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Experimental Investigation of a PVT System Using PCM

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ABSTRACT
The electrical efficiency of the PV panel depends on the material of the panel and its surface temperature. With the rise of surface temperature, the electricity generation decreases. Various cooling methods have been applied to decrease the surface temperature of the PV panel. This article experimentally investigates the performance of a PV panel by embedding PCM on its back and flowing water through the copper pipe which is incorporated inside the PCM to absorb the heat from it. As the surface of the PV panel heats up, PCM absorbs the heat and some of this heat is carried away by the flowing water. The surface temperature of the PV/T/PCM system on an average was 1.725 ^{0}C lower than that of conventional PV panel. The electrical efficiency of the PV/T/PCM system increased by 2.33% than conventional PV panel. The highest thermal efficiency of the PV/T/PCM obtained was 54.99%. It has been observed that the incorporation of PCM in PV panel could bring a significant improvement providing higher electrical efficiency and also thermal efficiency.

Keywords: Solar energy, PVT, PCM, Experimental, Paraffin

1. Introduction

The impact of renewable energy in recent years has been very significant. Due to the negative impact of conventional energy sources on the environment, the world is leaning more and more toward renewable energy sources. Moreover, conventional energy sources are depleting rapidly and their amount is limited. Fossil fuel combustion increases carbon emissions and pollutes the environment, consequently increasing global warming and climate change. According to the statistics of the World Health Organization (WHO) each year 160,000 people die from the effects of climate change and this number could be doubled soon [1,2]. So, it has become compulsory to look for clean alternative sources of energy if we want to sustain ourselves and future generations and also for the betterment of this planet. Renewable energy is a source of energy that could be used as an alternative to fossil fuels. Renewable energy sources are clean, nonpolluting, and inexhaustible [1]. In recent years developed and developing countries are increasing their use of renewable energy and trying to find new technologies for using this energy source more efficiently. Solar energy is one of the largest and most widely used sources of renewable energy. Theoretically, solar energy has the potential to meet the energy demand of the entire world if harvesting and distribution technologies are readily available [3]. Annually, nearly four million exajoules (1 EJ = 1018J) of solar energy reach the earth, with approximately 5x104 EJ claiming to be easily harvestable [4]. The use of solar energy has a significant impact on the environment. The installation of 113,533 household solar systems in California has minimized 696,544 metric tons of CO_2 emissions [5].

PV panels are used to convert this solar energy into electrical power. However, a PV panel's efficiency reduces with high temperatures. About 0.4% to 0.65% decrease in PV panel efficiency can be seen due to increased temperature [6-8]. Different methods have been applied to decrease the operating temperature of solar panels. Using PCM to reduce the temperature is one of the useful methods. It does not require any additional energy like some active cooling systems [8]. PCMs have large latent heat of fusion, are chemically stable, non-corrosive, non-toxic, and melting temperature is close to the operating temperature of the PV panel [9]. As the PV panel heats up, the PCM absorbs heat and melts as the temperature reaches its melting point [8]. Due to this PV panel's temperature does not increase and remains around the optimum operating temperature. Researches show that using PCM with a PV panel increases the electric power output by 1%-1.5% and efficiency increases by around 3.1%. [8]. According to the literature review, several studies have been conducted to determine the best methods for reducing the temperature of photovoltaic panels on hybrid photovoltaic thermal systems (PV/T) and photovoltaic with phase change material (PV-PCM) by utilizing various absorber plate designs, water pipe configurations, phase change materials, and performance-affecting configurations. No experimental investigation has found of PVT/PCM system using ¼" inch diameter copper pipe with this serpentine copper layout design in along with commercial grade paraffin wax. The current study aims to experimentally analyze the thermal and electrical performance of PVT/PCM systems and environmental conditions. A serpentine copper pipe layout is attached with the PVT/PCM system. Copper pipes are put into phase change materials to boost PCM's capacity to store heat, while water runs through the copper pipes to extract heat from the phase change material and do so.

2. Research Method

Paraffin wax as PCM was added on the backside of PV panel. A serpentine pipe layout of copper was embedded inside PCM to flow water through it. As the

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surface of PV panel heats up, PCM absorbs heat and melts when its melting point is reached. This reduces the surface temperature of PV panel. Water is then flown through the copper pipe. As it flows, it absorbs heat from the PCM and warms up. This warm water gives additional thermal efficiency of the system and can be used in domestic purposes.

Table 1 Specifications of the PV module

Model	POLY-20W
Dimension (mm)	360*500*25
Maximum Power (Pmax)	20W
Tolerance of Pmax	0±3%
Rated Voltage (Vmp)	18V
Rated Current (Imp)	1.82A
Open-Circuit Voltage (Voc)	21.5V
Short-Circuit Current (Isc)	1.67A
Maximum System Voltage	1000V
Weight (kg)	2.8

2.1 Mathematical formulation

The output electrical power of the system can be calculated using the following [10]:

$$Eel = Voc * Isc * FF \tag{1}$$

where V_{oc} and I_{sc} are the open circuit voltage and short circuit current of the PV module.

