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Experimental Investigation of the Effect of Gravity Assisted Heat Pipe on Photovoltaic Panel as Passive Cooling

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Abstract
In this study, the using heat pipes for passive cooling on the PV was experimentally investigated. Gravity assisted two-phase closed thermosiphon type heat pipes using two different working fluids as water and ethanol were manufactured. Prepared heat pipes were placed on the back surfaces of two of the three PVs with the same characteristics for passive cooling. Passive cooled PVs with water-heat pipe and ethanol-heat pipe were compared experimentally with reference PV at the same time and under the same conditions. As a result of the experiments, the highest power values of 10.49W, 10.56W and 10.56W were achieved, respectively, for reference, water-heat pipe and ethanol-heat pipe PVs.

1. Introduction

Energy is one of the important issues of today. In terms of environmental factors and sustainability, the use of renewable energy sources as clean energy is becoming widespread. The most common method for electricity generation with solar energy, which is one of the renewable energy sources, is the use of photovoltaic (PV) modules (Özbaş and Alkış, 2018: 508). Efficient operation of every system that is put into operation is desired. This situation is also valid for PV module systems. There are many factors that negatively affect the efficiency of a PV module. One of these factors is the outdoor temperature, which is one of the environmental factors (Idoko et al, 2018: 4). While some of the solar radiation is absorbed by the PV cell, the remaining part turns into thermal energy and causes the cell temperature to increase. As a result of the increase in the PV cell surface temperature, the efficiency of the PV module, which is approximately 15%, can decrease even more. Since the outdoor temperature cannot sufficiently lower the cell temperature that affects the overall performance of solar panels, innovative solutions should be produced to increase efficiency (Bahaidarah et al, 2016: 57). Additional cooling methods can be used to lower the cell surface temperature to increase the performance of the PV module. These cooling methods can be

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examined in two groups, active and passive (Sudhakar et al, 2017: 158). In the investigated by Elbreki et al, it is understood that active and passive cooling techniques are applied in two ways. In the first application, only cooling is provided on the PV. The other is the application defined as PV / T where the waste heat generated after cooling is used as recovery (Elbreki et al, 2017: 69). Maleki et al. in their research, they divided the PV cooling approaches into two main topics as active and passive methods. While examining the active methods in air cooling, liquid cooling and liquid spray heads, wick structure, phase change material (PCM) and heat pipes are classified as passive methods (Maleki et al, 2020: 209).

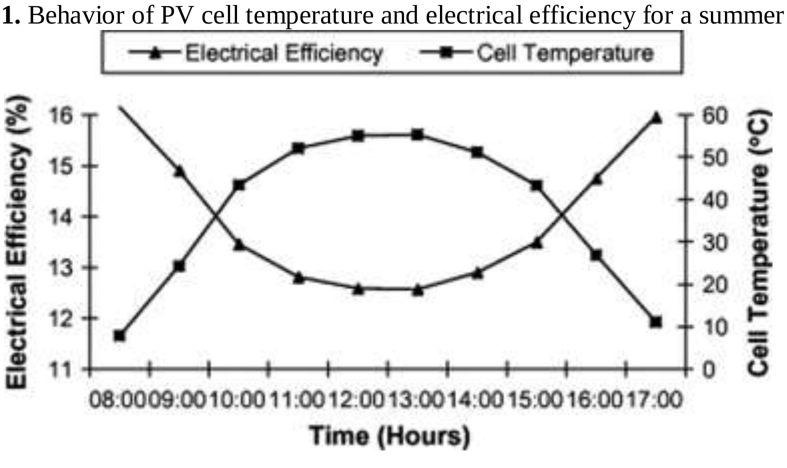
Akbarzadeh and Wadowski concentrated the solar radiation on a PV cell in their study and used gravity assisted heat pipes for cooling process. They increased the amount of solar radiation 20 times with the concentrator. They were able to keep the cell surface temperature below 46^{o}C with the heat pipe they used (Akbarzadeh and Wadowski,1996: 16). In this study, only passive cooling was applied on PV. Two groups of gravity-assisted heat pipes were manufactured using water and ethanol as working fluids for passive cooling. A total of three PVs with the reference PV have been experimentally compared.

