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Numerical and Experimental Study on Effect of Adding Vaseline and Paraffin on the Performance of Concentrated Photovoltaic Cells

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Abstract: The use of phase-changing materials is one of the methods used for passive cooling of concentrated photovoltaic cells. In this research, two types of phase changing materials were used, 50% Vaseline and 50% paraffin, where a numerical and experimental study was conducted to show the effect of using these two types of phase changing materials. In this research, a numerical as well as experimental study was carried out to study the improvement of the performance of the photovoltaic cell. for the numerical study, it was carried out using the ANSYS 2022 program, where the analysis was done in a three-dimensional geometrical (3D), and three models were analysed which are concentration photovoltaic without adding PCM (case 1), concentration photovoltaic cell with a mixture of paraffin and petroleum jelly at 50% (case 2), concentration photoelectric cell with PCM and fins (CPV/FPCM) (case 3), Experimental and numerical results showed convergence in the results and that the use of the mixture of phase-changing materials leads to a decrease in temperature by rate (7.97C°)(8.7331C°) for the second and third cases, respectively, and also leads to an increase in efficiency by rate (5.561%).

Keywords: Mokpe culture, practical intelligence, Mokpe Child, quantitative reasoning, quantitative skills.

Introduction

Since the dawn of civilisation, energy has grown in significance to human survival and development. According to the World Energy Outlook 2021, the global demand for energy would have increased by 30% by 2040 as a result of population expansion and advancements in industrialization [1]. The majority of energy is produced by burning fossil fuels like coal, oil, and natural gas. Regarding this, there are two primary concerns: the first is economic and has to do with the rising cost of gasoline and the potential for its shortage. Second, it has to do with the escalating levels of air pollution, climate change, and weather variations like floods and storms that harm the environment, spread disease, and result in a lot of fatalities. In the next decades, a lot of work has been done to use renewable energy sources like wind solar (electrical and thermal), geothermal, tides, and nuclear.

Solar cells used in photovoltaic (PV) systems cost roughly 60% as much as the entire system cost with less use of pv cell material and development of Photovoltaic technology in the near future, the cost of producing PV electrical power can be lowered [2]. A well-known fact of photovoltaic (PV) systems is that their output power varies directly with incident sun energy. Increase the incident direct solar radiation on a Photovoltaic module clearly leads to rise in the Photovoltaic module's output power. In other words, the expensive PV solar cell would be replaced with less expensive reflector materials such as mirrors, glass, aluminum foils, etc., concentrator techniques (CPV) are beneficial in reducing Photovoltaic material consumption per watt of produced power output sun. A solar cell's surface area is lowered by a factor of the concentration ratio, relative to the concentration of sunlight. but the disadvantage of use increases the temperature of pv. So, to keep the electrical performance of the PV module at a good level, it's important to use the right cooling method to lesser the pv surface temperature, which will make it last longer [3].

PCM cooling, passive cooling, active cooling, and PCM cooling with additives are the major categories that are used to define the different types of cooling methods that are utilized cooling [4]

Many researchers have studied the effect of using phase-changing materials on the photoelectric performance .

Ramy Rabie et al. (2017) [5]compared the thermal behaviour of a CPV with a PCM and heat sink in the shape of a modified parallelogram to that of a regular rectangle. Due to better heat transfer during the melting of PCM, their computer simulations showed that the new design was able to lowered the average temperature of PV by 5.7 degrees Celsius and the maximum temperature difference is 9 C°.

Mohamed Emam et.al 2018 [6]numerical simulation for designed system with four possible modules of PCM with heat sinks: module with single cavity, module with (3 and 5) parallel cavity, and 3-series of cavity module. and nine various arrangements of paraffin wax are investigated. at concentration ratios of (10 and 20). It's found that heat sink arrangements with (3 and 5) parallel cavities considerably reduce PV temperature when associated to (single and three-series) cavity heat sink setups. Also, usage of a five-parallel cavity is found to considerably improve solar cell temperature uniformity. Temperature uniformity is also significantly improved with varied pattern arrangements of the phase change materials using the three-parallel cavity architecture.

Ismaila Zarma [7] conducted numerical analysis of the hybrid system of (CPV Nanoparticle-PCM) with PV (CR) = 20. The impact of several nanoparticles on the general efficiency of a concentrator solar system is investigated. It is discovered that the use of Al_2O_3 considerably enhanced the thermal conductivity of PCM when compared to CuO, SiO_2 nanoparticles, which improves the melting rate and, as a result, lowers temperature of PV. Comparing pure PCM (0 wt%) to Al_2O_3-PCM at 5 wt%, it is discovered efficiency of the latter achieves is 8 percent and the temperature regularity of 12 °C, while the former only achieves 6.36% and 20 °C, respectively.

S. Manikandan 2019 [8] conducted numerical study uses COMSOL on CPV with heat sink and PCM. PCM lowered the CPV module's temperature significantly. CPV temperature was 55C° with 0.75mm PCM height. With 3mm of PCM in the heat sink, the temperature dropped to 32C°, and the CPV module's power and efficiency increased. For a typical working scenario with CR of 3 and PCM height of 3 mm, CPV with PCM had higher power production and efficiency than without PCM. and the efficiency and power of CPV with PCM system was 22% & 27%higher than CPV only respectively

Sharma et al. (2016)[9] studied PCM via thermal regulation to improve low-concentration BICPV system performance. IN This work indoor controlled experiment analytical model. PCM efficacy increased with irradiance. BICPV with PCM integrated system under 1000 W/m2 highly collimated continuous light increased relative electrical efficiency about 7.7% and decreased temperature about 3.8 C.

