Phase Changing Material Usage to Increase the Efficiency of Photovoltaic Panels

H. KARAKAYA, İ.E. ŞEN

Abstract— **The energy demand from renewable energy sources has been proportionally increased due to population growth. In renewable energy production, not only energy production but also efficient use is crucial. In recent years, photovoltaic panels, which are increasingly used and highly important in terms of renewable energy production, have warmed on the surface due to the radiation energy emitted by the sun, and this warmth reduces the efficiency of the panel. In this study, it is aimed to reduce this efficiency loss by using phase changing material with latent heat which is one of the thermal energy storage methods. One of the two solar panels placed parallel to the ground was filled with phase changing material. With this, it is aimed to cool photovoltaic panel by using calcium chloride hexahydrate phase changing material; and then radiation, air temperature, current, voltage, power, surface temperature, efficiency graphs were obtained. As a result of simultaneous measurements, the increase in yield was found to be 2.95%.**

Index Terms— **Efficiency, Latent heat, Phase change material, Photovoltaic panel.**

I. Introduction

INTENSITY OF solar radiation, surface cleaning & temperature, and angle of inclination of the photovoltaic (PV) cell are the specific physical parameters that affect the efficiency of PV panel.

Electricity is produced by PV panels which only convert 5-25% of solar irradiance into energy [1], and the remaining radiation is transformed into heat energy [2] which increases PV panel temperature [3]. Therefore, PV panel efficiency decreases, while the surface temperature increases [4] due to the internal charge carrying combination rates [5], which is the cause for reduction in maximum power production. As a consequence of this, a *suitable* cooling method that consists of active (directly reducing the temperature of PV panel) and passive method (methodology that works as a heat sink and takes the extra heat from the panel) should be used in order to increase the electrical efficiency of PV panels. Passive cooling method for PV panels is a widely used technique to sustain the temperature of PV module at a level which attains higher efficiency since active cooling method has rather more maintenance and operating problems. On the other hand, the Phase Change Material method is a passive temperature controlling technique of PV modules which does not need high operational cost; on the contrary, it uses less energy density [6].

Recent studies have revealed that, researchers have endeavored to build up a thermal model to evaluate the system of PV operating temperature considering fine details of heat transfer. In their study, Ceylan et al. (2014) experimentally investigated what kind of an effect cooling can have on the system [7]. When they carried out cooling operation by installing a spiral heat changer at the back of a PV panel, they found that the efficiency was 13%; however, when they did not perform cooling operation, it was 10%. In addition to this, they observed that as the sun radiation increased, temperature values decreased.

D'Avignon and Kummert (2016) conducted an experimental study in order to evaluate the performance of phase changing substance storage tank under various operating conditions on a dynamic test bench. There were plates like FDM capsule piles where the heat transfer liquid could move through the investigated horizontal storage tank. They observed significant differences in behaviors of FDMs under the same test conditions (Extreme cooling until different temperatures and different phase changing temperature) [8].

Kabeel et al. (2016) performed their study in the city of Tanta, Egypt using paraffin wax, a phase changing substance. They carried out the investigation experimentally employing air heaters with flat and V corrugated plates [9]. They studied the parameters that had influence on thermal performance of solar air heaters with and without substances. They concluded that the daily efficiency of V corrugated solar heater using FDM was 12% higher than that of the FDM not using solar heater, and that the daily efficiency was 15% higher when the flat plate was used.

Konuklu et al. (2017) produced diatomite phase changing material composites using diatomite raw material. As a result of differential scanning of the prepared composites, melting and freezing temperature of the synthesized composites were

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found as 41,97°C and 45,77°C by using calorimeter, respectively, while latent heat storage capacity was found as +45 and -44 J/g. They concluded that the above mentioned substances could be used for thermal energy storage [10].

In their study, Stropnik and Stritih (2016) conducted research on how to increase the efficiency of PV cells by using phase changing material. As a result of this study, they concluded that in Ljubljana, the photovoltaic cell, in which phase changing material was used, produced 7.3% more energy in a year [11].

In the study they carried out, Sarhaddi et al. (2017) investigated the heat storage performance of 2 weir type cascade connected solar power systems with phase-changing substances on sunny and semi-sunny days and without phase-changing substances; and they performed energy and exergy analyses. They found 74.35% energy and 8.59% exergy efficiency of solar energy with phase change substance for a half sunny day. They concluded that the highest irreversibility was obtained with the absorber plate [12].

