# Different methods of using phase change materials (PCMs) as coolant of photovoltaic modules: A review

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**Energy is an important parameter for the sustainable development of each country. Renewable energies are one of the main ways to reach this aim. Photovoltaic (PV) power plant is one of the most popular renewable power generation methods that is available in most parts of the world. Rising the PV cell temperature is one of the proved weak points, which negatively affects their electricity production. Different ways have been proposed in order to degradation of temperature effects on PV cells. One of them, is using phase change materials (PCMs) to prevent the rapid rise of the temperature of PV modules. PCMs absorb parts of the temperature of cells, which leads to decrease the PV temperature. Several methods were presented in PV/T field based on PCMs. The main purpose of this paper is to introduce the major coolant ways of PV modules and provides a review of different methods of cooling PV modules by using PCMs. For each section, some suggestions for developing purposes have been presented.** 

***keywords:*** *Review, Photovoltaic, PCM, Efficiency, PV/T, Micro-Encapsulated.*

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## 1. INTRODUCTION

Today's world is unimaginable without electricity. Electricity has been an inseparable part of life. Nowadays, using fossil fuels to produce power is less attractive, and the world is moving towards the use of innovative and renewable electricity generation, environmentally friendly. Photovoltaic (PV) power plant is one of these growing methods. Different aspects of a PV power plant are widely studied. Effect of ambient conditions on life duration of cells [1], off-grid PV systems [2, 3], life cycle assessment [4], semiconductors [5], PV floating plant [6], environmental impacts [7, 8], photovoltaic tracking systems [9], energy payback time [10], water pumping system [11] are some examples of nowadays researches in PV field. Crystalline PV cells are often made of silicon (Si) and gallium (Ga). These are members of the semiconductor materials family. Increasing the temperature in the semiconductors leads to reduce electrical conductivity and therefore makes the photovoltaic panels less efficient in the hot days of year, compared with the cool days, with the same sun irradiation. The favorable operating temperature range is -40°C to 85°C to achieve the best electrical efficiency of PV modules. It is found in literature review that the maximum photovoltaic operating temperature of 125°C has been reported in southern Libya, which caused to 69% reduction in nominal power of PV modules [12].

Tiwari et al. [13], in their research, plotted a graph to show the temperature and efficiency changes of PV panels during a day. It was found that each 1°C increase in temperature of PV cells, leads to about 0.45% drop in its efficiency [14, 15]. Several methods have been presented to overcome this problem. Table 1 presents an outline of these methods.

Nowadays, using phase change materials (PCMs), is widely considered for heat storage concepts in different applications such as: Solar ponds [16], heat exchangers [17], dryers [18], buildings [19], desalination plants [20, 21] refrigeration systems [22, 23], solar chimney [24] etc. Moreover, in recent years, PCMs become an interesting method in order to cool PV cells developed in many articles. In this field, numerical articles a small portion, and most of researches have been done experimentally. Furthermore, Experimental studies can be divided into indoor and outdoor categories. Indoor experiments were carried out in a simulated environmental condition with artificial light and heat, while the outdoor experiments were performed in a real situation under direct sunlight. Using PCM due to its low cost and no energy consumption has been more attractive by the researchers than the other methods. This paper introduces various methods that have been presented for the use of PCMs as a coolant of PV modules. In order to have a better mindset of each method, a schematic has been presented for each part. At the end of each section, suggestions are made on developing and

