A review on solar photovoltaic system with phase change material cooling

[1]Nimesh R. Patel, [2]Pavit B. Shah, [3]Alkesh M. Mavani

[1]Student, [2]Professor, [3]Professor
[1]Mechanical Engineering Department,
[1]L.D.R.P- ITR, Gandhinagar, India.

Abstract: Phase change material is widely used for thermal regulation and passive temperature control. PCM is recognized as one of the most promising material to store thermal energy in form of latent heat. High operating temperature of PV cell leads to decrease the conversion efficiency and life span. Thus PCM can be used to regulate the temperature of PV panel in order to enhance its performance. This paper is focused on cooling of PV panel by phase change material. A thorough review is carried out to investigate the different phase change materials, their performance and application in different systems.
This review includes both experimental as well as numerical study. This paper has concluded that paraffin wax is widely used for PCM cooling of PV panel. To increase heat transfer and thermal conductivity, fins and nano particles are used. It is also found that specific PCM with melting temperature should be used to achieve the uniform temperature distribution. Comparison of PCM for different climate condition has been also investigated. The stored thermal energy can be used for many thermal system applications. The outcomes of this study are discussed in conclusion section.

***Index Terms* – Solar PV panel, Passive Cooling method, Phase change material, Performance evaluation.**

I. INTRODUCTION

In this modern world, energy has become a crucial part of the daily life. One of the most popular technologies for harnessing this energy is the solar photovoltaic system, which converts solar energy directly into electrical energy without any other additional energy conversion step. The conversion efficiency of solar cell is mainly dependent on the material and operating conditions. The PV cell converts a certain wavelength of insolation that contributes to the direct conversion of light in to electricity and the remaining is dissipated as heat. Only 15-20% solar energy is converted into heat, remaining cause heating of solar cell [6]. It is reported in some literatures that every 1°C rise in operating temperature of PV cell leads to reduce its efficiency by 0.5% and power output by 0.65% [6][7]. Therefore, cooling of PV panel is necessary by using suitable cooling methods improve the power output per square meter area and to improve the economic aspects.

Researchers have proposed many cooling techniques. These cooling techniques are mainly divided into two categories: Active cooling techniques and Passive cooling techniques. These include natural air cooling, forced air cooling, water cooling, evaporation cooling, thermoelectric cooling, phase change material and transparent coating [5]. PCM can be used to store thermal energy. Ideal PCM for cooling must have high latent heat of fusion, high thermal conductivity, be chemically stable [7]. Other properties are discussed in next session. With the removal of excess heat out of the system by absorbing substantial latent heat during phase change process over a narrow range of temperature change, lower temperature of solar PV is achieved. This system is called PV/PCM system, which is shown in fig. 1

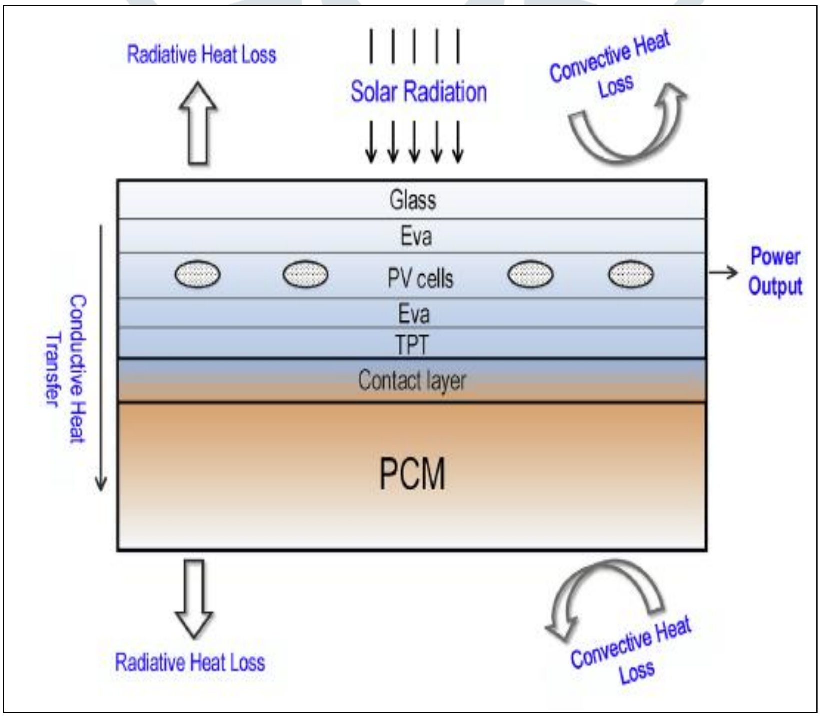

Figure: 1: PV/PCM system [7]

Some mathematical and numerical models of system have been developed in order to investigate the heat transfer process and melting process of PCM [9]. These models are solved by different techniques and software, in which finite element method, finite volume method, porosity method, heat capacity method, implicit finite difference method are mostly used for solution of model and for simulation, Matlab, TRANSYS and ANSYS are used [8]. ANSYS Fluent is widely used than other commercial software due to its abilities and flexibilities for modeling and simulation of fluid flow and heat transfer in complicated geometry [8]. The results are verified experimentally or with other research works. Effect of various parameters such as PCM thickness, change in melting temperature, and combinations of different PCM, wind speed, wind azimuthal angle, tilt angle, dust and ambient temperature on melting process of PCM has been studied [11] [12]. At the end of investigation optimum parameters have been found. In some research work, PCMs have been compared for different climatic condition for particular location and suitable PCM have been determined according to conditions and applications, while in others PCMs have been compared for different climatic condition for different locations [14]. To increase heat transfer, fins are mounted in PCM container. Effect of fins parameters are also studied in some research work [13]. Thermal conductivity of PCM is very low. Therefore, nano particles such as Al_2O_3, CuO are added to increase thermal conductivity [15] [16].

Thus, in this paper research work on PCM has classified according to system, types and applications. This paper provides a comprehensive review of how PCMs are used for improvement in performance of different PV systems, which is described in section 3. At the end conclusion is given.