FF is the fill factor expressed as the ratio of the maximum power gained from the PV module to the open circuit voltage multiplied by the short circuit current at the standard test condition:

$$FF = \frac{(V*I)max}{Voc*Isc} \tag{2}$$

In the above equation, V_{oc} and I_{sc} are the open circuit voltage and short circuit current that have constant values given by the manufacturer.

$$\eta_{el} = \frac{E_{el}}{E_{sun}} = \frac{Voc*Isc*FF}{G.A_C.\tau_g.\alpha_{cell}} \tag{3}$$

$$\eta_{el} = \frac{E_{th}}{E_{sun}} = \frac{m_f C_{p.f}(T_{f\,out} - T_{f\,in})}{G.A_C.\tau_g.\alpha_{cell}} \tag{4}$$

Overall Efficiency:

$$\eta_{ov} = \eta_{th} + \eta_{el} \tag{5}$$

2.2 Experimental investigation

To investigate the PVT system, the experimental setup was fabricated at the rooftop of the Heat engine lab, Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh, located at (latitude 24.3636° N and longitude 88.6284° E) during August 2022. Fabrication of the setup and experiment measurements are illustrated in the subsequent sub-sections.

2.2.1 Fabrication of the setup

In this experiment, outdoor conditions are used to evaluate the performance of the system. Two different PV modules are tested. One of them is combined with PCM using commercial-grade Paraffin wax and the other module is a conventional solar PV module shown in **Fig. 1**. Under the same outdoor conditions, both of the modules are compared with each other based on thermal and electrical performance. The specifications of PV

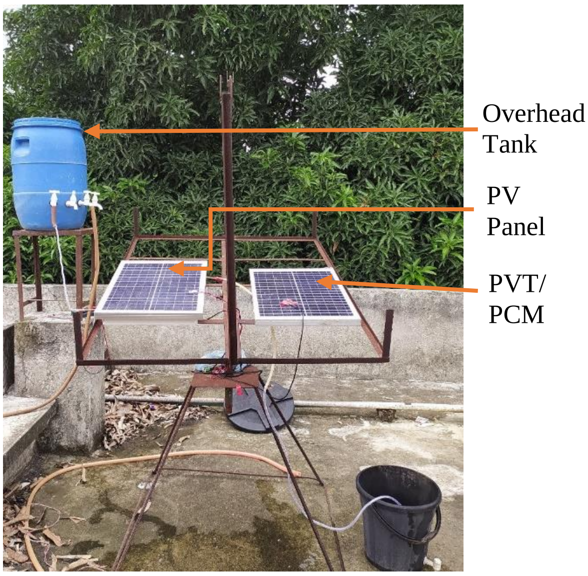

Fig. 1: Photographic view of experimental setup.

modules are shown in Table 1. The commercial grade Paraffin wax is selected for its favorable characteristics. The properties of commercial-grade Paraffin wax are depicted in Table 2.

Fig. 2: Photographic view of commercial grade paraffin wax with copper pipe layout

Table 2 Properties of PCM (Paraffin wax) [1]

Layer	Solid phase	Units
Temperature of transition	44	°C
Specific heat at constant pressure	2150	J/kgK
Density	805	Kg/m^3
Latent heat	18V	kJ

Thermal conductivity	1.82A	W/mK
Transitional interval	21.5V	ºC

In the PVT-PCM system, a serpentine layout pipe is attached under the PV panel. Initially, paraffin wax was melted by hot water so that it started melting progressively shown in **Fig. 2**. After that, the melted wax is poured into the back of the PVT module. The four edges and the back of the panel are insulated using tedlar, polyurethane, and PVC sheet. About 1 kg of paraffin wax was poured into the enclosure after considering the potential volume expansion during phase change processes. To avoid leakage, silicon sealant was used between the panel and insulation materials.

3. Result:

The experiment was conducted on the roof of the Department of Mechanical Engineering, RUET for 2 weeks from July 14, 2022, to July 28, 2022. The experiment was done for both conventional PV panels and PVT/PCM systems to compare the results. During the experiment, the temperature, current, and voltage of both panels were measured. **Fig. 5** shows the solar irradiance on July 21, 2022. The maximum solar irradiation was 826 W/m^2.

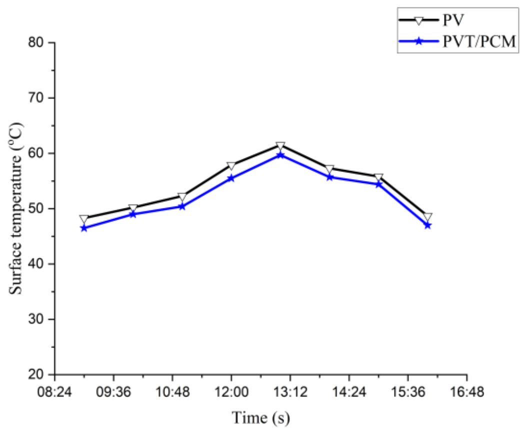

Fig. 3: Variation of temperature with respect to time between PV and PVT/PCM system

Fig. 3 presents experimental results of the conventional PV and PVT/PCM cell temperature and also shows the inside temperature of the PVT/PCM system measured on July 21, 2022. The cell temperature of the PV panel reached its highest 61.5^{0}C at 1.00 pm. For PVT/PCM the maximum cell temperature was 59.7^{0}C at the same time. The average temperature difference between the PV/T/PCM and PV panel was 1.725 ^{0}C.