**Table 1.** An overview of various methods as PV coolant

| Methods | Authors | Research type |
|---|---|---|
| Thermoelectric effect | Skovajsa et al. [25] | Experimental |
| | Kane and Verma [26] | Experimental |
| | Makki et al. [27] | Numerical |
| | Choi et al. [28] | Experimental |
| | Li et al. [29] | Experimental |
| Airflow | Sarhaddi et al. [30] | Experimental and numerical |
| | Mittelman et al. [31] | Experimental |
| | Hosseini Rad et al. [32] | Experimental and numerical |
| | Teo et al. [33] | Experimental and numerical |
| Cooling by water | Nizetic et al. [34] | Experimental |
| | Krauter [35] | Experimental |
| | Hamdan et al. [36] | Experimental |
| | Kavoosi [37] | Experimental |
| Nanofluid circulating system | Firoozzadeh et al. [38, 39] | Experimental |
| | Sardarabadi et al. [40] | Experimental |
| | Fayaz et al. [41] | Experimental and numerical |
| | Ghadiri et al. [42] | Experimental |
| | Michael and Iniyan [43] | Experimental |
| | Saffaian et al. [44] | Numerical |
| Using fins | Sedaghat et al. [45] | Numerical |
| | Firoozzadeh et al. [46] | Experimental |
| PCM | Al-Shannaq and Farid [47] | Review |
| | Nada et al. [48] | Experimental |
| | Stritih [49] | Experimental |

introducing research gaps in that field.

## 2. USING PURE PCM

Fig. 1 presents a schematic of using pure PCM as a coolant of PV module. Stropnik and Stritih [49] performed both experimental and numerical studies on using RT28HC with melting point of 28°C as PCM behind the panel in order to increase efficiency. Their research was carried out for a year in Ljubljana, Slovenia. The results demonstrated that the highest temperature difference between the panels with and without PCM was 36.5°C. Moreover, the produced electricity of conventional PV and PV-PCM panel, was plotted monthly during a year. Smith et al. [50], performed an experimental research on using PCM in order to cool PV panels down. Their experiment was done in the climate of western Mexico, and reported an increase of 6% in efficiency. Copper sulphate $5H_2O$, was used as PCM, by Rajaram and Sivakumar [51]. In that study, the PCM was kept in a container, mounted at the back surface of PV module. They concluded that the PCM could keep the PV cells at about 40°C for 120 minutes. Sharma et al. [52], used RT40 behind the PV panel in a laboratory by a solar simulator, in comparison with a conventional panel. They exhibited 13.7% rising in efficiency when PCM is added to the conventional panel. This research was done in ambient temperature of 59°C and irradiation of $1000W/m^2$. Indartono et al. [53] by using Petroleum jelly (Vaseline) as a PCM to control the temperature of two 10 W photovoltaic panels, showed an increase of more than 21% in efficiency. Their experiments were done in the Indonesian climate.

Mahamudul et al. [54], tested RT35 as a PCM in the Malaysian climate. Their results revealed that in the ambient temperature of about 53°C, the temperature of PV cells were kept at about 42°C for 4 hours. Nouria and Sammouda [55] numerically studied the PV modules integrated with different thicknesses of PCMs, under the Tunisian climate. They investigated the effects of wind speed, wind direction and dust accumulation on the temperature and also the efficiency of PV cells. Park et al. [56] focused their study on finding the best thickness of PCM layer for the climate of South Korea. Finally, the maximum improve 3% in electrical efficiency was reported.

From financial viewpoint of PV/PCM systems, Hasan et al. [57] performed a study on energy and cost saving of a PV/PCM system. They showed that the suggested prototype could be financially desirable in the hot and higher irradiation environment.

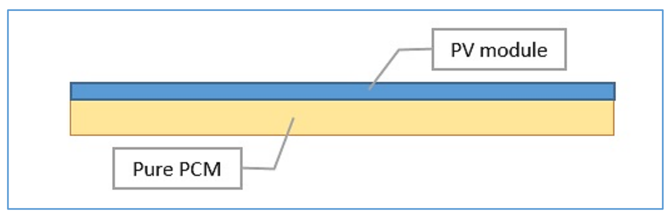


**Fig. 1.** Schematic of using pure PCM for cooling PV module.

## 3. IMPROVE THE PERFORMANCE OF PCMS

Due to the low thermal conductivity of phase change materials, in a number of studies, it has been shown that part of the PCM does not melt and remains in the solid phase. This means that some part of the heat storage potential is not used. Hence, in