2. Experimental Study

2.1. Photovoltaic

A photovoltaic (PV) cell is a device that converts solar energy into electricity with a photovoltaic effect (Chandrasekar and Senthilkumar, 2015: 90). The cooling method to be applied on PV should have a minimum temperature with a uniform distribution and protecting the cell. Fig. 1 shows the behavior of solar cell efficiency with increasing PV surface temperature. It is seen that as the cell surface temperature increases, the electrical efficiency of the solar cell decreases (Bahaidarah et al, 2016: 57).

Fig. 1. Behavior of PV cell temperature and electrical efficiency for a summer day

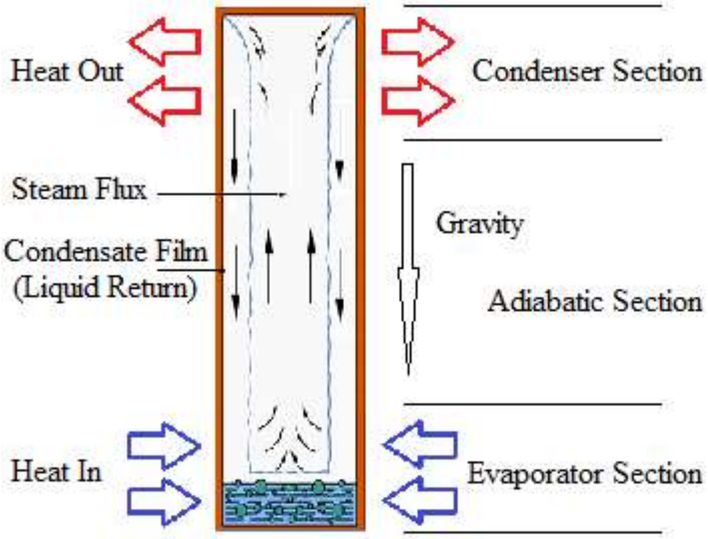


2.2. Gravity Assisted Heat Pipe

Heat Pipe (HP) is a two-phase thermal transfer device. Heat transfer is provided by taking advantage of the latent enthalpy of the working fluid during phase change. It is widely used for different systems for high heat flux for cooling purposes, as in fuel cells and electronic devices (Nazari et al, 2018: 32; Ramezanizadeh et al, 2018: 272).

Gravity assisted two-phase closed thermosiphon type heat pipe is a pipe with two ends closed filled with working fluid approximately 5-30% of evaporator's volume and containing both liquid and gas phases of the working fluid at the same time. (Faghri, 1995: 6).

Fig. 2. Gravity assisted two-phase closed thermosiphon



The physical mechanism of the heat pipe shown in Fig. 2 consists of three parts: the evaporator section, the condenser section and the adiabatic section. Working fluid rises in the vapor phase from the inner area of the pipe with the effect of the heat it receives from the evaporator zone and reaches the condenser zone. Here, the working fluid, which turns into a liquid phase by releasing its heat, descends from the pipe surface to the evaporator region in the form of a film by the effect of gravity and completes its cycle (Jafari et al, 2016: 53).

2.3. Experimental Setup

Three pieces of the commercial PVs whose electrical specifications were given in Table 1 were taken. While one was used as a reference, the other two were used for passive cooling application.