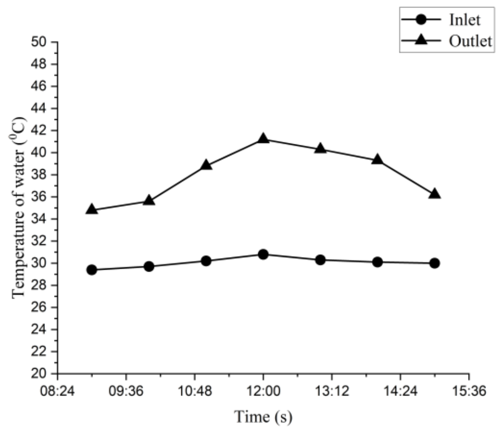

Fig. 4: Variation of water inlet & outlet temperature with respect to time of PVT/PCM systems.

Fig. 4 shows the water inlet and outlet temperature measured on July 21, 2022. The maximum water outlet temperature was 41.2^{0}C when the inlet temperature was 30.8^{0}C at 12.00 pm. The maximum temperature difference between the inlet and outlet water temperature was 10.4^{0}C.

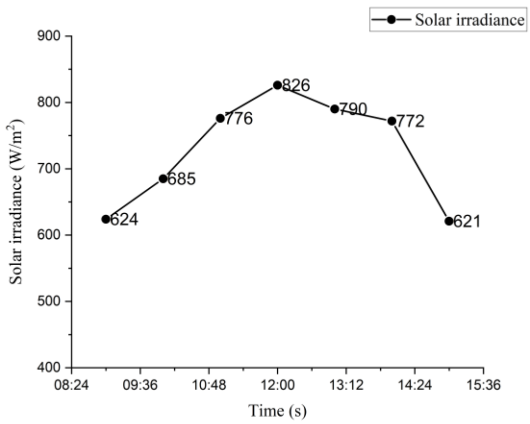

Fig. 5: Solar irradiance at different hours.

Fig. 6 shows the electrical and thermal efficiency of both panels. The maximum increase in PV/T/PCM electrical efficiency was 2.33%. The maximum thermal efficiency of the PVT/PCM system was 54.99%.

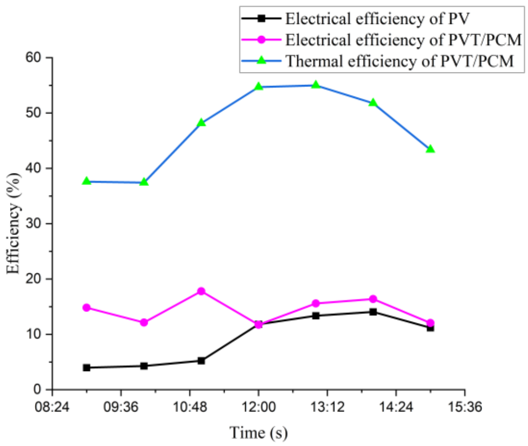

Fig. 6: Variation of efficiency with respect to time of conventional PV and PVT/PCM systems.

4. Conclusions:

The present work investigates experimentally the performance of a water-based PV/T/PCM system. The following conclusions were derived from the present work:

- It has been observed that incorporation of PCM on the backside of PV panel lowers its surface temperature and the maximum temperature obtained was 59.7^{0}C which was 1.8^{0}C lower than conventional PV panel.
- It is observed that the electrical efficiency of the PV/T/PCM system is higher than the conventional PV panel and the maximum increment in PV/T/PCM electrical efficiency was 2.33%.
- It has been observed that flowing water through PCM gives additional thermal efficiency and maximum efficiency obtained was 54.99%.

5. References

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NOMENCLATURE

A	Area of PV surface (m^2)
Cp	Specific heat at constant pressure ($J\ kg^{-1}\ K^{-1}$)
CPCM	Composite phase change materials
Eel	Module's electrical energy (W)
Ein	Incident energy at module top surface (W)
Et	Useful thermal energy in the system (W)
El	Lost energy from the glass layer to ambient (W)
FF	Fill factor
G	Solar irradiance (Wm^{-2})
h	Enthalpy ($J{\cdot}kg^{-1}$)
m	Mass flow rate ($kg{\cdot}s^{-1}$)
P	Pressure (Pa)
s	Entropy ($J{\cdot}kg^{-1}{\cdot}K^{-1}$)
T	Temperature (K)
V	electrical voltage (V)
K	Thermal conductivity ($Wm^{-1}\ K^{-1}$)
PV	Photovoltaic
PCM	Phase change material
PVT	Photovoltaic thermal system
PVT/PCM	Photovoltaic thermal system integrated with PCM
sc	Short circuit
t	Time
th	Thermal