Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

Using Hybrid System Photovoltaic Thermal /Phase Change Materials / Thermoelectric (PVT/PCM/TE): A Review

[1*]Ammar Maythem, [2]Ali Najah Al-Shamani
[1,2]Department of Technical Power Mechanics, Technical Engineering College / Najaf, Al-Furat Al-Awsat Technical University
(ATU), Najaf, Iraq
[*]corresponding contact: ammar.faisil.ms.etcn @student.atu.edu.iq

Abstract
During the last few decades, PV/T technology has attracted a large number of researchers and experts. In this research, previous research on Photovoltaic thermal (PVT), phase-changing material (PCM) and thermoelectric (TE) are collected for the purpose of knowing the properties and efficiency of each part so that we can collect them in one system and study their efficiency and the factors that affect them for the purpose of studying the possibility of generating electricity at night.

Keywords: Electrical, Renewable energy, Thermal, night, PV-TE.

1-1 INTRODUCTION

The depletion of conventional fossil fuel supplies has reignited interest in the use of renewable energy resources. As a result, an alternative energy source must be determined in order to meet our energy needs while also preserving conventional fossil resources. Solar energy is a renewable form of energy that has the potential to meet a considerable portion of the world's energy consumption. The evolution of renewable energy sources [1], such as solar energy, has resulted in a source of energy that is both environmentally friendly and clean. Solar energy is also a viable solution for the impoverished and rural populations who are unable to access contemporary energy sources. Solar energy can be used to generate both thermal and electrical energy. These two energies are produced in different ways, but if hybrid collectors are utilized, they can be produced simultaneously. The photovoltaic-thermal (PVT) collector is a hybrid system that combines two types of collectors: thermal and solar. A PVT collector is a device that collects solar energy, converts it to thermal and electrical energy, and then transfers the thermal energy to the fluid flowing into the collector [2]. PV panel, insulation, and frame make up a PVT collector. As a result, a PVT collector is made up of one or more covers (glass sheets) or a transparent material that is placed over an absorbent plate and has air flowing around it. Use of heat transfer area through absorber using finned absorber, corrugated surfaces, and porous media is one technique to improve the collector's efficiency of PVT collector.

2-1 PHOTOVOLTAIC THERMAL (PVT)

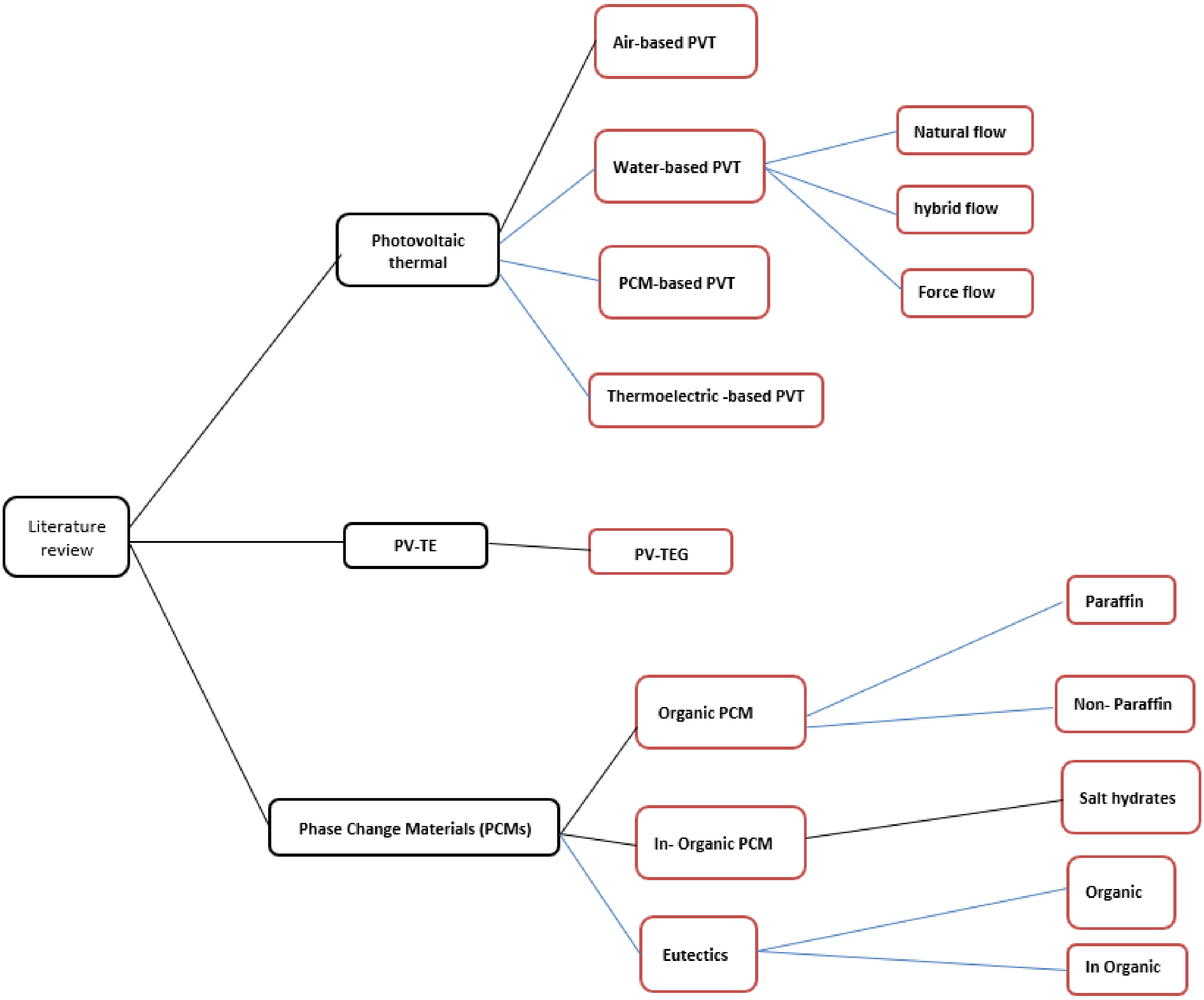
A solar thermal system consists of two parts: a solar module and a heat dissipation component that cools it. This technology has the ability to generate electrical and thermal energy at the same time. As a result, the PVT

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

system has better overall efficiency than the PV system. In the PVT system, improving the optical properties of the working fluid can improve efficiency. In other words, the better the performance of the PVT system, the higher the transmittance of visible light and solar infrared rays absorbed.

2-1-1 Air based PVT

Air is one of the most important natural factors affecting heat transfer, and air is relied on to cool cells. Some previous research will be discussed on how to take advantage of air cooling.



Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

C.S. Rajoria [2013] [3] In this research, an ecological economic analysis was conducted for two types of hybrid thermo-PV arrays (10.8 m and 2.16 m) and the temperature of the solar cells in the second case was lower, which results in 6.5% increase in electrical efficiency compared to the first case and the prices were compared on the basis of the total energy .