Su, Yan et al 2018 [10] conducted an experimental (outdoor) investigation of employing PCM cooling in a solar tracking CPV/T system, and the results demonstrate that the PCM cooling system can improve the effective enhancement range of output power from more than 300 W/m2 to more than 50 W/m2. Furthermore, as compared to the CPV-T system without PCM cooling, the average increases in electrical, thermal, and overall energy efficiency can be more than 10%, 5%, and 15%, respectively.

In this paper, the effect of using a mixture of phase-changing materials on the performance of a concentration photovoltaic cell was studied as shown in the next section.

Mostafa k.yousif and muna s kassim 2022[11] conducted numerical and experiential study the effect of Adding Vaseline and paraffin with aluminum matrix On the Performance of Concentrated Photovoltaic Cells the results and that the use of the mixture of phase-changing materials leads to a decrease in temperature (CPV/PCM2), (CPV/FPCM2) and (CPV/FPCM2P) are (7.97C°) (8.7331C°) (11.455 C°) respectively, and also leads to an increase in efficiency by rate (5.561%) (6.68%) in cases (CPV/FPCM2) and (CPV/FPCM2P) respectively.

Methodology of Study

The utilisation of phase change material to lower the temperature surface of the CPV system was investigated using both numerical and experimental methods.

Phase Change Material

(PCM) is a material that can switch between solid-solid, liquid-gas, and solid-liquid phases. Solid-liquid PCMs are the most common and are used in both theoretical and practical applications [3]. PCM is excellent for use as passive heat storage because at the phase transition temperature, it absorbs a considerable quantity of energy as latent heat. The solid-liquid PCM type of temperature controls has been employed in a wide variety of applications. The few investigations that have been done indicate that PCM has a significant influence on efforts to reduce the temperature of different electronic systems and components. [3] Vaseline and paraffin wax were used as the PCM in this study. 50 percent Vaseline and 50 percent paraffin were combined with these two mixes of phase change substances. The characteristics of. The properties of the mixture were examined in the laboratories of the University of Technology in Baghdad, which are shown in the in table 1.

Table 1: **pcm properties**

Property	Paraffin and Vaseline
Density (solid/liquid)	905/827
Specific heat (solid/liquid)	2.155/2.075 kJ/kg K
Viscosity	0.0882(mPa-**s**)
Thermal expansion	0.0001
Melting point	47c
Latent heat of fusion	199.5(kJ/kg)
Thermal conductivity	0.21

Heat Sink Fabrication and fins

The fin measures 0.2 cm, 2 cm, and 7 cm, respectively, in thickness, length, and spacing. According to earlier research that looked at the ideal number of fins that have an impact on cooling the photovoltaic panel with pcm, the fin count was found to be (9). The fin arrays used in the experiment are shown schematically in Figure 1.

Vertical fins were adhered to the heat sink's base plate to create the pattern you see there. The fins were firmly fixed to the surface of the diffuser to provide adequate contact with the back of the plate.

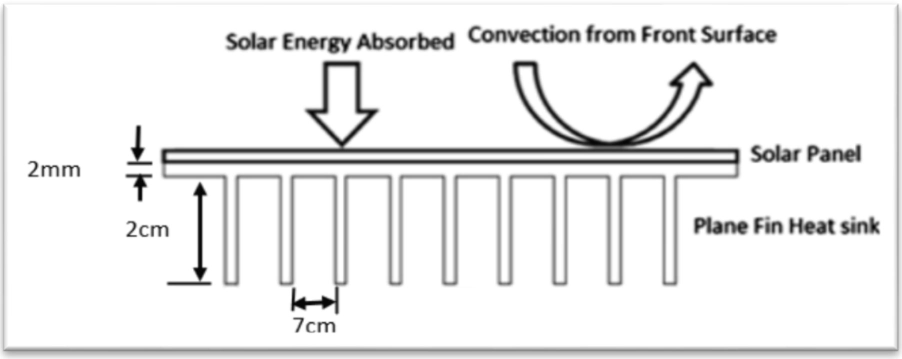

Figure 1 : Heat Sink Fabrication and fins

Thermal Modelling

The effectiveness of photovoltaic panels can be measured by the amount of incident radiation that is turned into usable electrical power under specific conditions of the surrounding environment

Based on how well the CPV cell works, some of the total energy (E) absorbed at the front of the CPV-PCM system is turned into electricity (E_l). But another part (E f) of the total energy absorbed is lost from the front surface of the CPV cell to the outside world through convection and radiation. This causes the temperature of the system to rise. You can get an idea of how much thermal energy is transported from the concentration photovoltaic to the PCM by using the following relationship:[12]

$$q_w'' = E - E_{el} - E_f \quad (1)$$

The energy collected by the photovoltaic could be written as shown below:

$$E_{SC} = \alpha_{SC}\, \beta_{SC} \tau_g\, G(t) \quad (2)$$

The energy absorbed by the TEDLAR can be written as shown below:

$$E_t = (1 - \beta_{SC})\, \alpha_{SC}\, \tau_g \quad (3)$$

Then The total energy written as shown below:

$$E = \left(1 - \beta_{SC}\right) \alpha_{SC}\, \tau_g\, G(t) + \alpha_{SC}\, \beta_{SC} \tau_g\, G(t) \quad (4)$$

The electric power produced by photovoltaic written as shown below:

$$E_{el} = \eta_{sc} \beta_{SC}\ \tau_g\ g\, G(t) \quad (5)$$

Where, η_{sc} is the photovoltaic efficiency which is a function of solar cell temperature and can be written as shown below:

$$\eta_{sc} = \eta_{ref}(1 - \beta_{ref}(T_{sc} - T_{ref})) \quad (6)$$

Where: β_{ref} and η_{ref} are the temperature coefficient and electrical conversion efficiency of a CPV cell at temperature of 25 °C.

