different measurements they used the following instruments:

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1. Voltmeter of type HC-300C-S-DV in the range of 0-50 V
2. Ammeter of type HC-300C-S-DA in the range of 1-10 A
3. Variable Resistor of porcelain-type (0-50 ohm, 150 W) was used as the load
4. A solarimeter is used to measure the real-time solar radiation intensity (W/m^2)
5. A wind speed sensor (YS-CF-X/S) is used to measure the wind speed (m/s)

Agilent 34970 A, Data Acquisition System has been used in order to collect the real time data of temperatures. Ambient temperature, solar panel temperature, temperature of the water in storage tank, and temperatures of water at inlet and outlet from water flume were monitored.

The solar panel conversion efficiency is calculated by using following equation:

$$\eta_e = P/A_t P_{in} = UI/A_t P_{in}$$

Where, ηe = photoelectric conversion efficiency (%)
P = power output (W)
U = voltage (V)
I = current (A)
P_{in} = solar radiation intensity (W/m^2)
A_t = total area of the solar panel

For the analysis of the study various graphs have been plotted. For example figure 9 shows the hourly power output for ordinary panel and panel with air cooled heat pipes whereas figure 10 shows the hourly conversion efficiency for ordinary panel and panel with air cooled heat pipes. Similarly figure 11 compares the power output for panel with air cooled heat pipes and panel with water cooled heat pipes whereas figure 12 compares conversion efficiency for panel with air cooled heat pipes and panel with water cooled heat pipes. Hourly solar radiation intensities are also plotted in all these graphs between 5 hrs and 19 hrs, which ranges from 0 w/m^2 to nearly 1000 w/m^2.

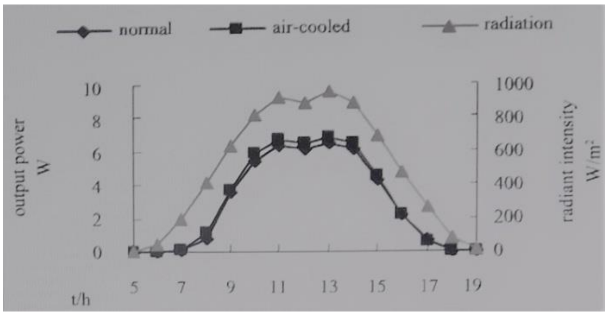

Fig 9.Power Output for air cooled heat pipe and ordinary panel[28]

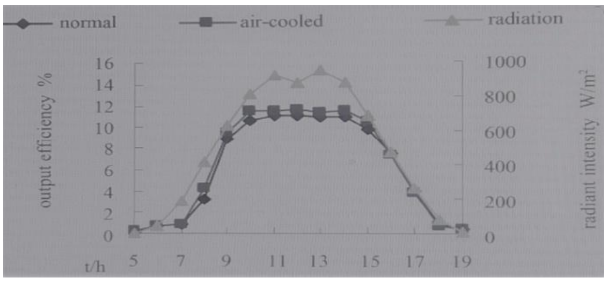

Fig. 10. Efficiency for air cooled heat pipe and ordinary panel [28]

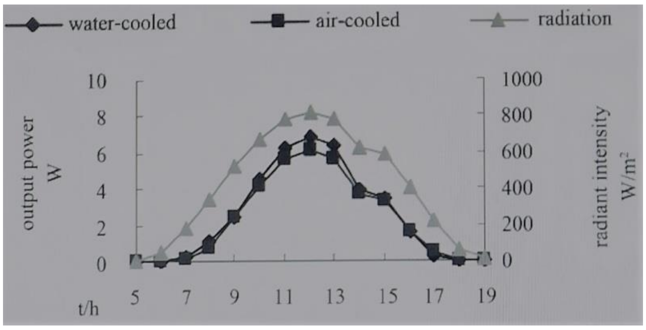

Fig.11.Power Output for air cooled and water cooled heat pipe [28]