Mohd Yusof [2013] [4] The researcher has selected three different designs of heat exchanger which are v-groove, honeycomb and stainless steel wool for actual study to improve the overall performance of the photovoltaic/thermal base solar collector. The efficiency of the v-groov was 7.04% the efficiency of steel wool 6.88% and the efficiency of honeycomb 7.13%, which means that it is the best efficiency.

Y. Li [2015] [5] An overall evaluation of the operating performance of a solar photovoltaic air conditioning system that can be used as a stand-alone or grid-connected system was undertaken in this article, and the following factors were considered: heating in the winter and cooling in the summer The inverter efficiency in today's system is roughly 70–80%, which means increased energy loss in energy conversion in the system, which drives the development of air conditioners that run on direct current or inverters that are more efficient.

Rounis et al. [2016] [6] The researcher presented the findings of a numerical study comparing the performance of BEP/T systems in this study. The investigation was conducted on a chilly winter day, a hot summer day, and in various conditions. A multiple-inlet BIPV/T system was found to have up to 1% higher electrical efficiency, equal to 7% more power added to a 120 kW system's total output, and up to 24% higher thermal efficiency, while resulting in the lowest and most uniform PV temperatures.

Maysam Gholampour [2016] [7] In this study the performance of flat panel photovoltaic/thermal systems was evaluated using active, equivalent thermal, and voltage efficiencies in a rigorous experimental and theoretical analysis. In Kerman, Iran, this device was designed, built and tested outdoors. The system was conceptually designed and experimentally confirmed (maximum 9.13 % RMSE and minimum R-squared 0.92). Using the generated form.

Juwel Chandra [2016] [8] The researcher designed a BVT solar collector system with a single antenna and a number of thin rectangular fins to disperse heat. A fin system fused by a thin flat metal plate was employed to examine the performance (TFMS). The temperature parameters were then monitored and compared to a number of other methods and configurations. The highest thermal efficiency and PV efficiency were found to be around 56.19 % and 13.75 %, respectively.

Mohamed El Amine Slimani [2016][9] The researcher is looking at the possibilities of including the formation of a hybrid photo-thermal solar collector in an indirect way. A study of the solar drying system has been conducted. The air goes via a double corridor below and above the photovoltaic unit in the existing layout of a solar photovoltaic/thermal air collector. The results showed that the electrical, thermal, and total energy efficiencies were 10.5 percent, 70 percent, and 90 percent, respectively. The findings of this study also show how significant the influence of certain factors and operations is Conditions affecting the hybrid complex's performance .

Sumit Tiwari [2016] [10] Under forced mode, a hybrid photothermal (PVT) solar dryer is presented. For the Indian Institute of Technology's various climatic circumstances, various parameters were analyzed (Delhi, India). The temperature of the greenhouse, the outside air temperature, and the temperature of the cells were all calculated. With the assistance of a MATLAB 2013a software. The calculations of thermal energy, electric energy efficiency, whose value is 68.5 % , 13.85% were shown in the results.

Ahmad Fudholi [2018] [11] The performance of a PVT collector with -groove was calculated using a mathematical model and compared to experimental results. To solve the temperature equation for each PVT system element, a matrix inversion method was used. The results of the mathematical model are 94 percent accurate when compared to experimental data. For theoretical and experimental research, the average PVT energy efficiency is 65.52 percent and 66.73 percent, respectively. For theoretical and experimental research, the average PVT exergy efficiency is 12.91 percent and 12.66 percent, respectively. For solar radiations of 385 and 820 W/m2, the average IP is 173 and 369 W, respectively. Solar radiation has a minor impact on efficiency in energy analysis, while mass flow rate has a large impact. Solar radiation and mass flow rate have little effect on PVT exergy efficiency in exergy analysis.

S. Senthilraja [2020] [12] This study aims to identify the performance of the solar collector (thermal photovoltaic) hydrogen production system. The water splitting system is manufactured with the help of solar energy. The results were an increase in the energy output with an increase in the flow rate and the highest thermal efficiency 33.8% and electrical efficiency 8.5%.

2-1-2 Water based PVT

Air cooling fails to accommodate the temperature rise at the surface of PV cells at high working temperatures, resulting in a crucial loss in conversion efficiency. Cooling with liquid Coolant as heat provides a superior alternative to air cooling. extraction medium to keep the temperature of the machine at the correct level PV cells and a more efficient use of collected thermal energy

Ning Xu, Jie Ji [2016][13] This research looks at the characteristics of a high-concentration photovoltaic/thermal (HCPV/T) module with a point-focus Fresnel lens. Numerical approaches are used to create the module's electrical and thermal models. The thermal model is based on a two-dimensional steady-state heat transfer model, whereas the electrical model is based on the Shockley diode equation. The models take into account the effects of environmental conditions and coolant water. Irradiance, ambient temperature, wind speed, water temperature, and mass flow rate are the models' inputs. Electrical and thermal efficiency are the most common outputs. When the simulated and experimental data are compared, there is a lot of agreement. The effects of various parameters on module performance are thoroughly examined thanks to the verified models. The HCPV/T module has a 28 % electrical efficiency and a 60 % thermal efficiency, according to the results. Solar irradiation, not cell temperature, has the greatest impact on electrical efficiency. The thermal efficiency improves as irradiance, ambient temperature, and water mass flow rate rise. Increased water temperature and wind speed, on the other hand, will reduce thermal efficiency. In addition, the HCPV/T module can provide hot water up to 70 C without significantly reducing electrical efficiency.

Mawufemo Modjinou [2016][14] The authors devised and built an unique micro-channel heat pipe array using a crystalline silicon (c-Si) solar photovoltaic/thermal system (MHP-PV/T). To produce electrical and thermal energy concurrently, the proposed design configuration integrated c-Si solar cells with broad micro-channel heat pipes (MHP) that were filled with a prescribed amount of acetone as refrigerant under a vacuum condition in the same insulated frame. The MHP-PV/heat T's and mass transfer properties were examined using both numerical and experimental methods. MATLAB was also used to investigate the heat pipe's transient behavior and parametric heat transfer constraints. The thermal instantaneous efficiency and the lowered temperature parameter were shown to have a linear relationship. With a 70 W electrical power output, the greatest instantaneous efficiency was found to be 54.0 percent. The daily thermal and electrical efficiencies were 50.7 percent and 7.6 percent, respectively, according to the findings. The MHP's transient behavior displays a faster thermal reaction to heat input in the 48.8–49.2 °C temperature range and a slower response when the thermal diffusivity is decreased to 0.05 cm2 /s.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

Ruobing Liang [2017] [15] We proposed the creation of a numerical model of a photovoltaic thermal collector and calculated the PV module temperature, as well as thermal and electrical efficiency, in the current experimental investigation., the PV module temperature, and the absorber plate temperature of the PVT collectors in The intercept of the theoretical line is 3.6 % higher than the experimental line when the average temperature of the working fluid is equal to the ambient temperature, i.e. at maximum thermal efficiency, but the intercept of the el, experimental line is 5.8 % higher than the el, theoretical line. It means that the PVT collector's mathematical model is fairly accurate, as the theoretical and experimental results are nearly identical.