II. Phase Change Material

PCM has been extensively studies for the thermal management of PV. PCM are substances which can store and release large amounts of energy to maintain a specific temperature range for a long period of time. Duration and temperature range over which the phase change takes place depends on the mass and thermal conductivity of PCM. Depending on the application, various properties are considered for selection criteria such as melting temperature, large latent heat, minimum subcooling, chemical stability, toxicity etc.

PCM can be classified into three main categories: organic PCM (e.g. waxes, paraffins, fatty acids, and alchoholes), inorganic PCM (e.g. salt hydrates) and eutectic mixtures [19]. These materials have different melting temperature ranges that determine their usability in specific application. The properties of different PCMs are described in fig. 2.

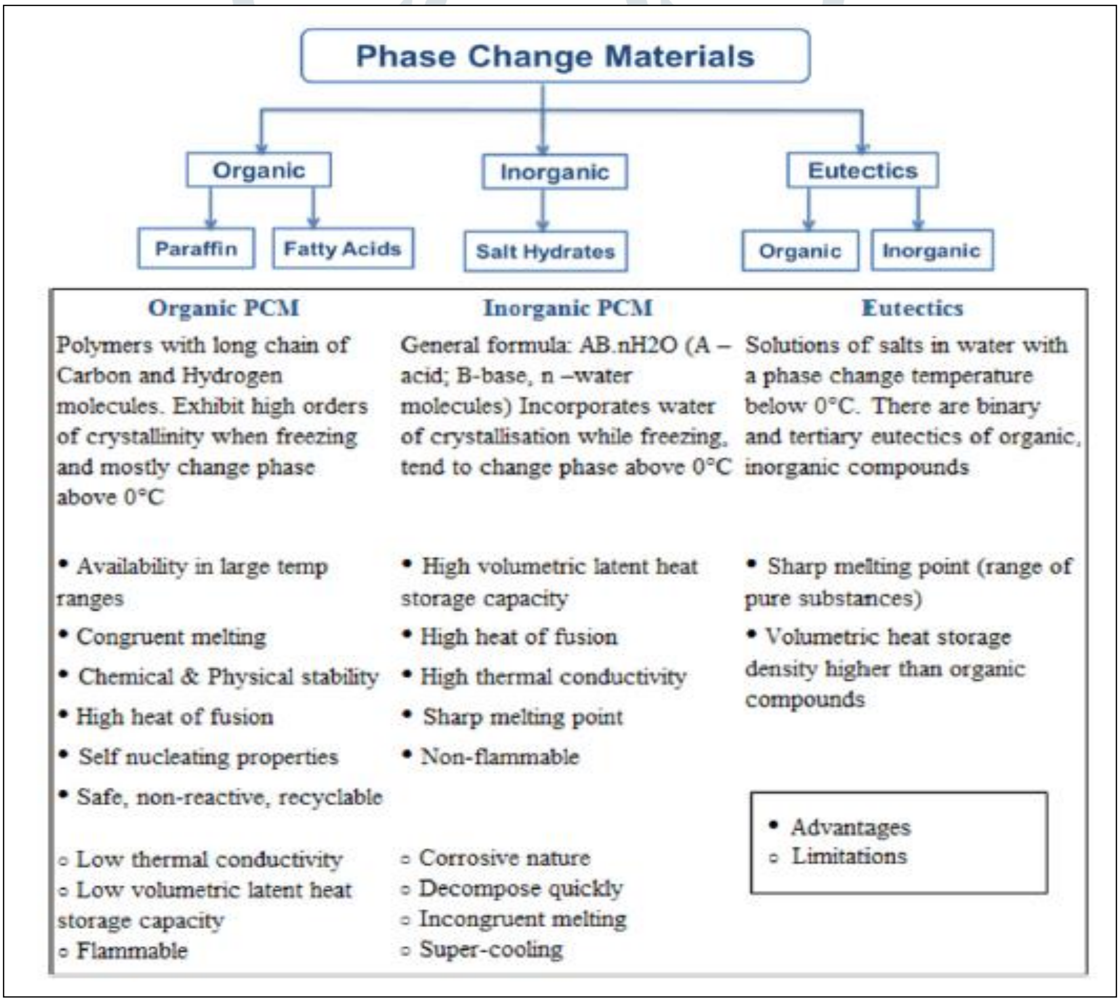

Figure: 2: Broad classification of PCM; advantages and limitations [21]

III. Types of phase change materials

In this section, techniques for cooling of solar PV panel by different types of PCM, their application for different system and types of study have discussed. This work is divided based on types of PCM.

3.1 Organic phase change material

Organic phase change material is normally chain of hydrocarbons. They are paraffin or non paraffin compounds. Having many advantages over other types of PCM, heat transfer study on PV panel integrated with PCM was conducted by Kant et al [22] in which Rubitherm RT35 [46] was used as phase change material. The numerical model was solved by using Multiphysics 5.0 with finite element analysis. In this model, effect of both conduction and convection heat transfer were considered in PCM melting process. It was concluded that maximum reduction in operating temperature was 6°C for PV/PCM with convection mode of heat transfer, and 3°C for PV/PCM system with only conduction mode of heat transfer. The PV/PCM system was optimized for wind velocity and tilt angle.

Three different PCM: RT18HC, RT25HC and RT35HC [46] were compared for constant solar radiation by Machniewicz et al [23]. They investigated transition temperature of PCM layer in order to avoid rapid temperature fluctuation on the PV back surface. To meet this requirement, dynamic simulation of PV/PCM system was conducted on ESP-r software. It was found that for RT18HC and RT25HC, most effective performance was achieved. It was stated that optimum temperature should be around 20°C and maximum relative increase in efficiency was equal to approximately 10%.