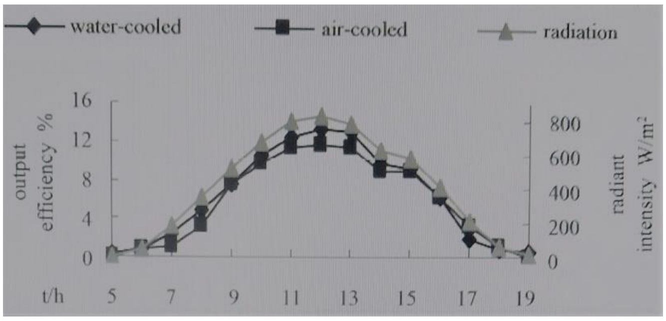

Fig. 12. Efficiency for air cooled and water cooled heat pipes [28]

From this study, Tang et al. [28] concluded that the temperature of the solar panel with air cooled heat pipe was reduced by 4.7 °C as compared to an ordinary solar panel without any cooling mechanism. In this case the power output and efficiency are increased by 8.4% and 2.6% respectively for the panel with air cooled heat pipes as compared to ordinary panel. This experiment was done in the day of month May, when the ambient temperature was 36 °C, wind speed was recorded as 5.32 m/s and the global radiation was measured as 26.3 MJ.

Further panel with air cooled heat pipes were compared with the panel with water cooled heat pipes. In this case they concluded that temperature in case of water cooling decreases by 8 °C as compared to air cooling. In this case the power output and the efficiency are increased by 13.9% and 3% respectively for the panel with water cooled heat pipes as compared to panel with air cooled heat pipes. This experiment was also done in the day of month May, when the ambient temperature was 35 °C and wind speed was recorded as 4.72 m/s and the global radiation was measured as 21.9 MJ.

4.4 Effect of Thermal Conduction Plates

In their experimental research study, Laith Habeeb et al. [29] used thermosyphon heat pipes on two modules, module I and module II out of three modules for cooling purpose. The third module was a normal module, without any cooling mechanism used as the reference module for modules I and module II. This module has been called as traditional module in the study. However, for improving the thermal conduction from the panel to the heat pipes they have employed copper and aluminum plates on the back side of module I and module II respectively. Because of using thermal conduction plates behind the modules, the heat conduction surface area increases allowing to increase the heat transfer rate from photovoltaic modules to the heat pipes. They carried out an experimental study and verified it mathematically.

In the case of module I, they used four thermosyphon heat pipes made of copper. The inner diameter of the heat pipes is 14 mm whereas the outer diameter is 16 mm. The evaporator length of the heat pipe is 1200 mm. The condenser section length of the heat pipe is 150 mm while its inner and outer diameters are 28 mm and 30 mm respectively. The distance between the two consecutive heat pipes was measured to be 140 mm. They used distilled water as the working fluid with a filling ratio of 55%. On the back side of the panel a copper plate of 0.07 mm thickness is used to cover the heat pipes in order to enhance the heat conduction from photovoltaic panel to heat pipe due to increased conduction surface area as shown in figure 13.

Fig. 13. Copper plate covering heat pipe and back of the panel [29]

Similarly, in module II, they used aluminum plate of the same dimension as in module I. The module II is cheap and economical as compared to module I. In this case they used six gravity assisted heat pipes having same specifications as in case of module I.

In both the systems, the heat exchangers called as water box by the authors are used on the heat pipe's condenser section sides. Condenser sections of all the heat pipes are immersed in the water box in both the modules. The heat from the condenser zones of the heat pipes is extracted by the water inside the water box. This high temperature water available from the heat exchanger can be used for specific thermal applications. Because of this heat recovery feature these systems are termed as HP-PV/T (Heat Pipe-Photovoltaic-Thermal) systems. The various temperatures of the systems including the inlet and outlet of water in the water boxes are recorded by using thermocouples at appropriate locations as shown in figure 14.

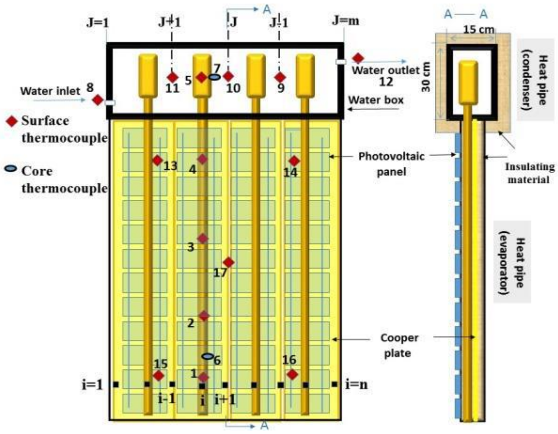

Fig. 14. Thermocouple locations in module I [29]