Long Hui [2017][16] In solar applications, heat pipe is a high-efficiency heat transfer device. An new building integrated heat pipe photovoltaic/thermal (BiHP-PVT) system was examined in this study, which provides electricity generation, services water pre-heating, and space air-conditioning load reduction. To begin, a dynamic model for a heat pipe photovoltaic/thermal (HP-PVT) system was created, and its numerical accuracy was verified through experimental validation. The BiHP-PVT system's annual performance was then assessed using a case study in Hong Kong based on average weather conditions. According to the simulation results, annual overall heat transfer through the external wall can be decreased to less than a fifth of what is currently done. Water heating efficiency and electricity generation efficiency are roughly 35% and 10%, respectively, on an annual basis. The entire electricity savings per unit façade surface area is 315 kW h/year. The BiHPPVT system offers more climate adaptability in addition to its outstanding energy performance.

Amira Lateef Abdullah [2020] [17]The researcher talked about the experimental data that is employed in a program that simulates internal experimental trials. It was compared to a standard white board without a cooling system using the Fifty system. The greatest electrical efficiency was 10%, with 500 W/m2, and the thermal efficiency was 66%, with 500 W/m2, and we finished with it. The lower the temperature and the higher the electrical efficiency, the higher the flow rate.

2-1-3 PCM-based PVT collectors

Changes in phase PCMs are substances capable of absorbing and releasing enormous amounts of energy as latent heat via a reversible isothermal process at a specific phase transition temperature. Due to its higher energy storage density within a smaller temperature range, latent heat storage with PCMs is better than sensible heat storage. Organic materials such as paraffin wax and fatty acids are classified as organics, inorganics such as salt hydrates are classified as inorganics, and eutectic mixtures of organic and inorganic PCMs are classified as eutectic mixtures of organic and inorganic PCMs are classified as eutectic mixtures of organic and inorganic .

Xiaojiao Yang [2017] [18] Photovoltaic/thermal (PV/T) panels are solar energy conversion devices that convert sunlight into heat and electricity. The use of phase change materials (PCMs) can effectively lower the temperature of a PV module, which is a key factor in a PV/T system's energy efficiency. The overall energy efficiency of the PV/T-PCM and PV/T systems were first compared in experiments. The thermal, electrical, and primary energy-saving efficiencies of the two systems were estimated by monitoring power output, backplane temperature, and tank water temperature. It was discovered that incorporating a PCM layer onto a PV/T panel successfully reduced heat loss to the ambient. When solar radiation is less intense or absent, the heat stored in the PCM can be discharged into the working fluid, extending the PCM's service life to the targeted building. The PV/T-PCM system's primary energy-saving efficiency rose by 14% in a controlled

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

indoor setting with a radiation of 800 W/m2 and a water flow rate of 0.15 m3 /h. These findings suggest that including a PCM into a PV/T system can significantly increase the system's energy efficiency.

Taher Maatallah [2019] [19] In India, a study of the PVT-PCM/Water system was carried out under atmospheric circumstances. Experiments comparing the overall performance of PV energy and PVT-PCM water-based panels were done. The PVT-PCM/water system was studied under various external environmental conditions, and it was discovered that PCM integration improved heat and mass transfer. When compared to a conventional PV panel, the electrical efficiency of the new PV panel is 26.87 percent and 40.59 percent, respectively, with a 17.33 percent increase in electrical efficiency. The water-based PVT-PCM system was discovered to have a payback time of roughly 6 years. It is 11.26 percent shorter than typical PV panels in terms of total power..

H. Fayaz [2019] [20] The researcher used the aluminum material for the thermal collector through a design to improve the heat transfer performance using the CAMSOL program. The experiment was conducted in free weather conditions and the electrical efficiency was improved by 6.2% and 4.8% PCM and electrical efficiency was obtained by 7.6 % 7.2% PVT-PCM experimentally and numerically .

Ali Naghdbishi [2020] [21] The researcher evaluated the electrical and thermal performance of the system (PVT\PCM) and compared the experimental results of the conventional photovoltaic unit (without thermal collector). The fluid increases the thermal energy efficiencies 23.5% and the electrical energy is 4.21% where there was a difference in temperature for the surrounding PVT surface and the sun.

2-1-4 Thermoelectric (PV-TE) hybrid systems

Thermoelectric (TE) modules are solid-state semiconductor devices that can convert heat energy to electrical energy or the other way around. Thermoelectric elements comprised of two different semiconductors, p- and n-type junctions, are coupled electrically in series and thermally in parallel to form a TE module.

Hamidreza Najaf [2013] [22] The Peltier effect has been offered as a new cooling mechanism.The photovoltaic cell itself investigates the cold energy refrigeration unit's safety and security. Hinged From estimating the temperatures within the system to calculating the required power refrigeration unit, the model was constructed and run using MATLAB. Low power consumption with an acceptable amount of electricity, resulting in the highest net output power under certain operating conditions. The results showed that more energy was generated by cooling, but only for the optimal current. The cooling impact was limited, with a temperature drop of little more than 8 degrees Celsius. Furthermore, it was discovered that System performance .

Dr.Vishal Verma [2013] [23] In a building-integrated system, TE coolers were used to help cool PV modules. To evaluate the performance improvement of the TE coolers on PV, a dynamic model of the BIPV/TE system was built, taking PV panel temperature into account. To improve heat transfer, the BIPV/TE system includes a TE module attached to the back of the PV module and a heat sink linked to the other side of the module. The results demonstrated that the BIPV/TE combined system can function at 53 °C PV module temperature without losing PV power, allowing the module to be cooled down by 10 °C, extending the PV module's life and hence its performance.

Jia Zhang [2020] [24] It's also been proven that efficient heat transmission can help PV-TE hybrid devices work better. By removing the upper ceramic plate of conventional TE devices, a variety of unique integrated PV-TE hybrid devices with improved heat transmission characteristics were created in this study. To prevent

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

an electrical connection between the PV cell and the TE device, an insulating layer was put on the back of the PV cell.

3- PCMs and the many sorts of PCMs

PCMs are organic or inorganic substances that absorb a lot of energy from the sun. During the phase shift process, thermal energy is stored in these materials. When the solid to liquid and liquid to solid phases change, these materials absorb and return thermal energy to the environment, respectively.

3-1 Types of PCMs

PCMs are classified into three categories: organic, inorganic and eutectic. the temperature ranges of the PCMs and their thermal conductivity are given

3-1-1 Organic PCM

Paraffins and non-Paraffins are the two types of organic materials. Corrosive materials include organic materials with homogenous melting, coreforming, and materials utilized as coatings. The organic PCMs used in building heating and cooling have a 20-32 C is the melting point.