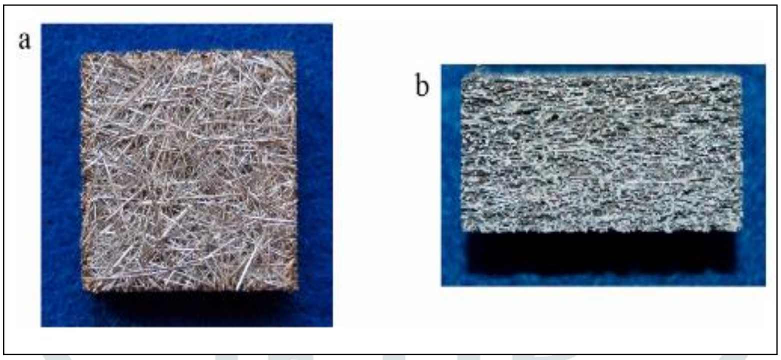

Figure: 3: Metal fiber structure (a) top view (b) side view [24]

In paper presented by Klemm et al [24], PCM fiber compound was made of metallic fiber structure, in which the voids were filled with the PCM shown in fig. 3. They evaluated thermal energy storage in phase change material to increase the efficiency of PV system. 3D model was solved in COSMOL Multiphysics. The ambient temperature was varied from 30°C to 45°C. Three PCM: RT54HC, RT50 and RT44HC [46] were investigated. For PCM RT54HC of 50mm thickness the optimum porosity was 1%. With decrease in porosity from 1 to 0.7, there was no significant enhancement. For 1% porosity with RT54HC the optimum thickness was obtained 50mm. Further increase in thickness had no significance improvement. Nouira et al [12] proposed a numerical model of PV system with phase change material. Three different PCM: RT25HC, RT35HC and RT44HC [46] were used for study. The model was solved in COSMOL Multiphysics. The ambient temperature was varied from 22.5°C to 37.5°C and solar radiation was varied from 0 to 1000W/m^2. For given condition RT44HC had better performance and maximum power output of 12W. Thus parametric study was carried out on RT44HC. Effect of dust accumulation, wind velocity and wind azimuthal angle were investigated. It was concluded that for higher wind speed and wind azimuthal angle, panel temperature was reduced. There was reduction in power output about 1.2W, 2.8W and 3W due to dust accumulation of 3g/m^2, 6g/ m^2, 9g/ m^2 respectively.

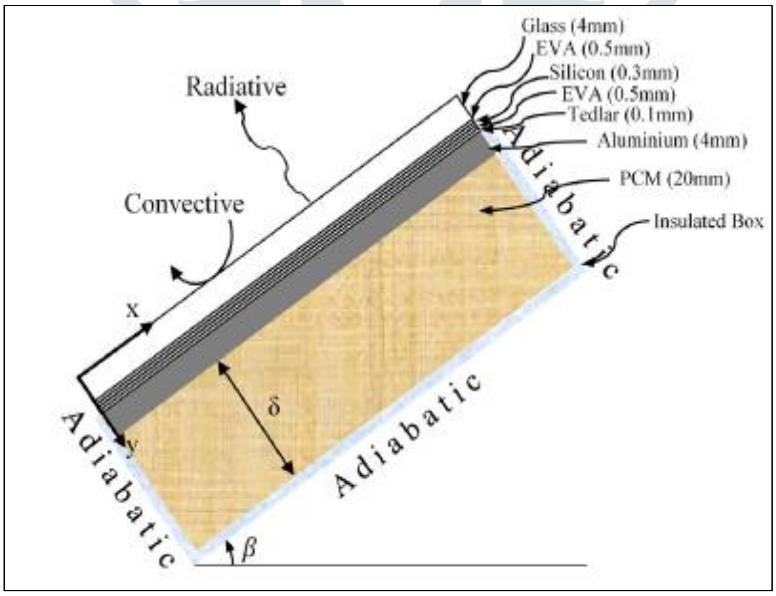

Figure: 4: View of the geometry [25]

One dimensional mathematical model for a tilted PV-PCM system in which all three modes of heat transfer were considered prepared by Khanna et al [25]. Adiabatic condition was assumed for side and bottom surface of the box contain RT25HC [46] as PCM material, shown in fig. 4. The effect of variation in tilt angle, wind azimuthal angle, wind velocity, melting temperature of PCM were investigated. The result indicated that the PV temperature decreased as tilt angle of the system increased and increased azimuthal angle and velocity of wind lead to decrease PV temperature. He also concluded that the melting temperature of PCM material should be near to ambient temperature to maintain the PV at lower temperature. In comparison with conventional PV the efficiency is increased from 17.1% to 19%. The results were validated with help of ANSYS FLUENT 17.0 software.

After parametric study same authors [26] optimized parameters in solar PV/T system. The effect of parameters such as wind velocity, wind azimuthal angle, ambient temperature and different melting temperature of PCM on optimum depth had been investigated. It was seen that for higher wind velocity, the optimum depth of PCM was reduced. Further optimization of fin parameters for modified finned PV/PCM system was carried out. [13] The effect of fins parameters such as length, thickness and spacing on PCM thickness was investigated. It was found that decrease in spacing lead to increase in cooling, so larger PCM thickness was required. If the length of fin was increased more heat transfer could occur. Optimum length was one when it touched the bottom of the container. For larger thickness of fins, more phase change material required, but beyond 2mm thickness it had no significant effect. RT35HC –paraffin wax was used as phase change material by Zhao et al [27]. They simulated the integrated PV-PCM system with different PCM thickness varying from 10mm to 40mm. For thermal performance analysis, 1-D thermal resistance model was built and simulated in MATLAB R2018a. The convective loss from bottom surface of PCM contain tank was considered. The results showed that the PCM's natural convective heat transfer rate could be 4 to 5 times than the conductive heat transfer rate which yield reduction in PV temperature by up to 24.9°C and electricity output was increased by 11.02%. For 20mm thickness significant improvement was shown, further increase in thickness had no effect but it would increase cost. Biwole et al [30] proposed mathematical model of heat and mass transfer coupled with PV/PCM system. Rubitherm RT25 [46] was taken as phase change material. In order to force the velocity field to be zero when PCM was solid, a volume force was included to buoyancy term in the Navier-stock's momentum conservation equation. They found that the simulated PV/PCM system allowed maintaining the panel's temperature below 40°C for constant radiation of 1000W/m^2 during 80mins.