As indicated below, the front loss, E_f of thermal energy due to the impact of radiation and wind speed can be calculated:

$$E_f = U_f(T_{sc} - T_a) \quad (7)$$

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$$U_F = \left(\frac{\delta_g}{k_g} + \frac{1}{h_f}\right)^{-1} \quad (8)$$

$$h_{conv,g-amb} = 5.7 + 3.8\,V_w \text{ if } Vw < 5\ m/S \quad (9)$$

Experimental work

In Baghdad, the CPV system is installed on a building's roof. Two monocrystalline PV modules with a peak power of 40 Watts are employed in this experiment, and their measurements are (67cm, 42cm, 2.5cm). The back of the PV panels were immediately in contact with the pcm container in figure 2. Voltage and current are measured and recorded using a multimeter. Five thermocouples that are connected to the data logger are located at the top and bottom of the CPV panels, and a sixth thermocouple records the outside temperature hourly. To track the insolation, a solar meter is positioned close to the location of the CPV module (incidence of sun irradiation). While using the CPV without pcm/normal PV as a guide, the CPV with pcm is referred to as the CPV/PCM module. the property of pv shown in table 2. And The experimental rig is shown in Figure 2.

***Table 2*: Photovoltaic properties [13]**

Component	$\rho(Kg.m^{-3})$	K $(W.m^{-1}K^{-3})$	$C_p(j.kg^{-1}k^{-1})$	Thickness mm
glass	3000	1.8	500	3
silicon	2330	148	680	0.3
EVA	960	0.35	2100	0.5
AL	2719	202.4	871	2
TEDLAR	1200	0.2	1250	0.1

Figure 2 : Experimental prototype of CPV/PCM

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1	PV with pcm	2	PV reference	3	reflector
4	thermocouple	5	Data logger	6	multimeter
7	anemometer	8	Solar meter	9	Structure

Figure 3: A; container before fill PCM B: container after fill PCM

Numerical

➢ Model:

Three-dimensional models of a pv without a pcm, a pv with a pcm, and a pv with fins and a pcm to assess the impact of PCM use on the CPV surface temperature, simulation using ANSYS FLUENT 2022 was carried out. Figure 4 depicts the simulation's geometry modelling.

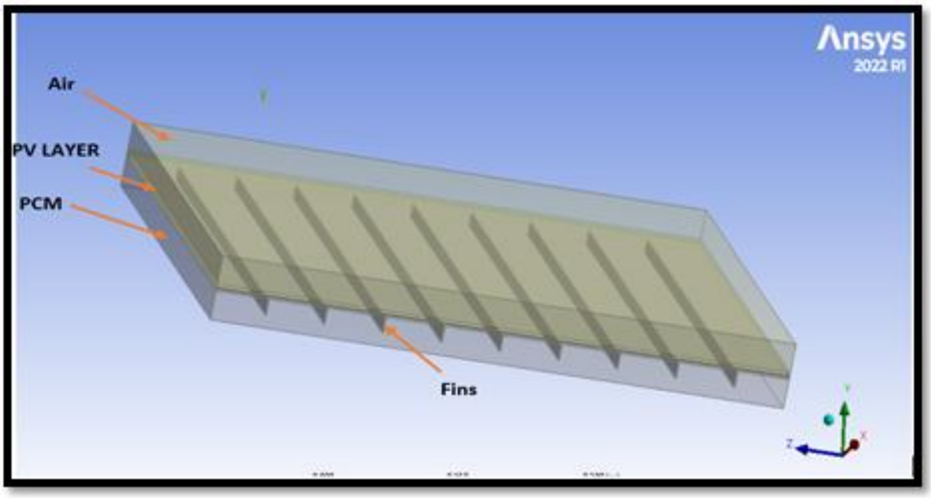

Figure 4: Geometry modelling

➢ **Mesh Independence Study**

Mesh independence analysis is critical for obtaining mesh-independent and correct findings with a minimal computing cost and time. To this aim, a mesh independence analysis is conducted on the CPV/FPCM system. As shown in Figure (5), the results of CPV/FPCM system simulation, PV temperature, are compared for different grid resolutions. This figure indicates that when the number of cells is raised from 1.075 to 1.86 million, it was observed that the hexahedral mesh with an element

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size of (3mm) gives the most accepted results in which there is no significant loss in results accuracy. While, the time for mesh generation and analysis is lower than the case of using tetrahedral cells, where it approximately drops to more than half the later. That is because the geometry is simple, and it is always recommended to use hexahedral mesh with simple geometry. The total number of nodes and elements are 1120691and 1075508, respectively.

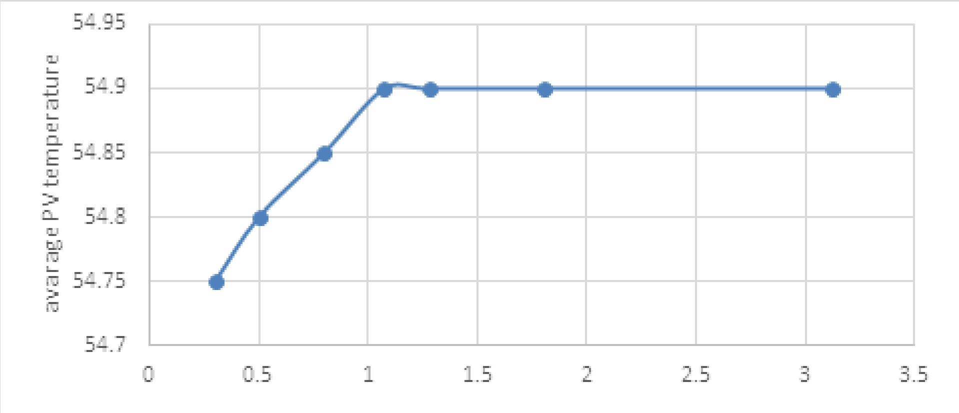

Figure 5: Mesh independence study results

- **FLUENT steps**

After a mesh file is exported, the first step is to check for errors in the mesh. Then a pressure base transient solver is chosen

The Discrete ordinate model (DO) was adopted in this study because it is considered the scattering factor for the species as it picks up the conditions of a cloudy day environment Furthermore, user-defined function (UDF) has been used as input of heat flux values into ANSYS Fluent (CFD). [14]

For PCM's melting and hardening processes, the solidification and melting model is turned on, and the mushy zone constant is set to 105

The selected materials for this model are PV layer, pcm, aluminium, and air. Photovoltaic and pcm properties were inserted while the other material properties were set as the default values in FLUENT database material list.