Tingyu Wang 2017 [25] In this study, a new microcapsule-based phase change composite (PCC) with carbon network was designed to improve thermal conductivity and thermal stability. The theoretical ones were computed using the effective medium theory (ETM). Furthermore, an effective theoretical model was proposed and modified to estimate the thermal conductivity of such composites with various expanded graphite mass fractions (EG). As a result, with 24 wt. percent EG, the obvious denser carbon network structure of PCC was further confirmed, and the corresponding thermal conductivity was improved by up to 24 times that of virgin paraffin.

Xia Liu 2017 [26] In this research, graphene and exfoliated graphite sheet were mixed with paraffin to make composites in order to improve the thermal performance of paraffin in thermal energy storage. Following the dispersion stability tests, the microstructure, chemical structure, thermal conductivity analysis, differential scanning calorimeter (DSC), and thermogravimetric analyzer (TG) are used to characterize the microstructure, chemical structure, thermal conductivity, enthalpy, and stability of the materials, respectively. The results showed that using graphene or exfoliated graphite sheet, the thermal conductivity could be considerably enhanced. The heat conductivity of paraffin/graphene composite was higher than that of paraffin/exfoliated graphite sheet composite at the same mass fraction. In addition, when the mass fraction of graphene or exfoliated graphite sheet was adjusted between 0–2.0 wt. percent, the enthalpy of phase change material (PCM) composites increased at first, then decreased.

Min Li 2017 [27] Ultrasonic dispersion and liquid intercalation are used to create a composite phase change material (PCM) made up of organic montmorillonite (OMMT), paraffin, and grafted multi-walled nanotube (MWNT). Thermal characteristics (latent heat and thermal conductivity) were determined using differential scanning calorimetry (DSC) and a thermal constant analyzer after the microstructure of the composite PCM was studied to determine the phase distribution. Paraffin molecules are intercalated in the montmorillonite layers, and the grafted MWNTs are disseminated in the montmorillonite layers, according to the findings. The latent heat of the OMMT/paraffin/grafted MWNT composites is 47.1 J/g, and their thermal conductivity is 34 percent higher than that of the OMMT/paraffin composites and 65 percent higher than that of paraffin.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

Luo Jian-Feng 2015 [28] By heating and compressing a mixture of squama expanded graphite (EG) and paraffin, composite phase change materials (PCMs) with high anisotropic thermal conductivity can be made. Numerical and experimental studies are conducted on the phase-change heat transfer properties of composite paraffin/EG PCMs. The phase change heat transfer model is simplified as a one-dimensional monolayer in the numerical simulation, and the monolayer is heated by two stable heat fluxes on both sides. The PCM composite is placed in a metal box in the experiment, and the underside of the metal box is heated with an electric burner. A heat flow is discovered to be carried from the metal box's side wall to the cover board, which subsequently heats the composite PCMs. The numerical simulation confirms the experimental phenomenon. The experimental results reveal that the composite PCM's thermal conductivity is anisotropic, and that the temperature curves are deflexed and scattered throughout the apparent heat transfer process of the PCMs in liquid state. The numerical findings show that convection between the environment fluid and the aluminum cover board causes the above phenomena of deflexed and scattered temperature curves. With each other, the correctness of both the experimental and numerical methods is checked.

X. Xiao [2013] [29] The researcher used paraffin in the latent thermal energy storage system LTIS to store solar energy. PCM was measured by the transient level heat source technique TBS in addition to the receiver condition. The thermal behaviors were analyzed using a differential scanning meter (DSC) and it was found that the surface porosity, which was obtained from the images, was within the limits of 90 – 94% , while that The porosity of paraffin was estimated at 97%, which means that the heat conductivity improved by using PCM significantly.

Peizhao Lv [2016] [30] In this research, the researcher used different particle sizes of kaolin to incorporate paraffin through the vacuum saturated nation method. The results showed that the paraffin/kaolin compound with the largest particle size of kaolin K4 has the highest thermal conductivity of 0.413 W/m. K at 20°C. Among the various compounds, the latent heat capacity of paraffin is 119.49 (J/g) and the temperature of change is 62° C. Storage clearance was studied.

Yuang Zhang [2016] [31] This research focuses on how to obtain new phase change materials with high enthalpy change and stable shape properties from the simple compound of paraffin. The transition enthalpy of the material can reach 220 J/G with a weight content of 74% paraffin. Put it at a temperature of 100 degrees Celsius.

Zongtao LI [2017] [32] In this paper, discuss the use of energy change materials (PCM) for cooling high density electronics, where change material (CPSF/B-FSPCM) was prepared by incorporating paraffin in (CBSF) using vacuum perfusion and the results showed An increase in the porosity from 47% to 74% and the thermal conductivity and latent heat changed from (17.18) (W/m. K) and (33.6) to (153.3) and (11.61) (KJ/kg), respectively. The temperature ranged between 93°C and 57°C, thus reducing the highest temperature by 16. 3°C proves this material has high potential for reliable thermal management.

Qinrong Sun [2017] [33] The researcher has developed a direct-number hybrid (PEG/CMPs) composite ((PEG) methodology with high thermal conductivity for advanced thermal energy storage. The results prove that the thermal conductivity of the compound (PEG/CMPs) increases 65 % and the temperature of supercooling occurs at 6.5 °C during storage/cooling energy.

Weixiong Wu [2019] [34] In this research, a flexible, stable, thermally shaped PCM compound consisting of PA and OBC and EG is applied. The results presented in this work indicate that the prepared procession PCM has a potential application for heat and has the potential for energy storage and thermal management. There are three main factors that affect heating and cooling processes: thermal conductivity, thermal conductivity, natural convection, and latent heat absorption.

Mohammd S .Yousef [2019] [35] The researcher studied the improvement of heat transfer properties in the PCM storage unit applied to the static solar energy system. Using cylindrical pin fins integrated in PCM, three cases were done, the first without PCM, the second with PCM, and the third with a solar stator with heat sink for the track fins built into PCM. The results for the distillates were 17% and 7% higher than the first case and the case second in a row.

Junbing Shi [2020] [36] The stable compound phase change material (FSCBCM) was prepared by absorbing (PEG) in this modified attapulgite (N-ATP) pore structure and thermal energy storage and leakage performance and then investigated in this and the results showed that the latent heat of (PEG/N-ATP FSCPCM) increased At 87% of (PEG/attapulgite) it was close to latent heat. The heat strength was better.

Ruchira N. Wijesena [2020] [37] This paper presents a new strategy for shape stabilization of liquid and solid phase change materials. Where the (PCM) materials were prepared based on the use of chitin nanofibers (CNFs) and the results indicated the stability of the shape of the compounds at 88% transmittance and it was seen that the (CNF) phase had an effect on the heat properties of the material (PEG-CNF) .