Kant et al. (2016) predicted that the surface temperature of the panel may decrease due to the high latent heat storage capacity of the PV panels used with phase change materials. They found that high wind velocity and tilt angle play an important role in decreasing the temperature of the panel as a result of the heat transfer modeling with the fluid dynamics program they employed [13].

Guarino et al. (2017) concluded that energy performance was appropriate as a result of empirical studies, and they supported them with simulation by embedding phase-changing substance in the southern façade of a building in cold climatic conditions [14].

Peng et al. (2017) investigated the relationship between surface temperature and efficiency of PV panels. They found that the efficiency of PV panels could reach up to the levels of 47% and the payback time might decrease by 20% as a result of experimental studies [15].

Andre et al. (2018) suggested that photovoltaic aqueous cooling system may have a positive effect on heat transfer. They observed that the efficiency of water-cooled panels increased by around12% in the study they carried out [16].

Chen et al. (2019) investigated the use of ventilation systems with phase changing material in thermal energy storage in their study. In the study, an office room in Beijing vicinity was chosen for research. Thermal model, heat transfer model and performance curve of the room were found out. When they provided cooling by using a phase-changing substance, the achievement from electrical energy was between 16.9% and 50.8%, but when cooling was not provided, it was between 9.2% and 33.6% [17].

Fayaz et al. (2019) made numerical analyses and compared them experimentally with the help of three dimension COMSOL software in their study to improve heat transfer and performance in photovoltaic thermal systems. They provided cooling with phase changing material with an input at 27 °C temperature with different flow rates and achieved maximum electrical efficiency 12.4% as numerical and 12.28% as experimental. Similarly, in the case when they carried out the analyses on the PV panel with phase changing substance, they achieved 12.75% and 12.59% electrical efficiency in experimental and numerical cases, respectively [18].

In our study, PV panel efficiency was provided using phase changing substance thus optimizing the surface temperature of PV panel to decrease efficiency losss because of high temperatures on PV panel surface [19].

II. Guidelines for Graphics Preparation and Submission

Experiment set was placed on Batman University central campus terrace during August 2019. The irradiation values varied between 11-919 W/m^2. One multimeter, 2 solar panels, 9 kg phase changing material, two recorders, 8 K type thermocouples, 1 laptop and 6 resistors were used in the experiment. Two identical 125 W solar panels with 114 cm length and 67 cm width with an open circuit voltage of 22.10 V and a short circuit current of 7.30 A were used in the experiments. Calcium chloride hexahydrate imported from abroad with a melting temperature of 30°C and a melting temperature of 140 kj / kg and a density of 1.71 g / ml was used in the solar panels [8]. Elimko 680 temperature data logger was used for measurements. GRAPHTEC midi LOOGER GL240 Series was used as voltage recorder. Measurements were carried out with ± 0.1% error.

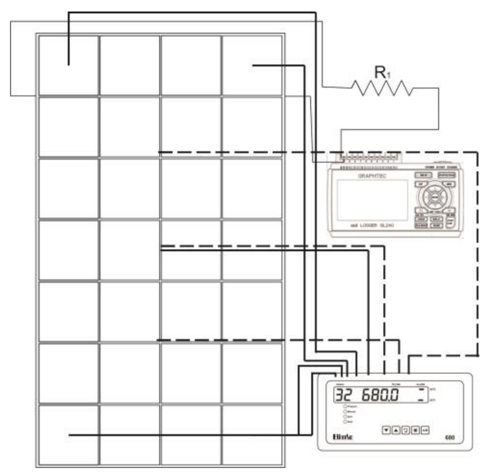

Fig.1. Experiment set

Temperature values were obtained from 5 different points indicated by bold lines in the Fig. 1. The temperature values of the phase changing substance were obtained from 3 different points, which are indicated by thin lines in the Fig.1. As can be seen in Fig. 1, a resistor of 3.3 Ω, shown as R_1, was used to obtain maximum power in photovoltaic panel.