The parametric study was performed by Ma et al [28] on PV system integrated with phase change material. A numerical simulation was conducted on ANSYS Fluent. Five different systems: RT35 with 30mm depth, RT35HC with 30mm depth, RT42 with 30mm depth, RT35HC with 40mm depth and RT35HC with 50mm depth were investigated. Fins were used to enhance heat transfer. It was found that RT35HC had given best performance among all systems. It could maintain PV temperature below 45°C for 318 minutes. For simulation constant solar flux, wind velocity and ambient temperature were used which were 900W/m^2, 27°C and 4m/s respectively. Later on same authors [29] performed mathematical and sensitivity analysis of solar PV panel with phase change material for 300 cases. Comparison between CFD model and numerical model was done. Convective heat transfer radiation of PCM material was also taken in account. It was concluded that the new enhanced heat rate model was better than CFD model and 1D resistance model due to less time consumption and no need to make assumptions. It was also concluded that if the PCM phase change temperature was 5°C higher than the ambient temperature then PV-PCM system had higher potential for implementation of solar radiation.

Polyethylene glycol 1000 (PEG1000) as phase change material for PV/PCM system was used by Baygi et al [33]. PEG1000 had some advantages such as lower cost, non flammability and non toxicity. The PCM material was filled in 8 rectangular shaped aluminum containers which were fixed at the back of the panel. The result indicated reduction in temperature of cell from 62°C to 47°C which enhanced the cell power generation by 8%. The change in orientation angle improved in the heat transfer distribution due to more absorption of sun spectrum and that lead to more electricity production.

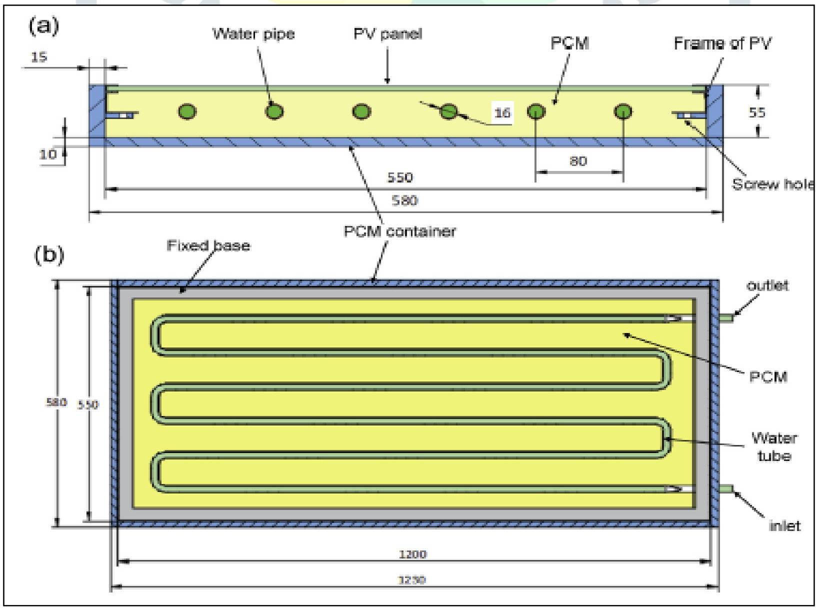

Figure: 5: The section view of PV/PCM/T system [7]

Novel PCM was used by Zhenpeng et al [7] in experimental study and performance analysis for novel PV system, PV/PCM and PV/PCM/T system shown in fig. 5. Paraffin wax was used as phase change material. The results showed that the maximum temperature difference between PV system and PV/PCM system was gained 23°C. For PV/PCM/T system water could be heated up to 41.6°C. It was concluded that energy stored in PCM could be used for practical application such as preheating of water. Sheep fat as novel phase change material was used by Siahkamari et al [16] for cooling of photovoltaic panel. For comparison, four system: PV system without cooling, PV system with paraffin wax, PV system with pure sheep fat, PV system with sheep fat and cuo (0.04W/V) were taken. Micro-cooling channels were installed on back surface of PV panel in order to regulate temperature of both PCM, shown in fig. 6. In the result it was concluded that sheep fat and cuo system had better performance than paraffin wax and pure PCM. The percentage maximum power increased for sheep fat and cuo, as compared to with no cooling system was 24.6% to 26.2% and compared with paraffin wax was 5.3% to 12%.

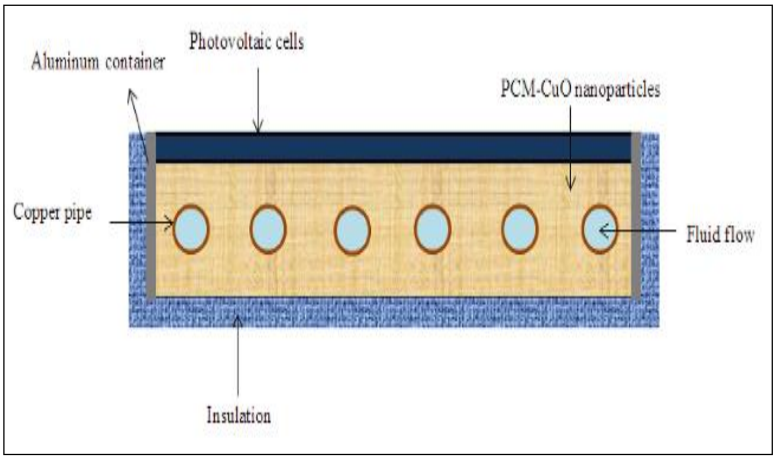

Figure: 6: copper microchannel tubes surrounded by PCM-CuO nanoparticles [16]

To improve efficiency and thermal regulation of building integrated PV system using PCM, an experimental study was carried out by Nada et al [35]. To enhance thermal conductivity, Al_2O_3 - nano particles were used. Three system: PV system, PV system with PCM RT55 [46] and PV system with RT55 and Al_2O_3-nano particles were investigated. The ambient temperature varied from 30°C to 38°C. The results mentioned that the average temperature reduction were 81.6°C and 10.6°C for PCM and PCM with Al_2O_3 system. The average increase in efficiency was 0.85% and 2.1% for PCM and PCM with Al_2O_3 system. Sharma et al [21] performed experiment on building integrated concentrated photovoltaic system (BICPV) using phase change material. Rubitherm series R42 was used as phase change material. Wacom solar simulator was used for constant solar flux 500, 750, 1000, 1200 W/m^2. Two systems, one without PCM and other with PCM were compared for performance analysis. For 1000W/m^2 solar flux, maximum temperature reduction was obtained by 11.6°C and electrical efficiency was improved by 7.7%. The increase in relative electrical efficiency was 1.50%, 4.20% and 6.80% for solar fluxes of 500, 750 and 1200 W/ m^2 respectively.