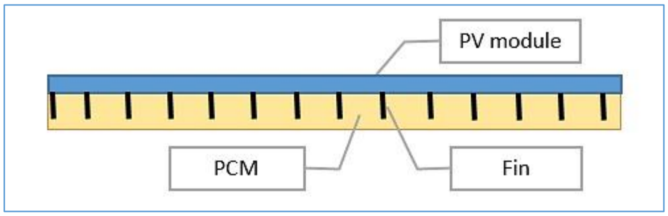


**Fig. 2.** A schematic of integrating fins in PCM for cooling PV module.

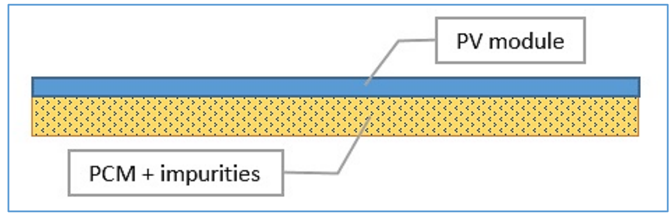


**Fig. 3.** A view of adding impurities to PCM.

some researches, this problem has been investigated, which is briefly mentioned below.

### A. Integrating fins

Using fin is one of common methods for increasing heat transfer. Fig. 2 shows one of these usages . Huang et al. [58] studied the influence of fins on three different materials: RT27, RT35, and Waksol A, as PCMs. Their work was carried out in an indoor condition experimentally. In their research, a number of fins with 8 different intervals were investigated. Finally, the Rayleigh number was calculated and plotted for all states of the tests. It is revealed that by reducing the fin interval, the Rayleigh number was decreased.

Khanna et al. [59] investigated experimentally and numerically the use of PCM and different configuration of fins. All of the models were made by Ansys 17.1 software. RT25HC with the melting point of about 25°C was used as PCM. In their paper, the effect of various configurations of fins i.e. , thickness, length, and fin interval were investigated. Finally, they reported the optimum state of fins in different conditions.

Huang et al. [60] have also investigated the use of fins for improving the melting process of PCM, used in PV panels. They did numerical simulations and solved the Navier-Stokes equations. They also experimentally tested this research to validate the numerical results. In another similar study, Huang et al. [61], explored the use of RT25 as a PCM and various layers of internal fins. They showed that the use of aluminum fins inside the PCM could create a temperature difference of more than 30°C compared with the non-fin mode.

In the experimental research, Firoozzadeh et al. [62] were used Polyethylene-Glycol 600 (PEG-600) as a PCM on the back surface of PV modules. Moreover, in order to increase the melting rate of PCM, the number of 10 longitudinal fins were used in PEG-600. Finally, the results show that the mentioned modify PV panel, at the last 80 mins of the experiment , had still about 9°C temperature difference compared with the conventional panel. The mentioned temperature difference leads to increase the electrical efficiency up to 4.6%. Moreover, in another study, they investigated the economic justification of using fins, behind PV modules [46].

#### *A.1. Follow up research*

Until now, several researches have been published on using fins in PCMs; but a comparison of different fin materials has not been done. Moreover, the geometry of fins in all studies were simple and straight. These two topics suggested to scholars to investigate.

### B. Adding impurities in PCMs

Adding impurities can improve the thermal conductivity of PCMs (Fig. 3). So, many studies were focused on this improvement. Haghighi et al. [63] investigated the effect of four different nanoparticles such as CuO, $TiO_2$, $Al_2O_3$, and graphene to paraffin. Finally, it was reported that $TiO_2$ in paraffin has the highest energy storage compared to the others. Luo et al. [64], used paraffin as a PCM. They used graphite particles inside the paraffin to increase its heat transfer coefficient. The results showed that this modification was able to hold the panel temperature below 50°C after about 200 minutes. This temperature control increased efficiency by 7.28%. Japs et al. [65, 66], added graphite to paraffin in order to increase the thermal conductivity of PCM, which led to increase the electrical efficiency. Atkin and Farid [67], compared the four different states of PV panels in an indoor condition. The first panel was a conventional panel . On the backside of the second panel, a layer of 30 mm thickness of paraffin (with a melting point of 40°C) containing graphite particles was used. The third panel was equipped with aluminum fins and the fourth one contained PCM, graphite, and fin together. Among these different states, the fourth one was able to improve the photovoltaic panel's electrical efficiency up to 12.97%.