- Boundary condition: the boundary condition use in the simulation can be seen in Table (3)

***Table 3*: Boundary condition used in the simulation**

NO	Area	Boundary condition
1	Front surface of PV	radiation & convection
2	Side wall of PV	adiabatic
3	material interface	Wall- coupled
4	Back surface of PV	convection

- Solution

The pressure velocity coupling equations in fin PCM were calculated using the semi-implicit method for pressure linked equations (SIMPLE) approach. To solve the pressure equations, the PRESTO methodology is used. For momentum and energy equations, power law is used, and the first-order upwind technique is used in the evaluation the pressure correction, liquid fraction, thermal energy, and velocity components, the under-relaxation factors are 1, 0.9, 0.3, and 0.7, respectively. The

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convergence was tested at each time step in the current study, A convergence criterion is a criterion used to confirm the convergence of a sequence. The default convergence criterion of the temperatures.

Result and dissection

Simulation results

Effect of Using PCM1 on PV Temperature

In general, at morning the surface temperature of CPV modules are almost the same in all cases. This is because the PCM is still solid at this point and hasn't started to melt yet. Then, it is obviously the surface temperatures of the all modal are different, since PCM starts to melt from that point. The CPVI index temperature was found to be higher than in the other cases. This happens because heat transfer from back layer of CPV to PCM, making the PCM gets warmer over time, especially in the layers that touch the CPV surface. As the melting process goes on, this increase spreads to the other layers of PCMS. After the PCM melts completely, the temperature of CPV with cases containing PCM increases compared to the photovoltaic panel. Due to the ability of PCM to hold heat for period time.

Figure (6) shows the relationship between the average temperature of the solar panel for the cases (CPVI), (CPV/PCM), and (CPV/FPCM) it was found that the use of (CPV/FPCM2) gives good results in thermal reduction management of the concentration photovoltaic panel compared to the other cases .And that the cases (CPV/PCM), (CPV/FPCM2) are close in effect in the thermal reduction management of the photovoltaic during the melting period, but after completing the melting, we notice a noticeable rise in the temperature of the (CPV/PCM), (CPV/FPCM). The average reduction in temperature for cases (CPV/PCM), and (CPV/FPCM) are (7.97C°) (8.7331C°) respectively

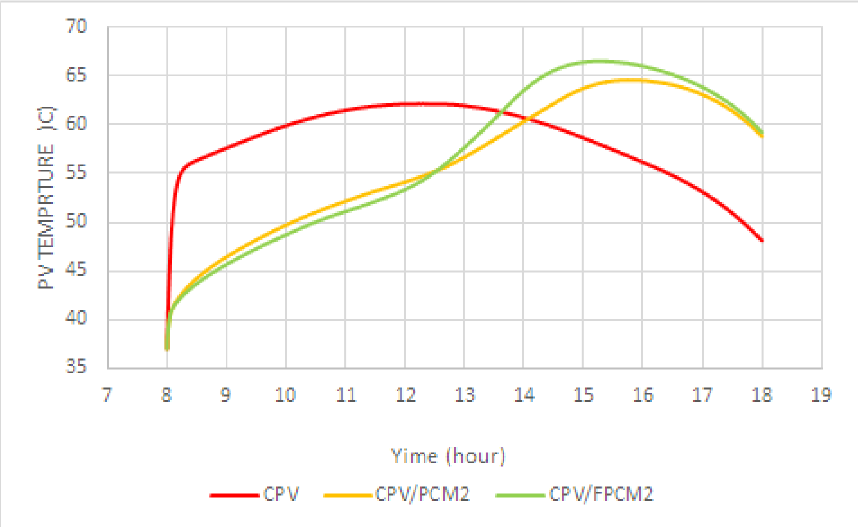

Figure 6: Temperature profile of PCM2

Figure (7) shown the contour temperature of CPV /PCM, CPV/FPCM it is clear that during the early period, the temperatures of the photovoltaic and ambient air are about (314) K. With the passage of time and the increase in the intensity of the solar radiation, the temperature of the CPV panel increases and the photovoltaic thermal management process starts when the heat is transferred from the CPV cell to the Phase change enclosure. It causes a temperature gradient pass during different phase change material layers. This gradation differs depend on the type of wax which used and it is shown in green Color .where the green color represents the degree of transformation from solid to liquid, and the yellow color changes most of the PCM1 to the liquid state, while the red color represents the degree to which the PCM1 is in a completely liquid state and This means that all PCM parts become the

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temperature upper than their melting point, and therefore, the Phase change material as a heat sink cannot maintain the heat taken from the CPV module as latent heat. As a result, PCM loses its capacity to thermally regulate the temperature of the CPV panel. which leads to higher temperatures in the PV panel

Figure (7-A) shows the contour of the temperature distribution between the air surrounding, solar panel and the PCM2 container attached to the back of CPV. Through these contours,

It is clear that the lowest temperatures are at the times (8,9,10,11) am when the heat gradually transfers to the PCM2 layers. While at times (12,1,2) pm represents the temperatures at which the PCM turns into a liquid. While the highest temperatures are at the times (3,4,5) pm when the temperatures are sufficient to melt the PCM2 completely.