3-1-2 Inorganic PCMs

Salt and metal hydrates are two types of inorganic compounds. In comparison to organic chemicals, inorganic compounds have a high latent heat per mass and volume, are cost-effective, affordable, and non-flammable. However, there are certain difficulties with these materials, such as undercooling and separation (which affect the properties of the phase change). The following is the general principle of salt hydrates. Dehydration is the solid-liquid phase transition of salt hydrates. Salt hydrates are a particularly important class of PCMs with the following properties: Low latent heat per volume, but high latent heat per volume low volume changes during melting, strong thermal conductivity Toxicology, homogeneous melting, and the density differential with water are all factors to consider. (as a result of which it is dumped at the end of the case)

Johannes P. Kotze [2013] [38] The study identifies AlSi12, a eutectic aluminum–silicon alloy, as a good candidate PCM. The melting temperature of AlSi12 is 577 degrees Celsius, which is higher than the operating temperature of most heat transfer fluids (HTFs). In a storage system that uses metallic PCMs, the eutectic sodium–potassium alloy (NaK) is identified as the optimal HTF. The TES-unit and steam generator are combined into one unit in this idea. Because NaK reacts strongly with water, AlSi12's high heat conductivity is used to build a safe idea. A steam power-generating cycle was considered as a proof of concept since it is well-suited for a TES using AlSi12 as the PCM. With 15 hours of storage, the plant was expected to deliver 100 MW. The proposal is viable, according to thermodynamic and heat transfer analyses. The cost of AlSi12 storage material is 14.7 US$ per kWh of thermal energy storage, according to the research.

W.Q. Li [2014] [39] The researcher deals with the thermal system of high energy (lithium-ion battery packs) using a sandwich structure combined with a copper foam impregnated with paraffin that was designed and experimentally realized, and the results showed that the temperature cannot be safe depending on the natural load while when using (PCM) maintains a temperature inside The battery improves the effectiveness of thermal conductivity, at a rate of 1 to 3 degrees Celsius.

Peng Zhang [2015] [40] In this study, the heating is experimentally and numerically examined for the paraffin/copper-foam composite (PCM) and the applicability of two degrees is studied. The energy equation

is validated by comparing the experimental and numerical results of the liquid-solid. The researcher recommended that the modeling method be considered. Further investigation of heat transfer can be applied .
Y.B. Tao [2015] [41]The study discusses the possibility of enhancing the thermal performance of PCM salts of high-temperature carbonate, where four types of carbon nanomaterials were selected, the first is a nano-material with a specific surface area such as graphene, and the specific heat can be improved up to 18.57%, and the second is a nano-material with a vertical structure. The thermal conductivity was calculated. Up to 56.98 %, the third focuses on CPCM melting temperature transfer and enthalpy melting, and the fourth is nanomaterials additives that have a limited effect. The results showed that the second substance (SWCNT) is the optimal additive to enhance the thermal properties.
Abid Hussain [2016] [42] An effective thermal management system for high-grade lithium-ion batteries using a new compound ((nickel foam-paraffin wax) was studied and the results were compared for two cases, the first with natural air cooling and the second with PCM materials. The effect of (PCM) is high to reduce the temperature, as it showed a decrease in temperature by 31% compared to the first case, with an average of 2 degrees Celsius.
Chuan Li [2019] [43]This research is concerned with the thermal performance of thermal energy storage for the high temperature packed layer (TES) containing carbonate salt based materials (CPCMS) made of eutectic materials. Extensive modeling is carried out under different conditions to know the effects of different factors such as radiant heat transfer and mass loading (TCEM) temperature, operating conditions and fluid transfer (HTF) on the performance of the system. The results indicate a decrease in charging and discharging operations to 30.3% and 29.2 %, and thus in general improving the rates of charging and discharging.
Angela C. Evers [2020] [44] The researcher studied, developed and tested the insulation of cellulose reinforced with PCM for use in the walls of the frame, where he used two types of PCMs, paraffin-based and hydrated salt-based using two concentrations, the first 10% and the second 20% in 1.22 m of the frame cavity. The results showed that the PCM paraffin-reinforced insulation reduces the average peak temperature by up to 9.2% .

4-1 TE (thermal electric device)

Using a thermoelectric generator is one promising option (TEG). Gas-free emissions, solid-state operation, maintenance-free operation without moving parts or chemical reactions, wide scalability, a long life period of reliable operation, and minimal environmental impact are just some of the benefits of thermoelectric (TE) devices. As a result, combining PV and TE to create additional electricity could be considered. When a photovoltaic module and a solar thermoelectric generator are combined, photons outside the narrow absorption wavelength range of a specific solar cell can be directed to the TE modules, which create energy via the thermoelectric effect. This would boost energy conversion efficiency while lowering heat dissipation by the PV module.
Ofer Beeri 2015 [45] A hybrid PV-TEG demonstrator based on CMJ architecture was empirically and conceptually tested in this study. The hybrid system's efficiency reached 32 percent using widely available MJ PV cells and TEG. With increasing sun concentration and temperature, the direct electrical contribution of the TEG to the hybrid system's efficiency increases, reaching a maximum of nearly 20% for a solar concentration of 300. When employing more modern PV cells and TE materials, further greater efficiency and power values are envisaged, with a real possibility of exceeding 50% total efficiency.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

Yun Da 2015 [46] In this research, it was proposed to use the full spectrum of solar energy in hybrid systems (PV-TE). The results indicate that the lower concentration ratio is more suitable for the hybrid (PV-TE) in both terrestrial and space applications, and the efficiency increased by 18.51%.

Ravita Lamba 2016 [47] In this research, results were discussed that provide a basis for improving the practical performance of the hybrid system (CPV–TEG) using the MATALB program, and the efficiency was improved by 5.8% by relying on the optimal concentration.

Rezania 2016 [48] A model of thermal photovoltaic hybrid panels (PV-TEG) was simplified, and the results showed that the radiant heat loss from the front surface and the convective heat loss due to wind speed are among the most important parameters in the performance of the hybrid panel, and (TEG) plays only a small role in energy and efficiency improved by 16.6% .

Wei Zhu 2016 [49] The conductor ensures a significant temperature difference on both sides of the TE module. Because of the extra The designed PV-TE hybrid system accomplishes electrical generation attributed to thermoelectric generator. In the outside test, the peak efficiency was 23%, which is 25% higher than PV (photovoltaic) cells. Furthermore, the thermoelectric generator delivers an additional 648 J of electrical energy even when it is not in use.

M. Benghanem 2016 [50] We conclude in this work that combining the thermoelectric device with the solar cells to produce a hybrid system will boost the efficiency of the solar cells.

The thermoelectric module is attached to the back side of the solar cells and is used to cool them. The effectiveness of solar cells increases by 0.5 percent every degree Celsius decrease in temperature as a result of this finding. The proposed hybrid PV/TEM system for PV applications in hot areas provides good performance at a cost of roughly 6% of the total cost of traditional PV systems .

Dianhong Li 2017 [51] The researcher proposed a one-dimensional model to analyze the characteristics of photovoltaic cells (PV-TE) and the system (exergy and energy) was analyzed. The results show that the high concentration ratio used in the hybrid system (PV-TE) enhances the efficiency of the system, and when using type (CIGS) it increased by 21.6 % and type (Thin flim sillcon) increased by 13.1%.