Nada et al. [48] performed an experiment on three PV modules contain: conventional PV module, PV/PCM module, and PV/PCM module integrated with nano $Al_2O_3$. In that study, paraffin-wax with melting range of 56-58°C was used as PCM. The results showed 8.1°C and 10.6°C drop in temperature and increase in electrical efficiency by 5.7% and 13.2%, for PV/PCM system and PV/PCM/Nanoparticle system, respectively.

#### *B.1. Follow up research*

According to the literature review, exergy and entropy analyses have not been performed for this developing method. So, as a thermodynamic view of this problem, researchers might consider this issue in future studies.

## 4. MULTI PCMS

There are few studies in the multi-PCM field, in the specific application of photovoltaic. Hassan et al. [68] have compared the use of two PCMs with two different melting points. They used Capric-palmic acid and $CaCl_2.\ 6H_2O$ with melting point of about 30°C and 22°C, respectively. The experiment was performed in Dublin, Ireland, under the ambient temperature of 63°C. It was shown that when using Capric-palmitic acid, 16°C and when using $CaCl_2.\ 6H_2O$, a 21°C temperature difference could be achieved. A view of the mentioned application has been illustrated in Fig. 4.

Huang [69] has conducted on simultaneous using RT27 and RT31 as PCMs, in order of cooling PV panels. During the test, this combination could kept the panel temperature below 30°C. In addition, he performed an experiment using RT27 and RT21. The stable temperature of about 25°C was reached during the test.

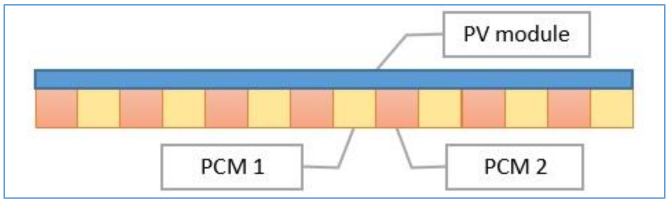


**Fig. 4.** A view of using multi PCM at the back surface of PV panel.

### A. Follow up research

In published papers, the PCMs with close melting temperatures were investigated. It is proposed that materials with greater difference between melting points are tested too. It is expected that it allows the panel to have better behavior under various temperature conditions. Furthermore, the exergy and entropy assessments have not been investigated for PV module.

## 5. MICRO ENCAPSULATED PHASE CHANGE MATERIAL

Employing Micro Encapsulated phase change materials, which are known as MPCM or MEPCM, is the latest method of using PCMs for different usages. When a PCM is used in the form of a microcapsule, the contact surface is increased and hence the heat transfer is increased too. MPCM is widely used in many fields of heating, ventilation, air conditioning, and heat storage systems. But a few articles have been presented on their usage in PV/T application.

Fig. 5 presents a schematic of the mentioned method. Qiu et al. [70] presented a theoretical study on the energy performance of a novel PV/T module that employed the MPCM slurry as the working fluid. Based on the Hottel-Whillier assumption, they predicted the energy performance of the MPCM slurry based PV/T system at a very good accuracy, with 0.3-0.4% difference compared to a validated model. They evaluated the results of laminar and turbulent flow cases and reported that the turbulent flow had better performance.

The first experimental research on MPCM slurry PV/T was done by Qiu et al. [71]. The test was performed under this operational conditions: (1) MPCM slurry weight concentration of 10%, (2) slurry Reynolds number of 3000, and (3) solar radiation of 500–700 $W/m^2$; finally, the system could achieve the net overall solar efficiency of 80.8–83.9%.