Figure (7--B) represents the temperature contours of CPV/FPCM1 from (8 am to 6 pm).the temperature of the photovoltaic panel increases and the photovoltaic thermal management process starts when the heat is transferred from the photovoltaic cell to PCM enclosure with the fins .where the fins show an important role in the heat distribution and we note the higher temperatures around the fins area compared to the PCM area.The figure also shows the uniform distribution of temperatures during the analysis period, Melting Process of PCM2

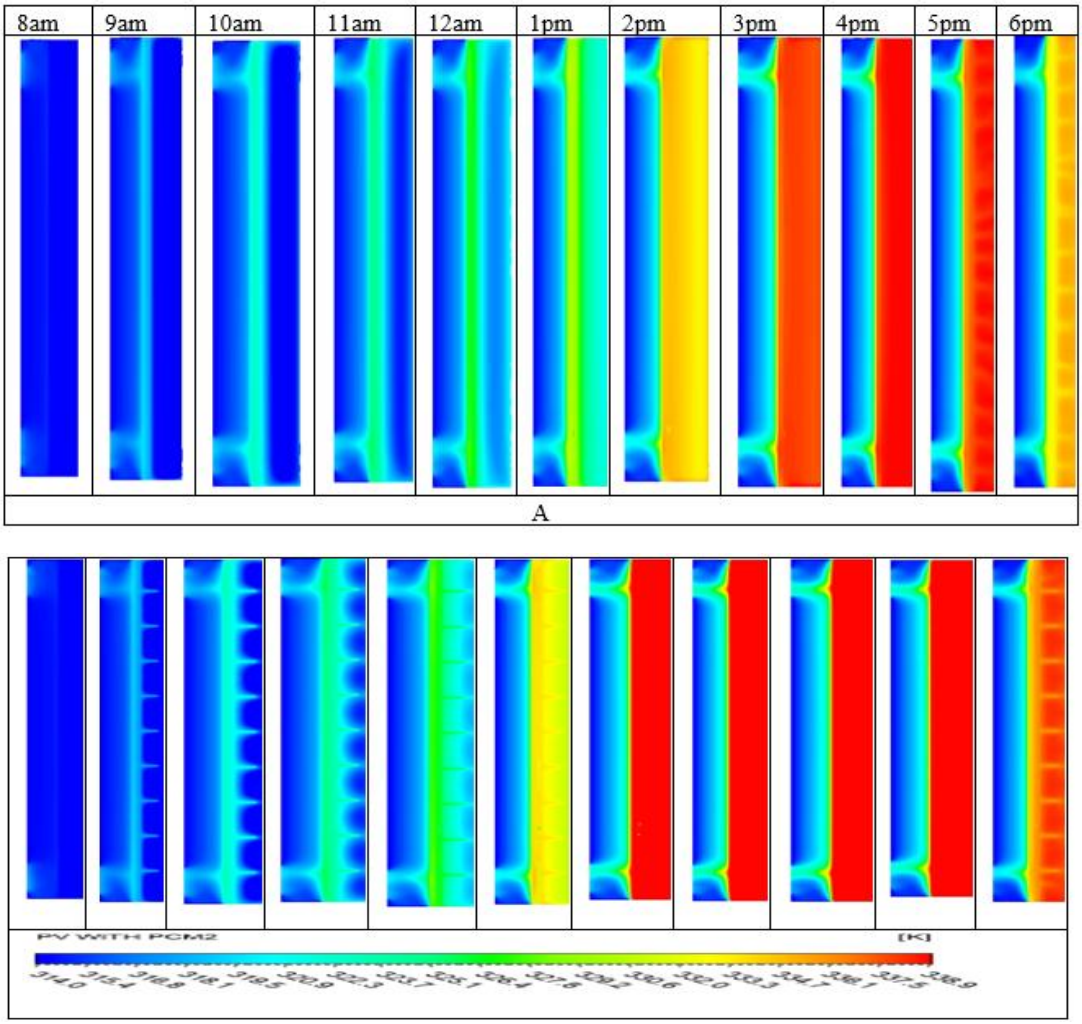

Figure 7: Temperature Contour of A: CPV with PCM B: CPV with PCM and fins sufficient to melt the PCM2 completely.

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Figure (8) represents the Liquid fraction contours of CPV/FPCM1 from (8 am to 6 pm).In general, in these contours, the blue region represents the solid region, the green region represents the mash region (mixture of liquid and solid), and the red region represents the complete melting region. At the start of the melting begins from hot contact part the thin film of melt over paraffin wax by conduction, this can be observed in the first three hours. As time progresses and more liquid paraffin wax is generated, Due to the greater natural convection in this area, the fusion layer gradually grows in size at a significantly faster pace near the top of the PCM cavity. and can be observed in the second three hours. The last three hours are enough to transfer each PCM into a liquid (red area).