To increase electric efficiency and power output of PV panel with use of PCM material RT28HC, Stropnik et al [5] performed an experiment investigation [46]. The experiment was validated by using TRANSYS software. Experiment was performed in ambient condition ranging from 8.5°C to 18.3°C. Maximum solar global radiation was 571 W/m^2 and highest diffuse radiation was 204 W/m^2. The result showed the maximum difference in temperature of the PV cell between conventional PV panel and PV-PCM panel was 35.6°C and average difference in temperature of the PV cell during experiment was 14.14°C. The maximum increase of the PV-PCM electric power was 23.2% and average increase was 9.2%. The difference between experiment and simulation result in the PV cell temperature were maximum 19.39% for conventional PV panel and 10.63% for PV-PCM panel due to variation in solar energy radiation beam because of partially cloudy weather.

A mathematical model for PV/T system using nano fluid coolant and nano-PCM was developed by Ali H.A. et al [9] and was experimentally validated for local climatic condition. The nano-SiC-Paraffin (nano-PCM) was used as PCM material in which copper round tubes were embedded. The mathematical model of PV/T/PCM system was solved by using MATLAB and the results were verified experimentally. It was concluded that the PV/T system glass temperature and cell temperature were reduced compared to standalone system. It was also manifested that the nano-wax used in PVT system didn't reach its melting point , however its heat drawn efficiency and transfer to nano fluid were varied appropriate due to enhancement in its thermal conductivity because of the added nano-SiC particles. It was found that the thermal and electric efficiency were 72% and 13.7% respectively and deviation between measured and model efficiency were 3.72% and 5.05% respectively. The overall system efficiency was 85.7%.

3.2 Inorganic phase change material

Inorganic phase change materials are mostly salt hydrates. Due to higher thermal conductivity and higher latent heat of fusion per volume, they can be used for cooling purpose. Calcium hydrate ($CaCl_2.6H_2O$) was used as phase change material by Emam et al [37]. They proposed a numerical model for concentrated photovoltaic system integrated with phase change material. The parametric study was simulated on ANSYS software. The parameters such as inclination angle varied from -45° to 45°, the PCM thickness varied from 50mm to 200mm were studied. The ambient temperature was kept 25°C. From simulation results it was found that the inclination angle had significant effect on transient average solar cell temperature. The minimum average solar cell temperature with reasonable uniformity was achieved at angle 45°, while the maximum solar cell temperature with worst uniformity was achieved at -45°. Increasing in thickness for same CR, lead to increase in the time required for complete melting and maintains lower PV temperature for more time. Solar cell efficiency was around 17% at inclination angle 45°, while for angle -45° there was drastic reduction in efficiency.

Performance of two PV/PCM systems with different phase change material and two different climates were compared by Hasan et al [38]. In first PV/PCM system, calcium-hydrate $CaCl_2.6H_2O$ was used as in organic PCM and in others eutectic mixture of fatty acids: 75.2% by weight of 98% pure capric acid and 24.8% by weight of 98% pure palmtic acid was used as PCM. In the experiment set up fins were used to increase heat transfer which is shown in fig. 7. It was concluded that calcium-hydrate had given better performance than eutectic mixture. The temperature drop and power saving were 3.4% and 3% respectively more than the eutectic mixture. For climatic performance comparison two locations were selected: Dulbin-Ireland (53.33N, 6.25W) and Vehari-Pakistan (30.03N, 72.25E). It was seen that PV/PCM system had better performance in warmer climate of Vehari than cold climate of Dulbin.

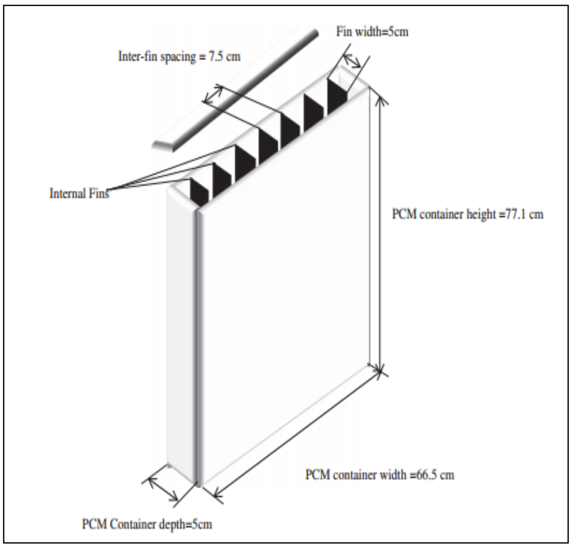

Figure: 7: PCM containers with vertically installed back to back fins [38]

Effect of PCM on performance of air cooled PV system was investigated by Choubinch et al [39]. PCM 32/280 –salt hydrate was used as phase change material. In experiment there were two systems of air cooling: natural circulation and forced circulation. For forced circulation, three different fan speeds were used: low speed (0.75m/s), medium speed (0.95m/s) and high speed (1.05m/s). The results are given below:

Table: 1: Variation of efficiency with different fan speeds [39]

Fan speed (m/s)	Max. Efficiency increasing (%)	Average Efficiency increasing (%)
High (1.05)	1.29	1.11
Mean (0.95)	1.29	1.06
Low (0.75)	1.29	1.11
Natural Mode (0)	1.47	0.98

An experimental study to investigate the performance on the PV module cooling effect by using compound enhancement technique was carried out by Salem et al [40]. This was conducted by employing water and/or Al_2O_3/PCM mixture with different mass concentration of nano-particles from 0 to1%. 20 Aluminum channels of the same length were fabricated and used either for passing the cooling water or were filled with the Al_2O_3/PCM mixture. An organic solution PCM – Calcium chloride hexahydrate $CaCl_2.6H_2O$ was used. The experiment was performed to examine effect of occupation ratio of the Al_2O_3/PCM in the channels from 0 to 100%. The results showed that Al_2O_3 (Ø=1%) /PCM mixture (25% PCM +75% water (5.31 Kg/s.m^2)) had achieved the better PV performance than the cooling with 100% water at the same operating condition. However this mixture did not provide the highest PV electrical output power, so it was concluded as superior solution for the PV cooling.