### A. Follow up research

According to other heat transfer studies in micro and nano, in most cases, the thermal performance in nanoscale is better than the micro scale. Since there is no study of using nano-capsules for PV panel cooling, this may be considered as an interesting and virginal topic by researchers.

## 6. PCM ACCOMPANIED BY NANOFLUID

A schematic of instantaneous using nanofluid and PCM as a coolant of PV panel has been shown in Fig. 6. Husseinzadeh et al. [72] experimentally investigated the comparison between the bare PV panel and the panel, which cooled by nanofluid and PCM simultaneously. In that study, nano zinc oxide (Zn/O) by 0.2 wt% concentration was used to make nanofluid, and moreover, paraffin as PCM. As a result, an increase of 29% was achieved power output of the PV system.

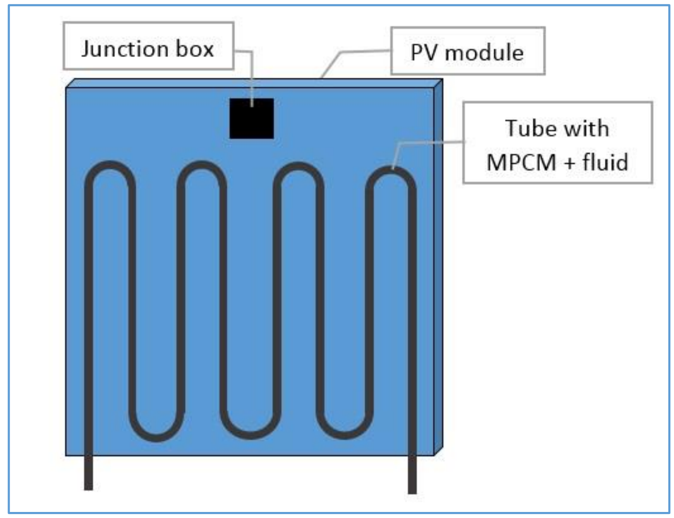


**Fig. 5.** A sight of integrating MPCM for cooling PV module.

In another similar study, Sardarabadi et al. [73] have done an experimental analysis on using nanofluid and PCM as a coolant of PV cells. ZnO by 0.2wt%, which dispersed in deionized water and paraffin-wax were used as nanofluid and PCM, respectively. They used 40W photovoltaic panels under the climatic condition of Mashhad, Iran. Their results show that the exergy efficiency of the nanofluid/PCM PV system is improved by more than 23% compared with the conventional panel.

In a novel study, Al-Waeli et al. [74] carried out experimental research on using SiC nanoparticles in paraffin-wax behind PV modules. In addition, nanofluid flew in a pipe passing through the PCM with a constant rate of 0.17 kg/s. They performed the experiment in the climate of Malaysia, under real condition. The increase of 13.7% in electrical efficiency has been shown in results. Al-Musavi et al. [75] numerically investigated the impact of paraffin as PCM and SiO2/water to reduce the temperature of photovoltaic panels. In that research, nanofluid was prepared in two various concentrations of 1 wt% and 3 wt%. The results illustrated up to 10% improvement in thermal efficiency when paraffin and nanofluid with concentration of 3 wt% were used, compared with the case of only water was used as a coolant .

### A. Follow up research

There are number of researches in PV/PCM integrated with a nanofluid. But the lack of an economical assessment in this field is seen. Generally, a scheme could be applicable when it is financially justified.

## 7. OTHER REVIEWS

Due to the wide range of articles related to the panels cooling, as well as the growing trend of research in this field, some reviews have been written on this subject, such as:

Waqas et al. [76] reviewed the works done in the field of PV/T cooling using phase change materials. In their article, in addition to expressing the main methods of using PCMs behind the panel, they also represented quantitative and statistical analysis of articles published in various journals. Chandel et al. [77] categorized both advantages and disadvantages of using PCM as a coolant of PV modules. Preet [78], published a review of the work done in the field of PV panel cooling by using water and PCMs in two separate sections.