Jin Zhang 2017 [52] The resulting electrical energy efficiency of the hybrid system (PV-TE) is calculated and the energy losses resulting from the inability to reverse heat transfer, which are considered small, are calculated. The system is improved by controlling the water tools in the cooling blocks, and using the (PCM) system, and the results showed an increase in efficiency, reaching 19.1%.

Ershuai Yin 2017 [53] This research discussed the thermal concentration ratio, where the effect of radiation change with time was neglected. The results showed that the ((PV-TE) couplin
enables the system to obtain the highest average efficiency for one day by improving the concentration ratio. The efficiency ratio increased from 15.97 % to 16.75% .

R. Bjørk 2018 [54]The researcher made a comparison between the independent PV of type (c-Si, a-Si, CIGS and CdTe) and the PV compound on it (TEG), where the photovoltaic efficiency was calculated by depending on the photovoltaic temperature and the efficiency value is approximately 34% .

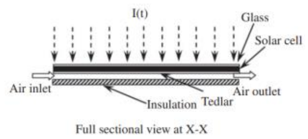
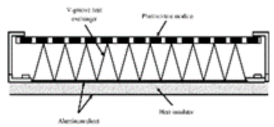
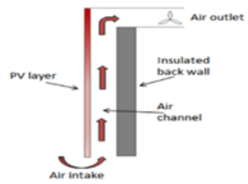
Guiqiang Li 2018 [55] This study, which relied on the internal electrical resistances for (TE), provided a knowledge of the maximum efficiency for (PV-TE) and the study was carried out using a cell (c-Si) and the results indicated that the highest resistance obtained for cell (c-Si) is 0.75 ohms and for cell (GaAs) is 2 ohms and the efficiency was 11.6%.

Yi-Peng Zhou 2020 [56] The researcher manufactured a device consisting of a coupling of several devices for the purpose of analyzing the advantages and disadvantages of the full solar spectrum. The comparison was

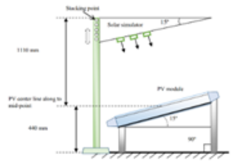
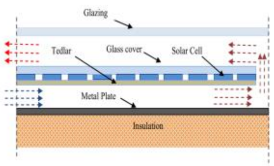
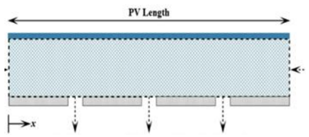
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

made between the independent (PV) system and the (PV-TE) system, where experiments were conducted in the same surrounding atmospheric conditions due to the fluctuation of solar energy, where on the sunny day the strength of the system (PV-TE/T) increased by 11.6% for the tandem (PV-TE) system, and this percentage increased to 36.6% .

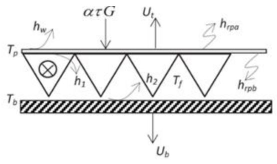
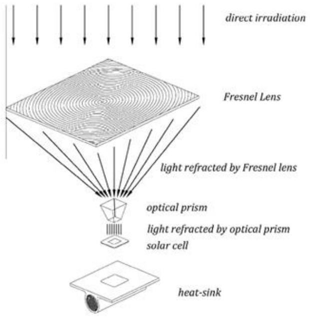
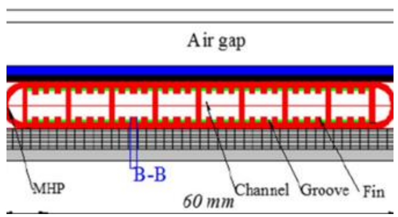
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

Summary of some Photovoltaic thermal (PVT) research					
NO	**Author (s) and work year / place**	**Electrical efficiency%**	**Thermal efficiency%**	**Capture**	**Notes**
			Air based PVT		
1	**C.S. Rajoria (2013)** [3] / **[INDEA]**	6.5%	--------------		an ecological economic analysis was conducted for two types of hybrid thermal-PV arrays(10.8 m and 2.16 m).
2	**Mohd Yusof (2013)** [4]/ **Malaysiana**	V-groove is 7.04% stainless steel wool is 6.88% honeycomb is 7.13%	V-groove is 71% stainless steel wool is 86% honeycomb is 87%		the efficiency of honeycomb 7.13%, which means that it is the best efficiency.
3	**Y. Li (2015)** [5]/ **China**	12.4%	77.7%	--------------	The inverter efficiency in today's system is roughly 70–80%, which means increased energy
4	**.Rounis et al. [2016] [6] / Montreal**	7%	24%		A multiple-inlet BIPV/T system was found to have up to 1% higher electrical efficiency.

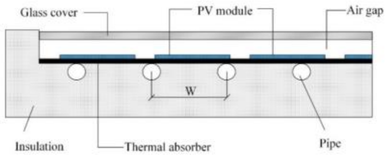
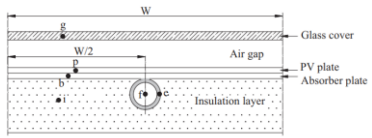
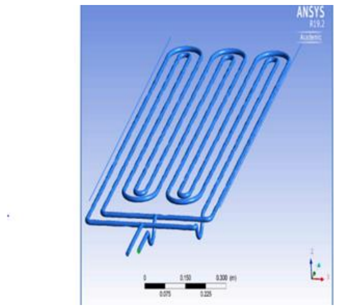
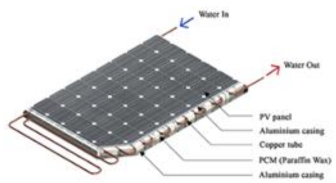
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

5	**Juwel Chandra [2016] [8]/ Malaysia**	13.75 %	56.19 %		A fin system fused by a thin flat metal plate was employed to examine the performance (TFMS)
6	**Mohamed El Amine Slimani [2016] [9]/ Hungary**	10.5%	70%		The numerical results show the energy effectiveness of this hybrid collector configuration and particularly its interesting use in an indirect solar
7	**Sumit Tiwari (2016) [10]/ India**	13.85%	68.5%		As the temperature of the photovoltaic module increases, its efficiency decreases.
8	**Maysam Gholampour [2016] [7]/ Iran**	9.13%	------		The system was conceptually designed and experimentally confirmed (maximum 9.13 % RMSE and minimum R-squared 0.92)

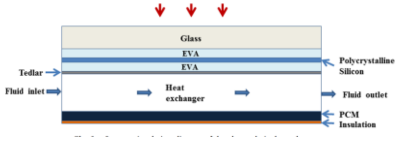
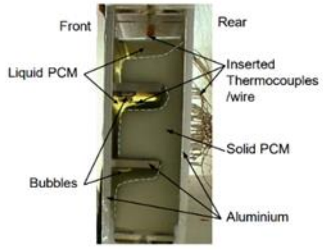
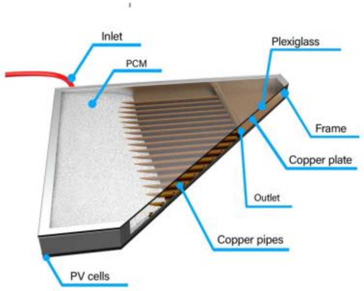
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