Laith Habeeb et al. [29] conducted an experiment on 18/7/2017. Both the modules were tested with constant water flow rate of 10 l/h. The average temperatures of the modules recorded at 12:00 hr are 68.68 ºC for module I, 76.7 ºC for module II and 85.36 ºC for traditional module. On this day the ambient temperature was recorded as 48.7 ºC. These results clearly show that average temperatures of module I and module II are significantly less than traditional module.

On 21/7/2017, they conducted another experiment, for this experiment they kept the water flow rate as 15 l/h. In this case the average temperatures of the modules recorded are 64.06 ºC for module I, 75.53 ºC for module II and 86 ºC for traditional module. The ambient temperature was recorded as 47.2 ºC. Here again the average temperatures of module I and module II are quite less as compared to traditional module.

Figure 15, shows the temperature variations in the modules with respect to time. From the results of this study, it is concluded that increasing the flow rate of water does not affect much, whereas the surrounding temperature has a significant effect on temperature values of the photovoltaic modules.

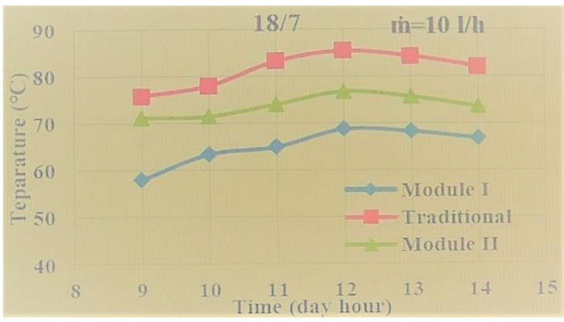

Fig. 15. Temperature variation with time for all the modules [29]

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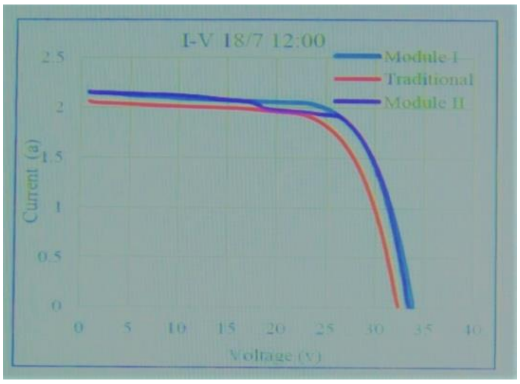
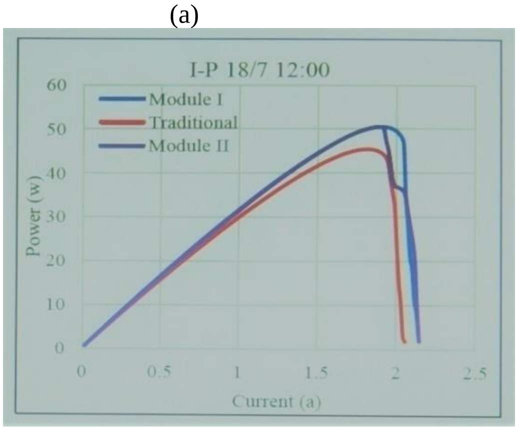
Further the characteristics of the photovoltaic (PV) panel obtained with the help of a solar device known as module analyzer, have been recorded and reported in this study thoroughly [29]. As reported by authors, on 18/7/2017, at 12:00 hrs , the Open Voltage is 33.84 Volt, Short Circuit Current is 2.1453 Amp, Max Power is 50.5623 Watt, Max Voltage(voltage at maximum power) is 26.384 Volt, Max Current(current at maximum power) is 1.9164 Amp and the Efficiency is 16.8372 % for the module I. For module II, the Open Voltage is 33.493 Volt, Short Circuit Current is 2.148 Amp, Max Power is 50.57426 Watt, Max Voltage is 26.96 Volt, Max Current is 1.8759 Amp and the Efficiency is 16.84%. Now for the traditional module the recorded values are; the Open Voltage is 32.366 Volt, Short Circuit Current is 2.0571 Amp, Max Power is 45.4297 Watt, Max Voltage is 24.908 Volt, Max Current is 1.8239 Amp and Efficiency is 15.128 %. Figure 16 shows (a)I-V(Current Vs Voltage) and (b)I-P (Current Vs Power) characteristics for module I, module II and the traditional module for the day of 18/7/2017 at 12:00 hrs.