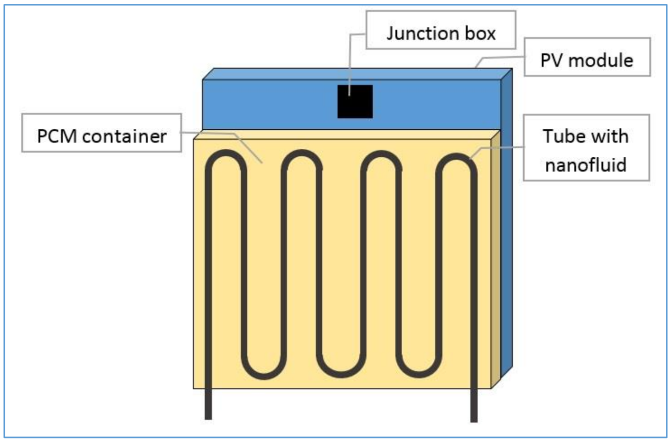


**Fig. 6.** A schematic of employing nanofluid in PCM as a coolant of PV panel.

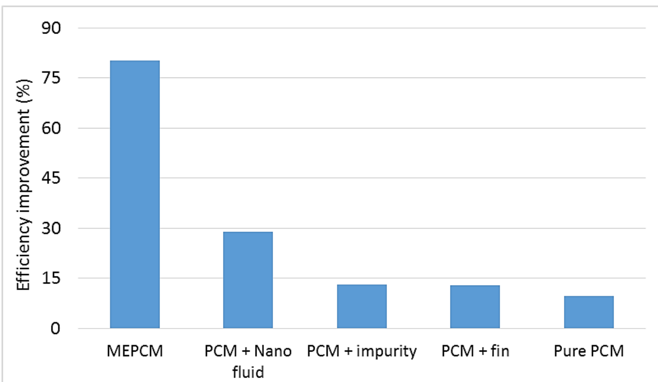


**Fig. 7.** Comparison of efficiency improvement of different optimizing PCM methods.

Sahota and Tiwari [79] exclusively reviewed the numerical and experimental works in this field. In addition, they provided the equations needed for different calculations of PV panel cooling. Salehi and Solyali [80] had a review on maximum power point tracker (MPPT) methods and their applications in photovoltaic systems. Finally, they presented a table to simplify the classification of different methods of MPPT.

## 8. METHODS COMPARISON

Based on the addressed headline, various methods of using PCM for cooling PV modules were explained. Accordingly, Fig. 7 has been depicted. In this figure, the highest improvement in efficiency for each method was reported and compared to the others.

As shown, using MEPCM has the highest efficiency improvement compared with the other techniques. But it should be noticed that this method is an active one, so consumes energy. The amount of efficiency improvement of passive techniques is another aspect. Using pure PCM, adding fin, and adding impurity to PCM have almost the same influence on PV efficiency. Energy payback time calculation could be a suitable tool to distinguish between both active and passive methods. Unfortunately, researchers did not pay attention to this determining factor.

## 9. CONCLUSION

In this paper, a review of cooling PV cells methods by means of phase change materials was presented. Because of the low thermal conductivity of PCMs, most scholars tried to overcome this problem. The results of this article are summarized as follows:

1) Using PCM can increase the thermal and electrical efficiency of PV cells more than 10% while does not cost much.
2) Both integrating impurity and metal fins to PCMs, can greatly enhance the PV cells ′ performance.
3) Most of the materials , which used as PCM, had melting point of about 25°C-35°C, which is the best thermal operating condition for PV panels.
4) Using PCM integrated with nanofluid circulation is very attractive for scholars. This method provides up to 30% enhancement in the efficiency of PV modules.
5) Cooling PV cells has a positive effect on modules lifetime directly.
6) Using micro-encapsulation PCM has the highest improvement in electrical efficiency by more than 80%, although it consumes energy.

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