Table 1. Electrical specifications, STC 1000W/m^2, 25^{o}C

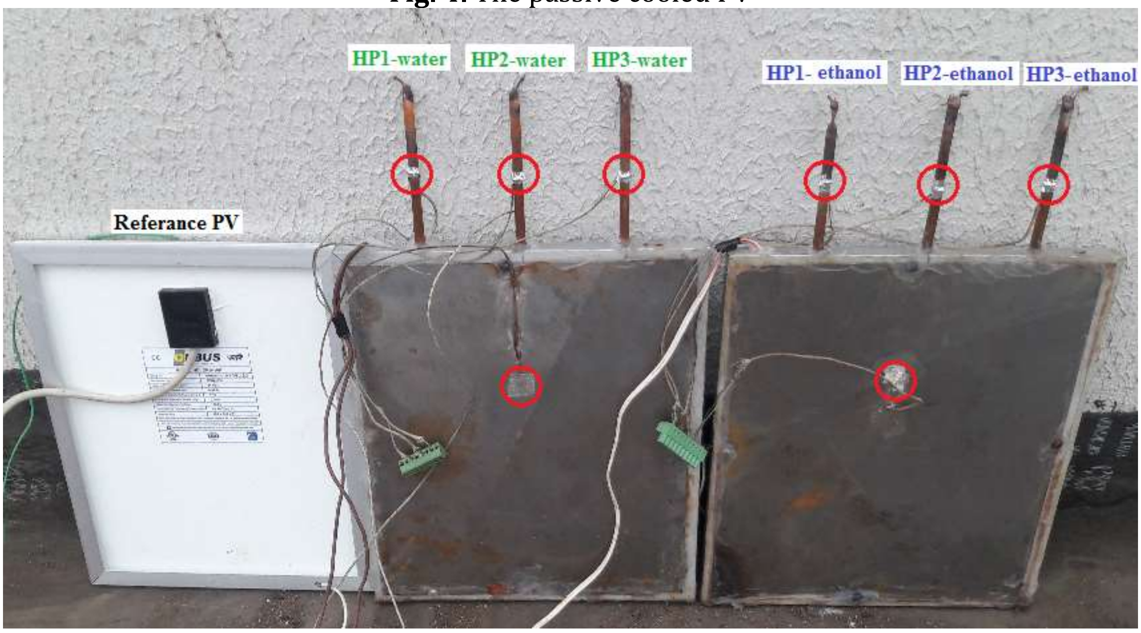
Maximum Power	Pmax	10W
Maximum Power Voltage	Vpmax	17.5V
Maximum Power Current	Ipmax	5.7A
Open Circuit Voltage	Voc	22V
Short Circuit Current	Isc	6.2A

For passive cooling, six pieces gravity assisted two-phase closed thermosiphon type heat pipes of the same diameter and material were manufactured. Three of these were filled with pure water as working fluid, and the other three with pure ethanol. The back surface of the PV was covered with a metal plate and filled with water in order to ensure a uniform heat transfer to the evaporator sections of the heat pipes. Fig. 3 shows the passive cooled PV, whose design and manufacturing has been completed for the experiment.

Fig. 3. The passive cooled PV

Solar radiation, ambient temperature and wind speed for the experiment day were taken from the meteorological station in Yesilyurt DC Vocational School. Type K thermocouple was used for temperature measurements on the test system and collected with a UDL100 type data logger. Temperature measurement points on the systems are shown in Fig. 4 and Fig. 5. In addition, CHY 21 - LCR Multimeter was used for open voltage and current measurements.