3.3 Eutectic phase change material

Eutectic phase change materials are mixture of organic-organic and/or inorganic-inorganic and/or organic –inorganic compounds. The mixture of capric-palmtic acid was used as phase change material by Browne et al [17]. The set up is shown in fig. 8. They had studied PV/T system integrated with phase change material. The experiment was performed for 7 days. The results showed that the time for which the heat was stored, was approximately two times of PV/T system. The heat gain by water in the PV/T-PCM system was around 6°C higher than the alone PV/T system.

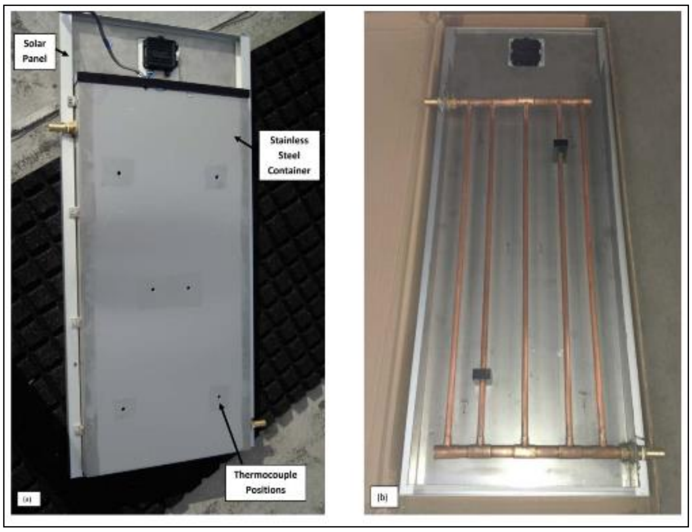

Figure: 8: (a) sealed container (b) pipe network in position in container [17]

IV. COMPARISON OF DIFFERENT PCMS

The CFD model was developed to investigate five PCM (Paraffin C18, C22, C15, Palmtic acid, Sodium phosphate salt) as well as the effects of copper foam as the porous medium by Mousavi et al [41]. Copper foam was used as porous medium to investigate the thermal performance of PVT system integrated with phase change material. The model was solved as steady state by using ANSYS FLUENT/CFX and verified with the results of an experimental study by previous research work. It was concluded that Paraffin wax C22 showed the highest thermal efficiency 83.5% while sodium phosphate salt showed highest electrical efficiency 13.8%. In addition the results proved that the electrical efficiency could be enhanced by 2.3% in comparison with the simple PVT system by using the effect of metal foam as porous medium. Kazemian et al [42] numerically investigated photovoltaic thermal system integrated with phase change material and compared with experimental data of previous research work. 3D model of PVT/PCM system was simulated by using transient solver in ANSYS Fluent 16.2 and parametric study was performed for a chosen range of properties of the most available PCMs on the market. The conclusion was summarized as increasing the coolant mass flow rate from 30 Kg/h to 70 Kg/h caused reduction in the percentage of melted PCM from 48.9% to 43.1%. Enhancement of enthalpy of fusion and thermal conductivity also increased the thermal efficiency and electric efficiency.

For BIPV/PCM system, Ho et al [43] carried out numerical evaluation for thermal and electric performance of building integrated photovoltaic system integrated with phase change material (BIPV/PCM). The parametric analysis was conducted for two phase change material of melting temperature T_m = 26°C and T_m =34°C and two aspect ratios A_m =0.277 and A_m =1. Three weather conditions winter (T_a =20°C), normal (T_a =26°C) and summer (T_a =20°C) were used. For summer condition, the lowest efficiencies without and with PCM were 17.86% and 17.99%. For winter condition it was 19.09% and 19.49%. For normal condition, different combination of melting point and aspect ratio were compared. It was found that MEPCM layer with A_m=0.277 and 1 increased and decreased the minimum efficiency by 0.09% and 0.18% respectively. While T_m=28°C and T_m=34°C increased the minimum efficiency by 0.09% and 0.12% respectively.

Motiei et al [44] performed transient simulation of PV/TEG/PCM system for 24hr of day 5^{th} January (winter) and 6^{th} July (summer). Three different system: sole PV panel, PV/TEG system, PV/TEG/PCM system were compared. During winter season, ambient temperature varied from 1°C to 5°C and during summer season, it varied from 19°C to 27°C. The 2D model was solved on ForTrans-90 software. In comparison of PV/TEG system with sole PV panel without PCM, the temperature reduction and efficiency improvement were 8.9°C and 0.59% respectively during summer condition and 4°C and 0.29% respectively during winter condition. For summer condition three PCM of melting temperature 34-36°C, 44°C and 51°C were used. The temperature reduction and efficiency improvement were gained by 23.7°C, 19.5°C, 14.9°C and 1.67%, 1.37%, 1.05%. For winter condition another three PCM of melting temperature 10°C, 18.2°C and 26.6°C were used. As compared to sole panel the temperature reduction was obtained by 13.3°C, 8.3°C and 3°C and efficiency improvement was obtained by 0.94%, 0.59% and 0.22%. The optimum thickness of PCM was found 115mm and 45mm in summer and winter condition respectively.