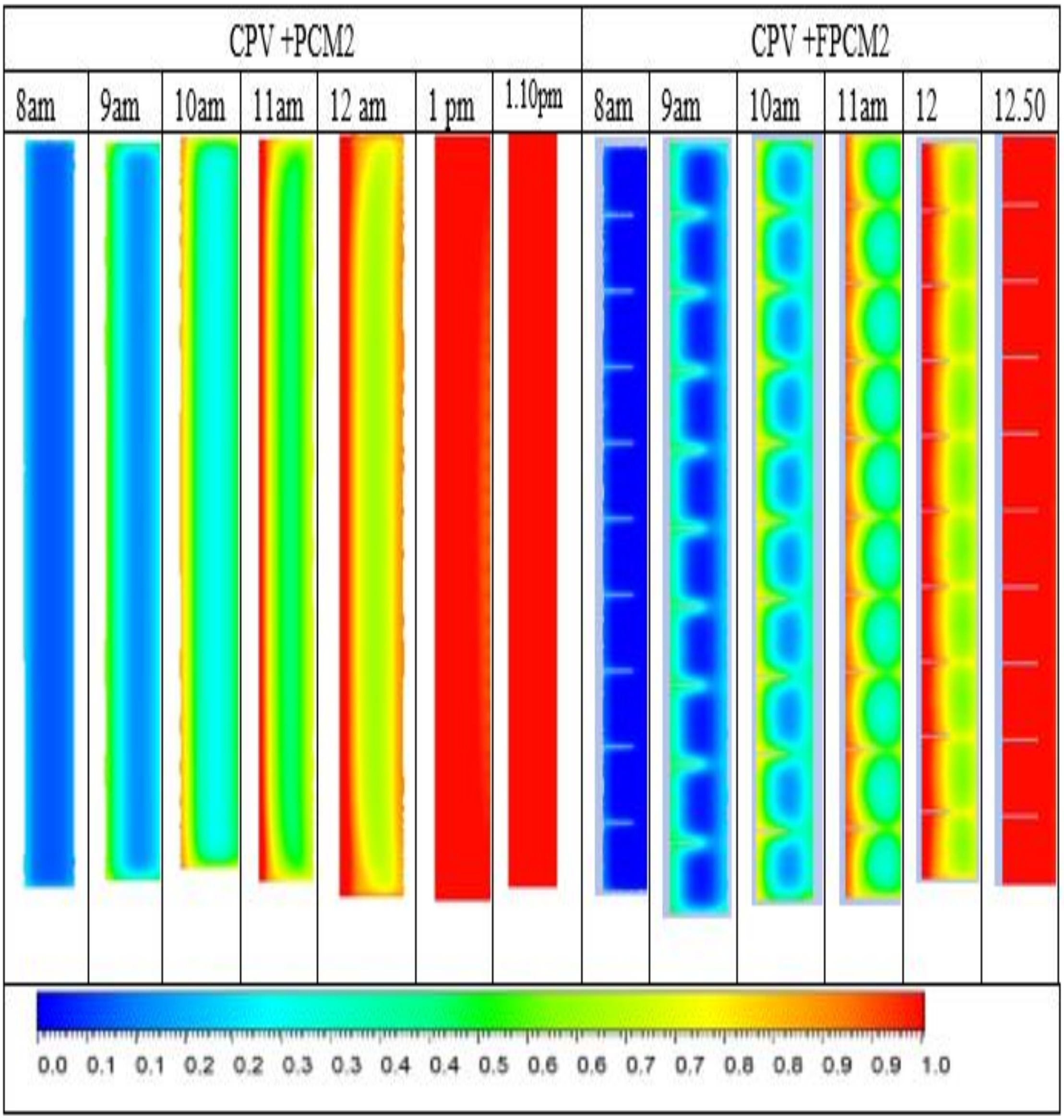

Figure 8: Liquid fraction CPV /PCM and CPV /FPCM

Effect of using PCM2 on electrical efficiency

Solar cell electricity conversion efficiency was calculated using Eq (6). electrical conversion efficiency with time is presented in Figure (9) Conversion efficiency varies inversely with time. it was found out that the efficiency of case (CPV/FPCM) is greater than other case, the average enhancement in efficiency for (CPV/PCM2), (CPV/FPCM2) are 5.561%, 6.68%, respectively.

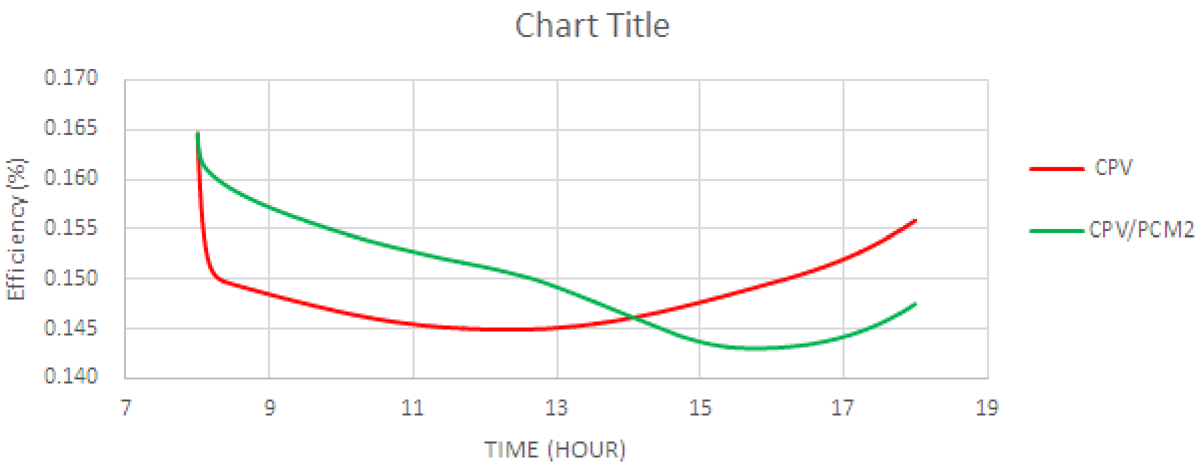

Figure 9: Efficiency of case (CPVI, CPV/FPCM2)

Experimental Results

Open-circuit current

Figure (10) shows the relationship between the current in states CPV, CPV/FPCM,) during time. It is clear that the highest value of the current was found in the photovoltaic panel without PCM compared to other cases. In all cases, the value of the current increases gradually until it reaches the highest value at 12 AM and then begins to decrease due to the decrease in the intensity of solar radiation. Also, the value of the change in the current is very small between cases because the value of the current is not affected by the change in temperature, but it is affected by the intensity of solar radiation.