III. Mathematical Background

The latent heat is calculated as follows:

$$Q = mL \tag{1}$$

Here: Q – is the latent heat of the phase changing substance;

m – is the mass of the phase changing substance;
L – is the specific latent heat coefficient of the material;

The voltage is calculated as follows:

$$V = IR \tag{2}$$

Here: V – is the voltage of the photovoltaic panel;
I – is the current of the photovoltaic panel;
R – is the resistance;

The power is calculated as follows:

$$P = IV \tag{3}$$

Here: P – is the power of the photovoltaic panel;
I – is the current of the photovoltaic panel;
V – is the voltage of the photovoltaic panel;

The efficiency is calculated as follows:

$$\eta = \frac{Pout}{Pin} * 100 \tag{4}$$

Here: η – is the efficiency of the photovoltaic panel;
$Pout$ – is the output power of the photovoltaic panel which comes from solar irradiation;
Pin – is the input power of the photovoltaic panel which is created in itself;

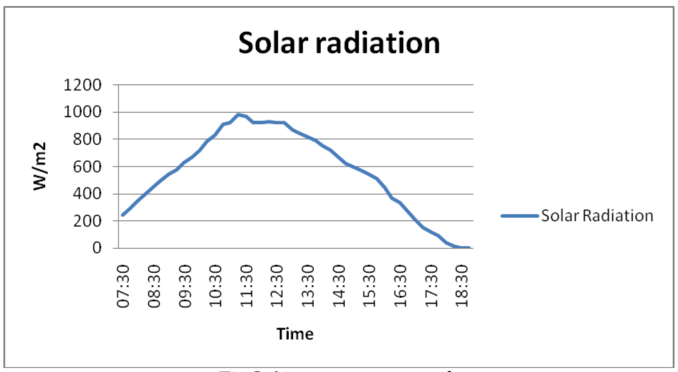

Fig.3.Air temperature graph

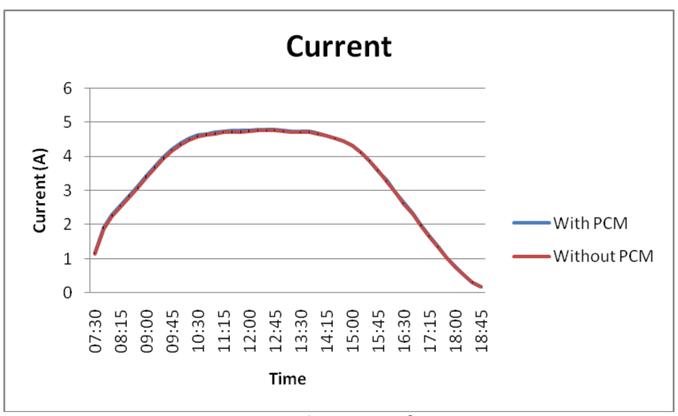

Fig.4. Current graph

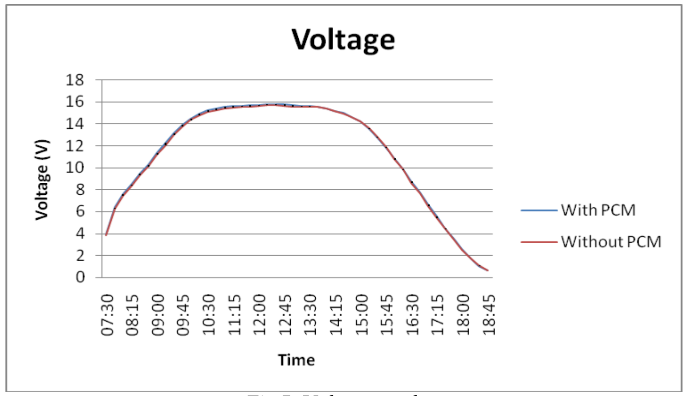

Fig.5. Voltage graph

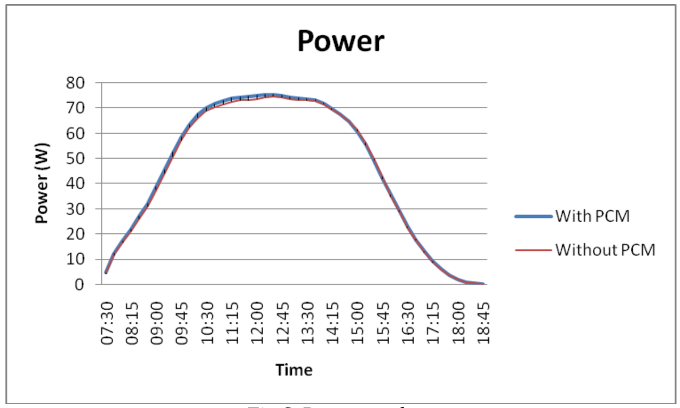

Fig.6. Power graph

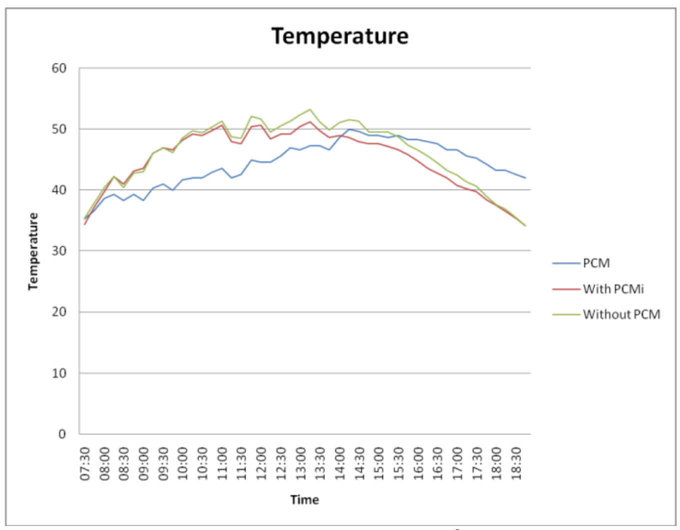

Fig.7. Temperature graph

IV. DISCUSSIONS

The graph of the radiation values is shown in Fig.2. The highest radiation value was measured as 981 W/m^2 at 12:30. As with the power, in voltage and current graph, the maximum values were measured at 12:30, which demonstrates that this graph supports the other graphs. As shown in Fig.3, the maximum air temperature is 32.47°C at around 13:30 and the minimum air temperature is 24.62°C at 7:30. In Fig. 4, as the sun rises, the sun rays fall more perpendicular on to the panel surface, the production capability of the panel increases and it can produce higher current values. The maximum current value obtained using phase changing material is 4.78 A at 12:30. However, 4.75 A was obtained at the same time without phase change material. As shown in the Fig.5, the voltage rises were observed as a result of the solar rays falling perpendicular to the PV panel surface. The maximum voltage value obtained using the phase changing material is 15.30 V at 12:30. However, 15.7 V is obtained at the same time without phase change material. The power graph that is multiplied by current; and voltage graphs increase with increasing of solar radiation on to the surface of the PV panel. As can be seen in the Fig. 6, the power reaches the maximum value at noon; and then starts to decrease again. The maximum power obtained using the phase changing substance is 75.45 W at 12:30. 