Fig. 4. The passive cooled PV



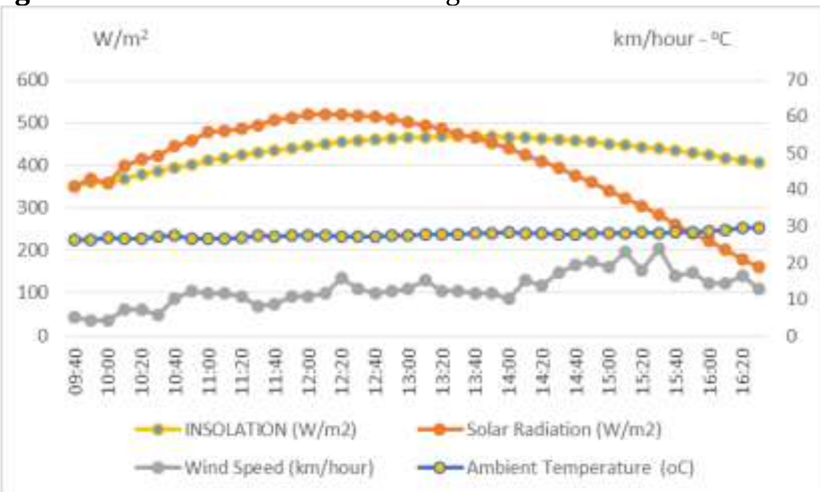
The experiments have been made in the autumn months at GPS coordinates of 41°14′N and 36°26′E (Samsun, Turkey). Therefore, in order to benefit more from the sun, the inclination angle of the systems was set as 41°. In Fig. 5, a general view from the experimental setup is given.

Fig. 5. A general view from the experimental setup

3. Results

The distribution of meteorological data and insolation values for the date of 28 September 2020, when the experiment was studied, is given in Fig. 6.

Fig. 6. The distribution of meteorological data and insolation values



In Fig. 7, the front surface temperature distribution of the PVs applied passive cooling with the reference PV is given. As can be understood from the figure, a uniform temperature distribution is observed in the PVs applied passive cooling, while an unstable temperature distribution has occurred in the reference PV. In addition, it has been seen that the PV front surface temperature is reduced by passive cooling.

Fig. 7. The distribution of meteorological data and insolation values

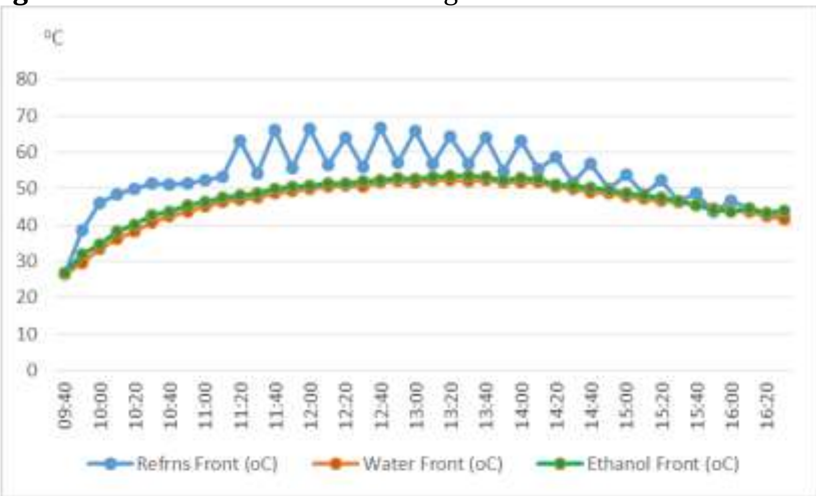
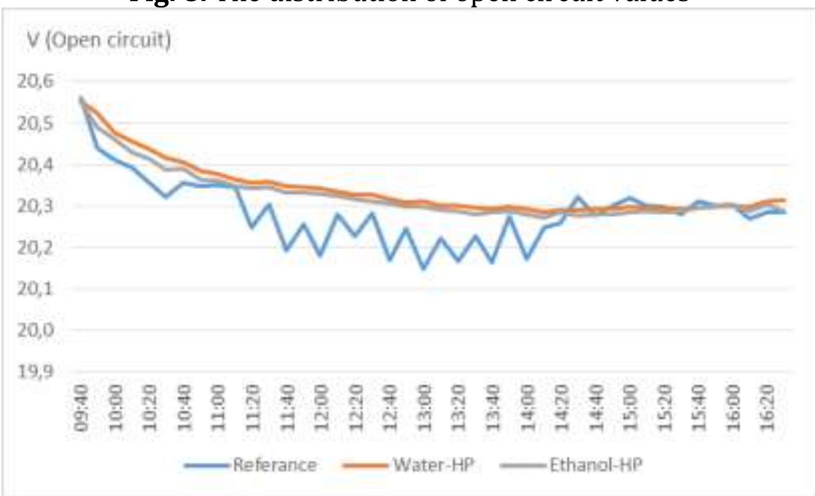