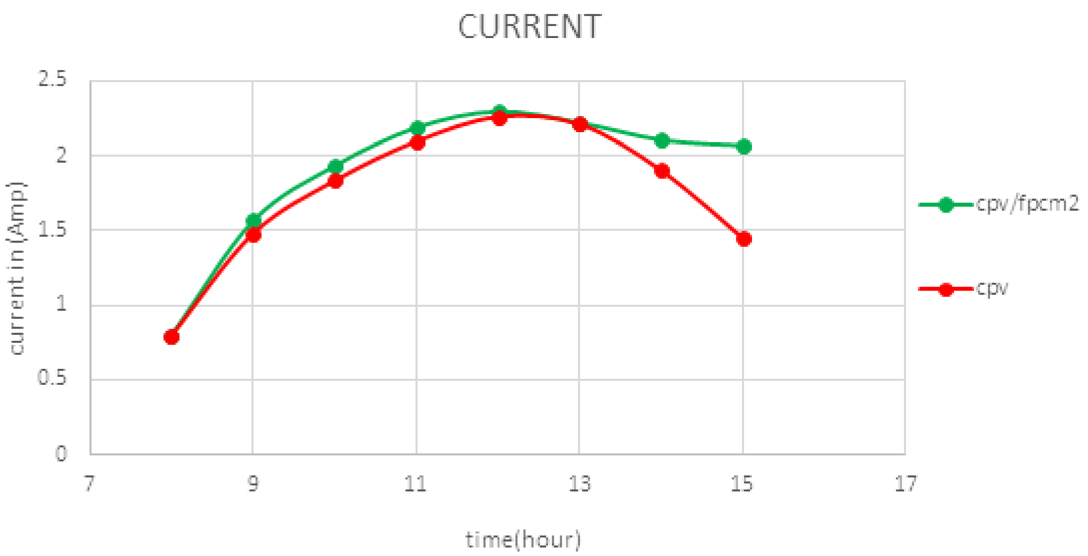

Figure 10: Relationship between the current in states (CPV, CPV/FPCM,)

Open-circuit voltage

Figure 7 shows the hourly variance of VOCs for (CPV, CPV/FPCM) cases. revealed in the figure, the VOCs of the cases decrease over time based on the rise in the intensity of solar energy. Though, the rise in the intensity of the sun leads to an increase in the temperature of the units, which tends to reduce the VOC until it reaches the middle of the noon, when the intensity of the solar radiation begins to decrease and increases VOCs for the (CPV ,CPV/FPCM) modules. Figure. As well illustrations that the voltage of the CPV-FPCM is permanently up than the CPV case as well as Voltage of PV/FPCM

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case is permanently up than other case in period between (8am to 12.30 am) and after this time the VOCs of CPV is become higher than CPV-FPCM.

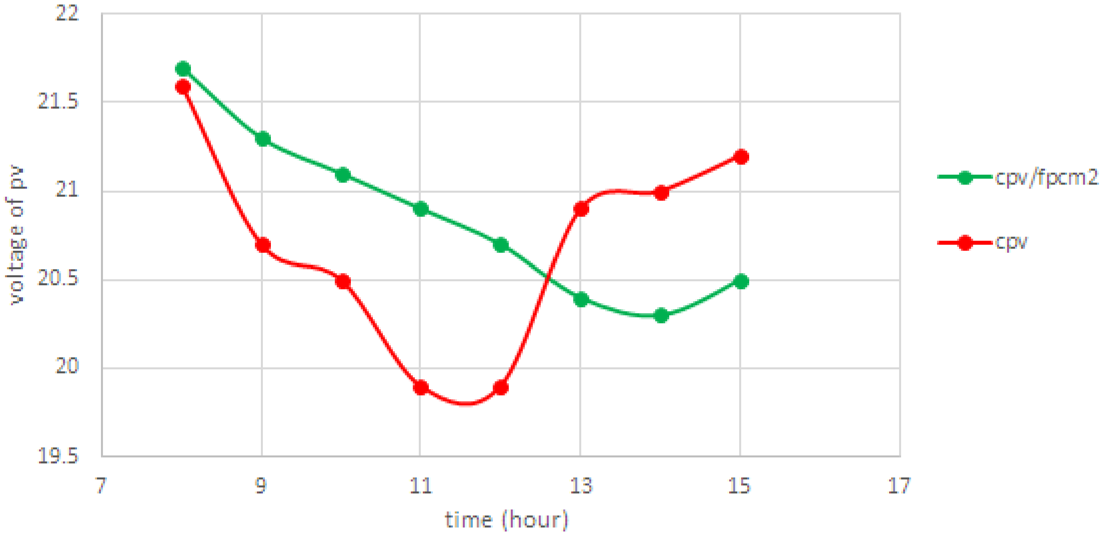

Figure 7 : hourly variance of VOCs for (CPVCPV/FPCM)

Power in case modules

The measured VOC and ISC values for the cases were used to calculate the output power carried by CPV case throughout the day. hourly distribution of output power can also be used to compute the average output power. hourly output powers for the various modules are depicted on the Figure 8. As seen in the figure, the output power profile has same behavior to the solar intensity. Figure also displays that output power of CPV-PCM case is always more than CPV module. This can be related to the usage of fins with PCM and fins, which decreased module temperature and increased open circuit voltage. In comparison to other cases, CPV-FPCM exhibits a greater decrease in temperature and an increase in voltage. The average improvement in output power for cases (CPV/FPCM) is (10%) compared with (CPV) module.