74.69 W is obtained at the same time without phase change substance. The graph in Fig. 7 demonstrates the time-dependent temperature. The red and green lines indicate the surface temperature of the PV panel. At 13:15, the maximum temperature of the PV panel surface with phase changing substance is 51.2˚C, whereas the other PV panel without phase changing substance is 53.26˚C. The temperature of the phase-changing substance is measured at a maximum of 50˚C at 14:15. 9 kg phase changing substance used in the experiment melted from 8:00 to 9:00.

V. CONCLUSION

Nowadays, fossil fuels are insufficient to provide energy for the increasing energy demand. As a solution to this issue, energy production, which consists of renewable energy sources, known as eco-friendly, is increasing rapidly. Not only energy production provides a solution for the growing energy demand as a consequence of population growth, but also using the same energy source with more efficient way is necessary. PV panels, which use clean renewable solar energy, and therefore eco-friendly, are efficient in electricity generation. For these reasons, in this study, it is aimed to decrease the high temperature formed on the PV panel surface by using phase changing substance to provide higher efficiency.As a result of the experimental studies, the PV panel was cooled by using phase changing material called calcium chloride hexahydrate; and radiation, air temperature, current, voltage, power, surface temperature, yield graphs were obtained. The efficiency increase in PV panel was measured as 2.95% by using phase changing substance. The maximum increase for current and voltage was equal to 1.46%. The result can be a small achievement in this experiment when we consider small scale increase in efficiency of PV panels. However, it will play an important role in large-scale investments.

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BIOGRAPHIES

HAKAN KARAKAYA was born on 20.12.1979 in Çelikhan district of Adıyaman/Turkey. After successfully completing Elazığ Gazi Anatolian Technical High School Mechanical Department in 1997, he enrolled in Fırat University Technical Education Faculty Mechanical Education Department in 1998 for his undergraduate education. After completing his undergraduate education in 2002, he started his graduate studies at Fırat University, Institute of Science and Technology, Mechanical Education/Energy. After completing his master's degree in 2005, he started his PhD studies in the same field. After completing his doctorate in 2010, he started working as an Assistant Professor in Batman University, Department of Mechanical Engineering. He is also working as the manager in Vocational school of Beşiri organized industrial zone. Hakan Karakaya is married and has one child.

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