9	**Ahmad Fudholi [2018][11] / Malaysia**	12.91%	65.52%		mprovement potential under solar radiations of 385 and 820 W/m2 and mass flow rates between 0.007 and 0.07 kg/
10	**Senthilraja [2020] [12]/ India**	8.5%.	33.8%	--------------	study aims to identify the performance of the solar collector (thermal photovoltaic) hydrogen production system
Water based PVT					
11	**Ning Xu, Jie Ji [2016]** [13] **/ China**	28 %	60%		the HCPV/T module can provide hot water up to 70 C without significantly reducing electrical efficiency
12	**Mawufemo Modjinou (2016)**[14]/ **China**	7.6%	50.7%		The MHP's transient behavior displays a faster thermal reaction to heat input in the 48.8–49.2 °C temperature range

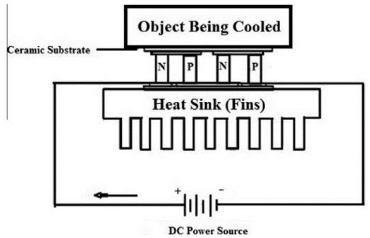
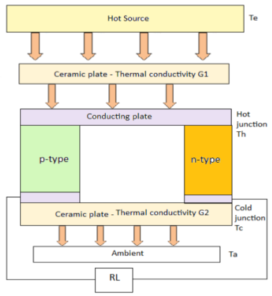
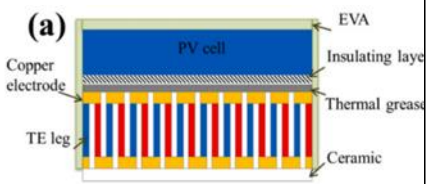
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

13	**Ruobing Liang (2017)** [15]/ **China**	14.25%	62%		Tpv increases from 50.65 to 71.25 when the °C Ta rises from 0 to 30 . °C
14	**Long Hui [2017]** [16] **/ China**	10%	35%		The entire electricity savings per unit façade surface area is 315 kW h/year
15	**Amira Lateef Abdullah [2020][17]/ Malaysia**	10%	66%		The increasing mass flow rate lead to reduces the cell temperature and increases the electrical efficiency
PCM-based PVT collectors					
16	**Taher Maatallah [2019]** [18]/ **India**	26.87%	40.59%		Experiments comparing the overall performance of PV energy and PVT-PCM water-based panels were done

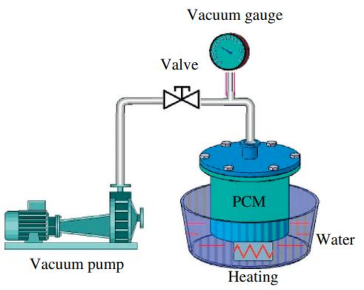
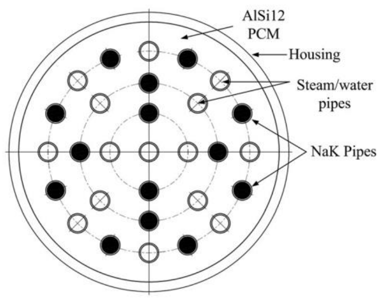
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

17	**H. Fayaz [2019]** [19] / **Malaysia**	6.2% 7.6%	---------		The researcher used the aluminum material for the thermal collector
18	**M. J. Huang [2011]** [20] / **Ireland**	---------	---------		The average temperature 19 °C
19	**Ali Naghdbishi [2020]** [21] / **Iran**	4.21%	23.5%		compared the experimental results of the conventional photovoltaic unit (without thermal collector)
Thermoelectric (PV-TE) hybrid systems					

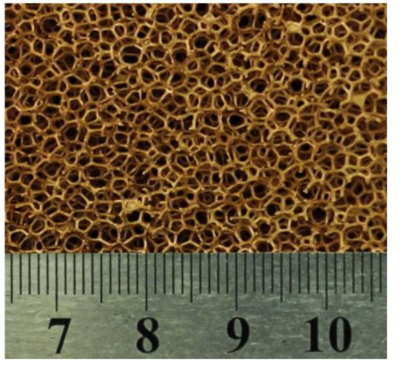
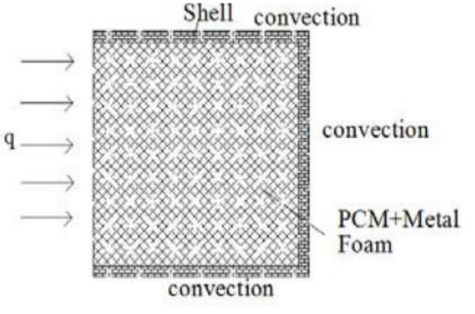
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

20	**Hamidreza Najaf [2013]** [22]	----------	----------		temperature drop of little more than 8 °C
21	**Dr.Vishal Verma [2013]** [23]/ **India**	----------	-----------		allowing the module to be cooled down by 10 °C
22	**Jia Zhang [2020]** [24]/**China**	----------	----------		. This shows that PTE of the integrated hybrid device S2b is increased by 61.66% relative to that of S1b when 15 C cooling (C4)

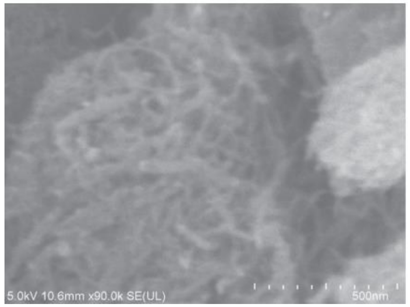
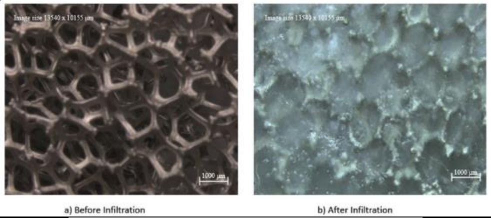
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

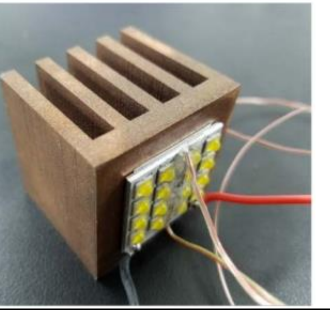
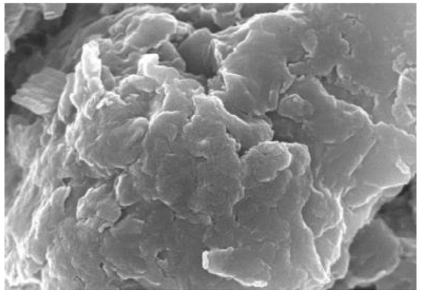
PCM (Phase Change Material)				
No	**Author (s) and work year / place**	**PCM used**	**Capture**	**Note**
23	**X. Xiao [2013]** [29] **/China**	Paraffin wax		The porosity of paraffin was estimated at 97%, which means that the heat conductivity improved by using PCM significantly.
24	**Johannes P. Kotze [2013]** [38] **/ South Africa**	AlSi12		With 15 hours of storage, the plant was expected to deliver 100 MW