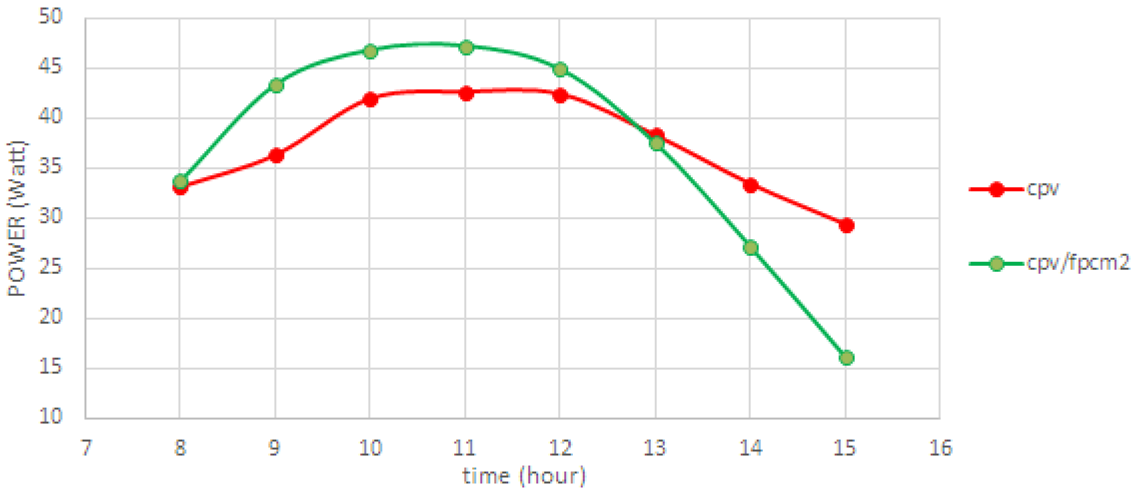

Figure 8: Relation between power for (CPV, CPV/FPCM)

Conclusion

This work conducted a numerical and experimental study on innovative solutions to improve the performance of CPV panels.

During the numerical study, three models were analyzed, which are (CPVI) (CPV/PCM), (CPV/FPCM).

in the experimental study, it was conducted the effect of using pcm was studied, the result shown below:

1. the temperatures of CPV decrease when using PCM, and that the rate of temperature decreases during the melting period Wax for (CPV/FPCM2) is (8.7C°)
2. the amount of improvement in efficiency (CPV/FPCM2) is (5.561%)
3. the average improvement in power for concentration photovoltaic in cases (CPV/FPCM2) is (10%) respectively compared with (CPV) module.
4. the use of fins helps in the distribution of temperatures, which leads to the melting of the wax uniformly compared to the case of pcm without using the fins.

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References

1. IRENA, “Renewable energy highlights Renewable electricity generation by energy source,” no. August. pp. 2018–2019, 2021. [Online]. Available: www.irena.org/statistics
2. İ. G. and N. Onat, “CostCalculation.pdf.”
3. U. C. A. D.M.C. Shastry, “Thermal management of photovoltaic module with metal matrix embedded PCM,” J Energy Storage, vol. 28, p. 101312, 2020, doi: 10.1016/j.est.2020.101312.
4. A. S. H. Mohamed Sharaf, Mohamed S. Yousef, “Review of cooling techniques used to enhance the efficiency of of photovoltaic power systems,” Environmental Science and Pollution Research /springer, vol. 29, pp. 26131–26159, 2022, doi: 10.1007/s11356-022-18719-9.
5. mohmud ahmed Ramy Rabie, hamdy hassan, shinchi ookara, “Performance enhancement of the concentrated photovoltaic using pcm configuration,” Energy Procedia, vol. 141, pp. 61–65, 2017.
6. M. A. Mohamed Emam, “Cooling concentrator photovoltaic systems using various configurations of phase-change material heat sink,” Energy Conversion and Management journal, vol. 158, pp. 298–314 Contents, 2018, doi: 10.1016/j.enconman.2017.12.077 Received.
7. I. Zarma, M. Ahmed, and S. Ookawara, “Enhancing the performance of concentrator photovoltaic systems using Nanoparticle-phase change material heat sinks,” Energy Conversion and Management, vol. 179. pp. 229–242, 2019. doi: 10.1016/j.enconman.2018.10.055.
8. S. C. K. s.Manikandan , Selvam , Nikunj Poddar , Kishlay Pranjyal , Ravita Lamba, “Thermal management of low concentrated photovoltaic module with phase change material S.,” Journal of Cleaner Production journal, vol. 219, p. 359e367, 2019, doi: /10.1016/j.jclepro.2019.02.086.
9. T. K. M. Shivangi Sharma a, n, Asif Tahir a, K.S. Reddy b, “Performance enhancement of a Building-Integrated Concentrating Photovoltaic system using phase change material,” Solar

Energy Materials & Solar Cells journal homepage, vol. 149, pp. 29–39, 2016, doi: 10.1016/j.solmat.2015.12.035.

10. Y. Su, Y. Zhang, and L. Shu, "Experimental study of using phase change material cooling in a solar tracking concentrated photovoltaic-thermal system," Solar Energy, vol. 159, pp. 777–785, Jan. 2018, doi: 10.1016/j.solener.2017.11.045.
11. M. S. K. M. Mostafa K. Yousif1, "Effect of Adding Vaseline and paraffin with aluminum matrix On the Performance of Concentrated Photovoltaic Cells," advanced engineering science, vol. 54, no. 08, pp. 2631–2648, 2022.
12. C. K. Zelin Xu, "Concentration photovoltaic-thermal energy co-generation system using nanofluids for cooling and heating," Energy Convers Manag, vol. 87, pp. 504–512, 2014, doi: 10.1016/j.enconman.2014.07.047.
13. C. H.A. Nasefa, b, S.A. Nadaa and Hamdy Hassan, "Integrative passive and active cooling system using PCM and nanofluid for thermal regulation of concentrated photovoltaic solar cells," Energy Convers Manag, vol. 199, Nov. 2019, doi: 10.1016/j.enconman.2019.112065.
14. ANSYS, ANSYS FLUENT theory guide. 2011. [Online]. Available: https://scholar.google.com/scholar_lookup?title=ANSYS FLUENT 17.2 Theory Guide&author=ANSYS&publication_year=2017