(a)



(b)

Fig. 16. (a) I-V and (b) I-P characteristics for all the modules [29]

5. CONCLUSION

It has been established through an experimental study that by using water as working fluid in the thermosyphon heat pipe, the cooling of the panel and hence its performance improves significantly as compared to when ethanol is used as the working fluid in the heat pipe. A model based simulation study shows that low phase change temperature of the working fluid inside the thermosyphon heat pipes improves the panel performance considerably as compared to high phase change temperature. Also, the effective cooling of condenser zone of thermosyphon heat pipe results in higher performance of the photovoltaic panel. Experimental study performed on the thermosyphon system of PV modules by circulating water and air indicate that by using water circulation instead of air circulation around condenser zone of heat pipe, the photoelectric conversion efficiency and the power output of the photovoltaic panel could be enhanced by a noticeable amount. Further, for heat conduction augmentation between the panel and the heat pipe's evaporator section, a novel technique can be employed. Metallic plates can be effectively used to conduct more heat from the panel to the heat pipe's evaporator section. This study reveals that by using copper plate the performance of the solar panel is increased to a large extent, as compared to when aluminum plate is used. From analysis of different studies, it is concluded that thermosyphon heat pipe cooling has a good potential, is viable and is a promising cooling solution for photovoltaic solar panels.

REFERENCES

[1] Sharma A., Tyagi V. V., Chen C.R., Buddhi D., "Review on thermal energy storage with phase change materials and applications ", Renew sustain Energy Rev, Vol.13, 2009, pp. 45-318.
[2] W. He, T. T. Chow, J. Ji, et al., “Hybrid Photovoltaic and Thermal Solar-Collector Designed for Natural Circulation of Water”, Applied Energy, Vol. 83, No. 3, 2006, pp. 199-220.
[3] Ozbas E., Alkis M., “Investigation of Cooling Techniques Applied toPhotovoltaic Modules”, ISAS 2018-Winter, 2nd International Symposium on Innovative Approaches in Scientific Studies, November 30 - December 2, 2018, Samsun, Turkey.
[4] Fundamentals of Photovoltaic Materials, National Solar Power Institute, Inc, Olivia, Mah NSPRI, 1998, pp. 1-10.
[5] E. Skoplaki, J.A. Palyvos,“On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations”, Solar Energy 83, 2009, pp. 614–624.
[6] F. Grubisic Cabo, S. Nizetic, T. Giuseppe Marco, “Photovoltaic Panels: A Review of the Cooling Techniques”, Transactions of FamenaXl, Special issue 1, University of Catania, Italy, 2016.
[7] Z. J. Weng and H. H. Yang, “Primary Analysis on Cooling Technology of Solar Cells under Concentrated Illumination”, Energy Technology, Vol. 29, No.1, 2008, pp. 16-18.
[8] M. A. Farahat, “Improvement the Thermal Electric Performance of a Photovoltaic Cells by Cooling and Concentration Techniques”, 39th UPEC International, Bristol, Vol. 2, 2004, pp. 623-628.
[9] Y. H. Zhao, et al., “A Sort of Micro Heat Pipe Array and Processing Technics”, Chinese Patent: 200810225649.
[10] S. Armstrong, W.G. Hurley,“A thermal model for photovoltaic panels under varying atmospheric conditions” Applied Thermal Engineering, 30, 2010, pp. 1488-1495.
[11] M. Mattei, G. Notton, C. Cristofari, M. Muselli, P. Poggi,“Calculation of the polycrystalline PV module temperature using a simple method of energy balance”, Renewable Energy 31, 2006, pp. 553–567.
[12] R. Venkateswar, M. Venkatesh, K. Venkatesan, “Experimental Analysis of Water Cooled Photovoltaic/Thermal Hybrid System”, Int. Journal of Current Engineering and Scientific Research, 4(6), 2017, pp. 10-12.
[13] Elbreki, A.M., Alghoul, M.A., Sopiana, K., Husseine, T., “Towards adoptingpassive heat dissipation approaches for temperature regulation of PV module as a sustainable solution”, Renewable and Sustainable Energy Reviews, 2017, pp. 961-1017.