V. CONCLUSION

A comprehensive review and analysis of phase change material cooling techniques for photovoltaic panel are discussed in this paper. Proper PCM cooling improves the thermal, electrical and overall efficiency, which in turn also decreases the cell degradation rate and increases the life span of the PV module. Different tools such as schematic diagrams, pictures and equations are used to clarify, illustrate, analyses and compare this technique for different system to address the unwanted influence of temperature on PV performance. Several papers from different research field are reviewed and classified based on type of material, system, investigation and their contribution to achieve cooling to improve performance of the PV panel.

After investigating the various PCMs used to deal with the aim of increasing efficiency, it has found that PCM cooling have substantial potential to reduce the operating temperature of PV panel. The majority of the conducted research studies were focused on use of organic PCM, especially paraffin wax which is available in market and recyclable than other types of PCM.

Different experimental set ups are developed. Effect of different parameters affected on the PCM melting process has been also investigated. It has been concluded that latent heat of fusion, melting temperature and volumetric expansion coefficient of PCM are the critical properties on which time period of cooling and volume of PCM depends. These two parameters are optimized in many papers for specific operating condition.

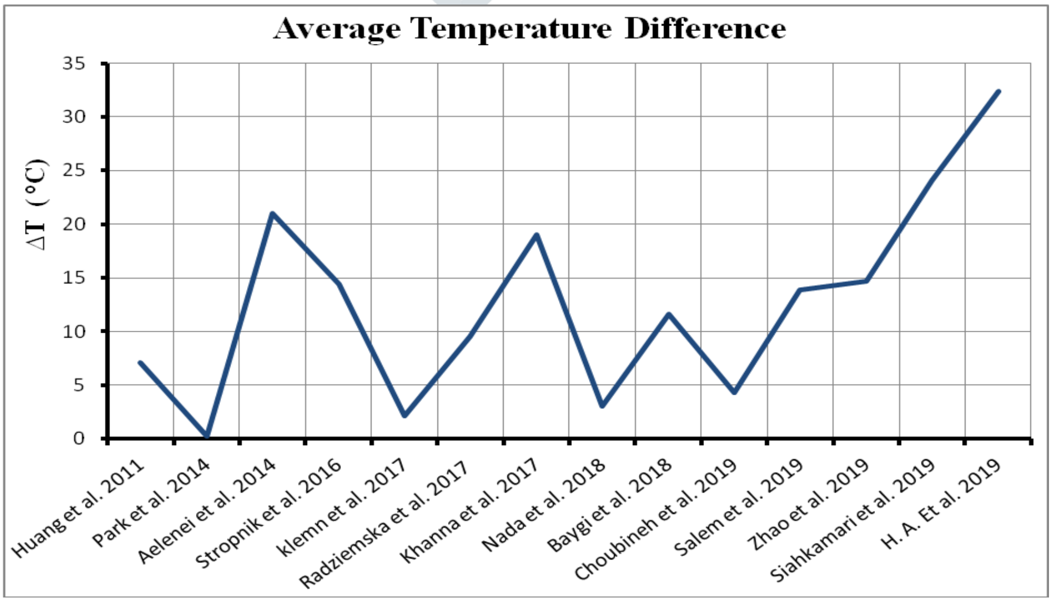

Figure: 9: Average temperature difference achieved in different research

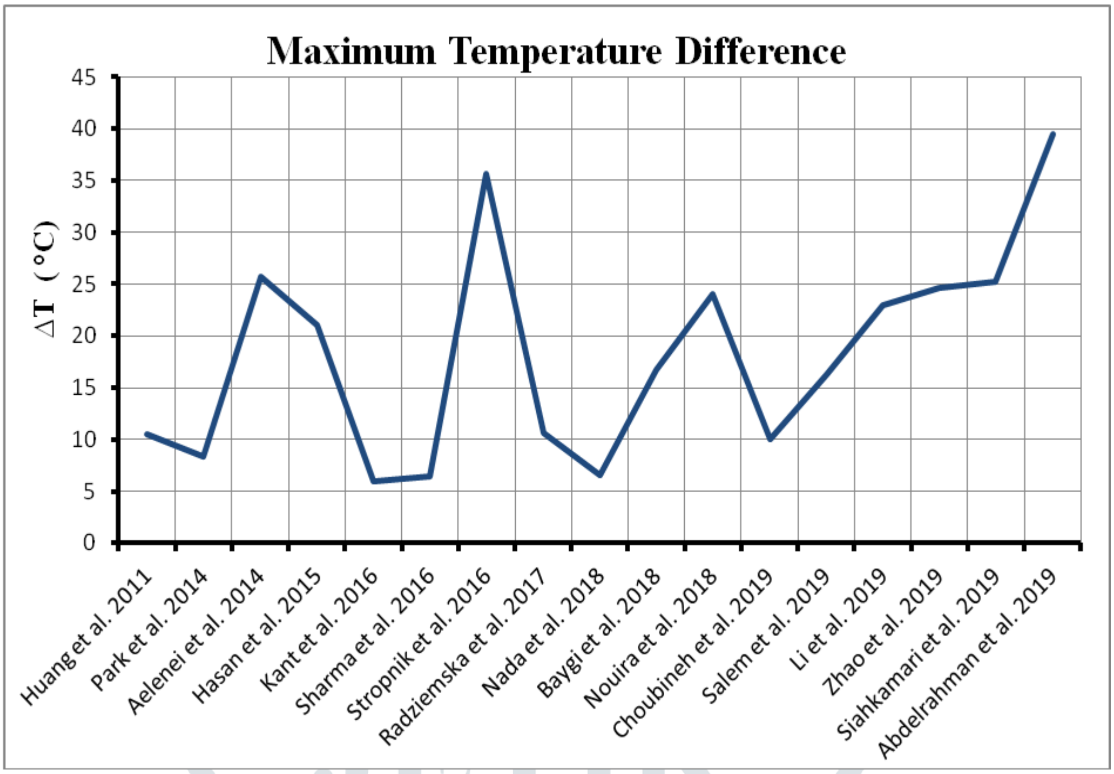

Figure: 10: Maximum temperature difference achieved in different research

The major limitation of organic PCM is low thermal conductivity. Therefore, fins have been used to increase heat transfer and different configurations such as cylindrical fins are used. Furthermore, nano materials such as Al_2O_3, SiC, CuO have added to PCM in order to increase the thermal conductivity of PCM. Average and maximum temperature difference achieved in different research study are shown in fig. 9 and fig. 10. Similarly average and maximum electrical efficiency and in increases in efficiency is presented in fig. 11 and fig. 12.