Fig. 8 shows that heat pipe passive cooling has a positive effect on the open voltage generated in PV. The best result was achieved in water-HP cooled PV, while ethanol-HP cooled PV took the second order.

Fig. 8. The distribution of open circuit values



Experiments were performed between 09.40 and 16.30 hours and only hourly values are given in Table 2. In the table shows the back surface temperatures of the passive cooled PVs, that is, the temperature values of the evaporator parts of the heat pipes. In addition, the temperature values of the condenser parts of the heat pipes are also seen.

Table 2. Temperature values of the heat pipes in the PVs

	Water-HP				Ethanol -HP			
	HP1	HP2	HP3	PV Back	HP1	HP2	HP3	PV Back
Time	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)
09:40	26,3	26,4	26,7	25,8	26,4	26,4	26,5	25,7
10:40	35,4	36,1	37,3	38,7	39,4	40,5	40,0	42,3
11:40	40,2	40,8	41,7	45,0	44,0	45,1	44,4	48,7
12:40	41,6	42,5	42,7	47,5	44,8	45,8	45,6	51,1
13:40	43,4	44,7	44,2	49,1	45,8	46,9	46,7	52,3
14:40	41,6	42,8	41,9	46,8	43,2	43,9	43,8	49,7
15:40	39,4	40,2	39,8	43,5	40,2	41,0	41,1	45,5

Electrical measurements taken on PVs are given in Table 3. It appears that the voltage (V) generated with passive cooling increases. There was no significant difference in the current (A) values.

Table 3. Electrical values of the PVs

	Referance	Water-HP	Ethanol-HP	Referance	Water-HP	Ethanol -HP
	Voltage	Voltage	Voltage	Current	Current	Current
Time	(V)	(V)	(V)	(A)	(A)	(A)
09:40	20,56	20,55	20,55	0,28	0,28	0,28
10:40	20,36	20,40	20,39	0,41	0,41	0,41
11:40	20,19	20,35	20,33	0,50	0,49	0,49
12:40	20,17	20,32	20,31	0,52	0,52	0,52
13:40	20,17	20,29	20,28	0,49	0,49	0,49
14:40	20,28	20,29	20,28	0,41	0,41	0,41
15:40	20,31	20,30	20,30	0,29	0,30	0,29

The amount of power generated in PVs is shown in Table 4. The effect of passive cooling has been positive to the generated power. There has been an increase in power compared to the reference PV. The highest values were achieved at 12.40 o'clock.

Table 4. The amount of power generated in the PVs

	Referance-PV	Water-HP-PV	Ethanol -HP-PV
Time	P (watt)	P (watt)	P (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 study, a gravity assisted heat pipe is used as a passive cooler in a PV. In addition, two different working fluids, as pure water and ethanol, were compared using a heat pipe. It has been observed that the heat pipe has a positive effect on the PV as a passive cooler. The average power output were calculated 8.25W, 8.32W and 8.27W respectively for the reference, water-heat pipe and ethanol-heat pipe PVs. Experimental comparison can be made by increasing the length of the heat pipe condenser zone in subsequent studies. More effective passive cooling can be achieved by increasing the number of heat pipes. Using nano-fluids other than pure water and ethanol, its effect on passive cooling can be investigated. The experiments were performed in Samsun with its climatic ambience and in the autumn season. If the study will accomplish in the summer season and/or hotter region, undoubtedly higher effective passive cooling be obtained.

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