[14] Maleki, A., Haghighi, A., Assad, M.E.H., Mahariq, I., Nazari, M.A., "A reviewon the approaches employed for cooling PV cells", Solar Energy, 2020, pp. 170-185.
[15] Pushpendu Dwivedi, K. Sudhakar, Archana Soni, E Solomin, I Kirpichnikova, "Advanced cooling techniques of PV modules : A state of art", Case Studies in Thermal Engineering, Vol. 21, 2020, pp. 1-17.
[16] J. K. Tonui and Y. Tripanagnostopoulos, "Improved PV/T solar collectors with heat extraction by forced or natural air circulation", Renewable Energy, 32, 2007, pp. 623–637.
[17] N. Marc-Alain Mutombo, "Studied the Performance analysis of thermosyphon hybrid photovoltaic thermal collector", Journal of Energy in Southern Africa. Vol.27, No.1, 2016.
[18] William G. Anderson, Sanjida Tamanna, David B. Sarraf, and Peter M. Dussinger,"Heat Pipe Cooling of Concentrating Photovoltaic (CPV) Systems", Advanced Cooling Technologies, Inc., Lancaster, PA, 17601, 2008.
[19] Giuseppina Ciulla, Valerio Lo Brano, Maurizio Cellura, Vincenzo Franzitta& Daniele Milone,"A Finite Difference Model of a PV-PCM System", Energy Procedia, 1st International Conference on Solar Heating and Cooling for Buildings and Industry, California, 2012.
[20] Tonui, J.K.&Tripanagnostopoulos, Y. "Performance improvement of PV/T solar collectors with natural air flow operation", Solar Energy, 82(1), 2008, pp. 1–12.
[21] Anderson WG, Dussinger PM, Sarraf DB.,"Heat pipe cooling of concentrating photovoltaic cells" In: Proceedings of the 33rd IEEE photovoltaic specialist's conference, 2008, pp. 1–6.
[22] Akbarzadeh, A. &Wadowski, T."Heat pipe based cooling systems for photovoltaic cells under concentrated solar radiation", Applied Thermal Engineering 16(1), 1996, pp. 81–87.
[23] S. Kalogirou and Y. Tripanagnostopoulos, "Performance of a Hybrid PV/T Thermosyphon System", World Renewable Energy Congress, 2005, pp. 1162-1167.
[24] Jafari, D., Franco, A., Filippeschi, S., Marco, P. D., "Two-phase closed thermosyphons: A review of studies and solar applications", Renewable and Sustainable Energy Reviews, 2016, pp. 575-593.
[25] Engin Ozbas & Gaziza Datkayeva, "Experimental Investigation of the effect of Gravity Assisted Heat Pipe on Photovoltaic Panel as Passive Cooling", Journal of Current Research on Engineering, Science and Technology", Vol. 6, No. 2, 2020, pp. 23-32.
[26] Zakariya Kaneesamkandi, "Steady State Thermal Analysis of Thermosyphon Heat Pipe Photovoltaic Panel Cooling Mechanism", International Journal for Modern Trends in Science and Technology, Vol. 2, No. 1, 2016, pp. 7-10.
[27] Watmuff, J.H., Charters, W.W.S. and Proctor, D., "Solar and Wind Induced External Coefficients Solar Collectors" Int. Revue d'Hellio-technique 2, 56, 1977.
[28] Xiao Tang, Zhenhua Quan, Yaohua Zhao, "Experimental Investigation of Solar Panel Cooling by a Novel Micro Heat Pipe Array", Energy and Power Engineering, Vol. 2, 2010, pp. 171-174 .
[29] Laith Jaafer Habeeb, Dheya Ghanim Mutasher, Faiz Abid Muslim Abd Ali "Solar Panel Cooling and Water Heating with an Economical Model Using Thermosyphon", Jordan Journal of Mechanical and Industrial Engineering, Vol. 12, No. 3, 2018, pp. 189-196.