Various methods and software have been used for modeling and simulation of heat transfer process and melting process in PCM. The methods include various numerical methods, mathematical model, heat and mass transfer analysis and thermodynamic analysis. 1D model are widely developed for simulation and they have showed high accuracy. It is also observed that some 1D model have more precise results than 2D or 3D models since there are factors such as quality of mesh, assumption and boundary conditions which affects the accuracy. In 2D and 3D models, conductive and convective heat transfer heat has taken in account. Many commercial types of software are used to solve models such as ANSYS Fluent, ANSYS CFX, TANSYS, MATLAB, COSMOL Multiphysics etc. Out of this ANSYS Fluent is widely used for simulation of PCM because its abilities and flexibilities.

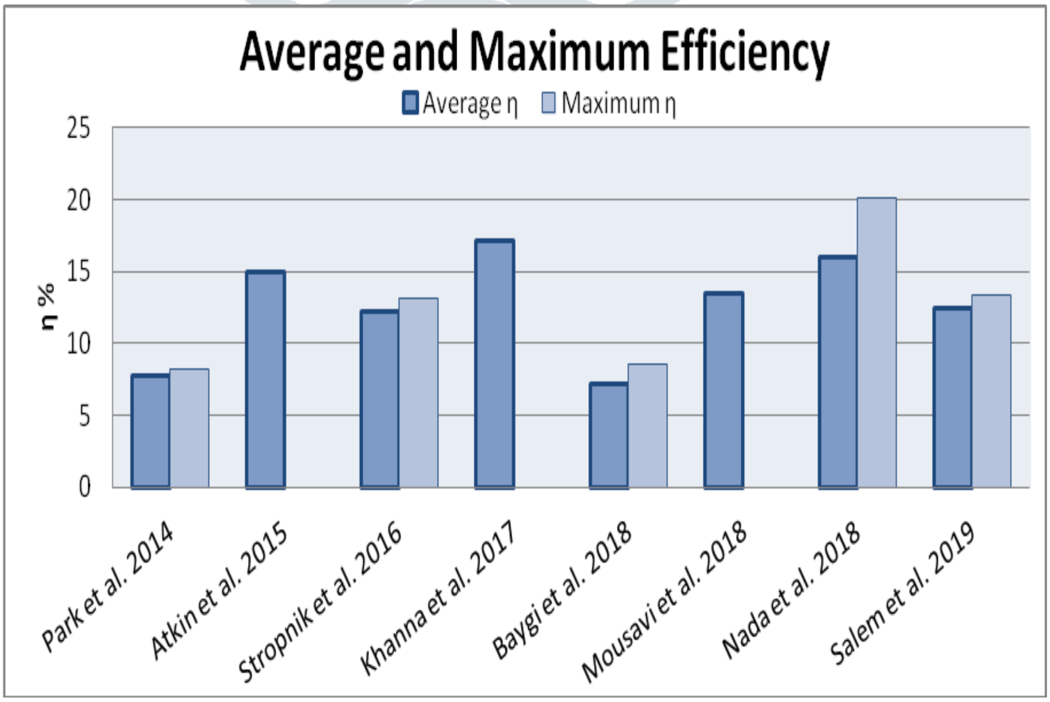

Figure: 11: Average and maximum efficiency achieved in different research work

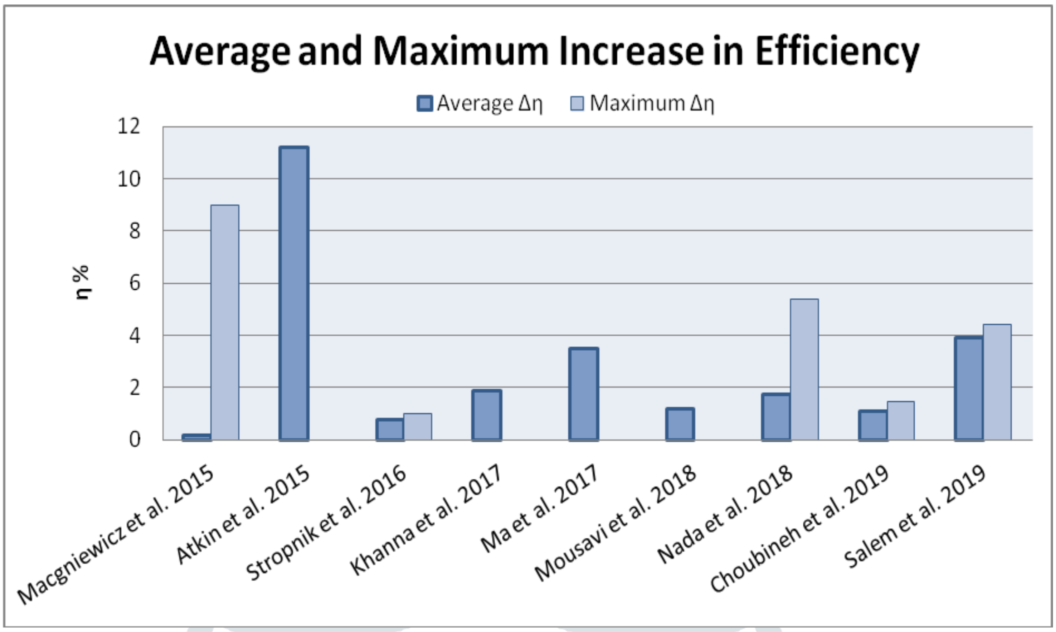

Figure: 12: Average and maximum efficiency increase achieved in different research work

Finally, based on application of PCM in different types of system, it is concluded that the thermal energy stored in PCM can be used to many preheating applications such as PV/Thermal, BIPV/PCM, CPV and PV/TEG/PCM system. In future, more research work could be carried out on PV degradation, impact on operation and maintenance, long term benefits and longevity of the phase change material cooling.

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