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

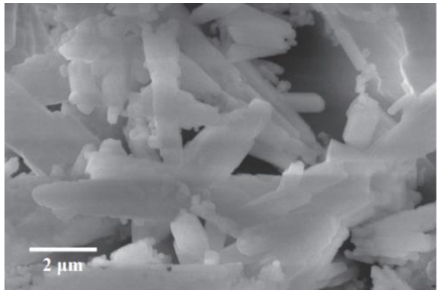
25	**W.Q. Li [2014]** [39]/ **China**	foam-paraffin		the battery surface temperature increased with an increase in the porosity and the pore density of the metal foam.
26	**Luo Jian-Feng [2015]** [28]/ **China**	paraffin		
27	**Peng Zhang [2015]** [40] / **China**	paraffin/copper		results indicates that heat transfer characteristics can be well depicted by two-temperature energy equation

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

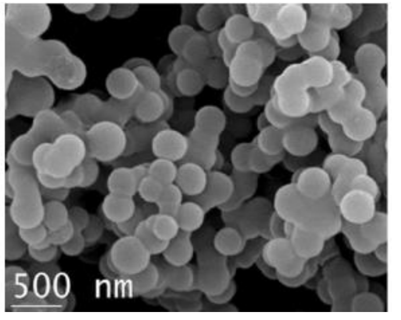
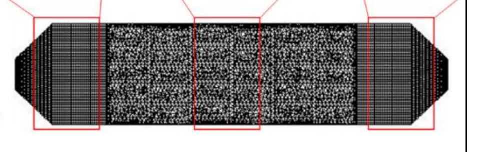
28	**Y.B. Tao [2015]** [41] / **China**	carbonate salt		The thermal conductivity was calculated. Up to 56.98 %.
29	**Abid Hussain [2016]** [42]/ **Hong Kong**	nickel foam-paraffin		showed a decrease in temperature by 31% compared to the first case, with an average of 2 °C
30	**Yuang Zhang [2016]** [31] / **China**	Paraffin wax		The transition enthalpy of the material can reach 220 J/G with a weight content of 74% paraffin. Put it at a temperature of 100 °C

31	**Peizhao Lv [2016]** [30]/ **China**	paraffin/kaolin		the temperature of change is 62° C
32	**Zongtao LI [2017]** [32] / **China**	paraffin		thus reducing the highest temperature by 16. 3°C proves this material has high potential for reliable thermal management.
33	**Min Li [2017]** [27]/ **China**	paraffin		the thermal conductivity of the OMMT/paraffin/grafted MWNT composites is 34% higher than that of the OMMT/paraffin composites and 65% higher than that of paraffin .

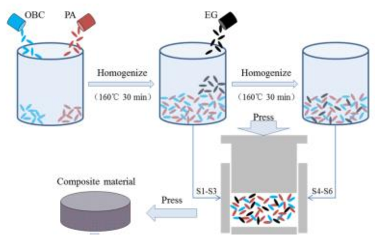
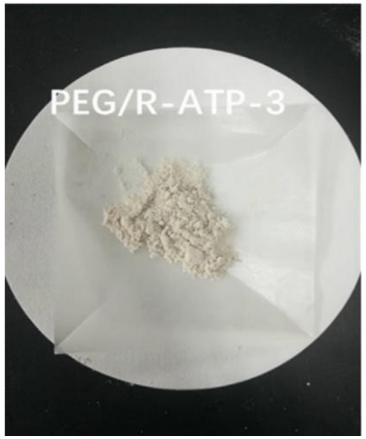
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

34	**Xia Liu [2017]** [26]/ **China**	paraffin		thermal conductivity of paraffin/graphene composite was greater than that of paraffin/exfoliated graphite sheet compose.
35	**Tingyu Wang 2017** [25]/ **China**	paraffin		thermal conductivity was increased by as much as 24 times of the pristine paraffin.

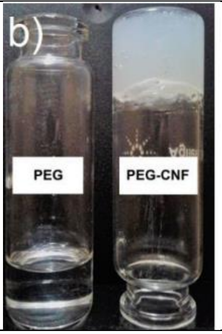
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

36	**Qinrong Sun [2017]** [33]/ **China**	polyethylene glycol (PEG)		The results prove that the thermal conductivity of the compound (PEG/CMPs) increases 65 % and the temperature of supercooling occurs at 6.5 °C during storage/cooling energy.
37	**Mohammd S .Yousef [2019]** [35]/ **Egypt**	Paraffin wax		(case 2) negatively reduces the daylight productivity by 7% with an enhancement in the overnight (case 1). The total daily accumulated yield of freshwater of (case 3) was greater than that of case 1 and case 2 by 17% and 7 %, respectively. Also,
38	**Chuan Li [2019]** [43]/ **China**	carbonate salt		The results indicate a decrease in charging and discharging operations to 30.3% and 29.2 %

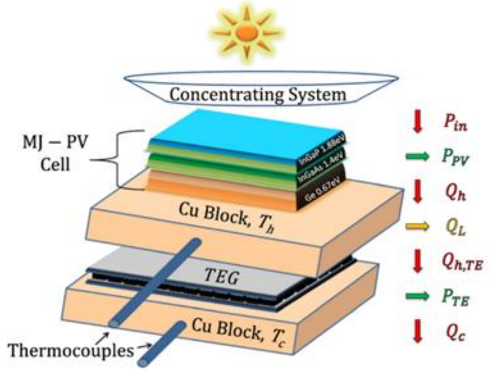
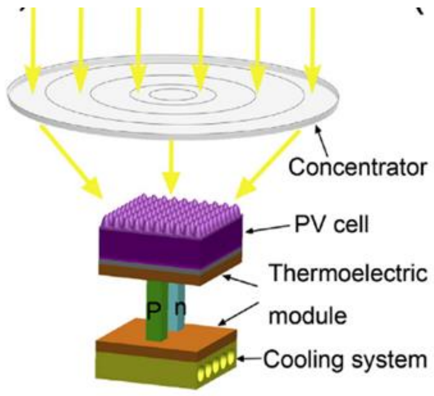
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

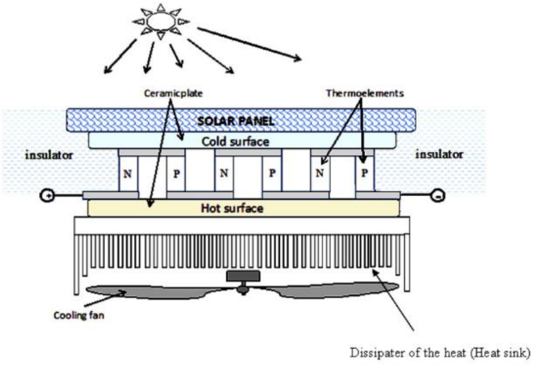
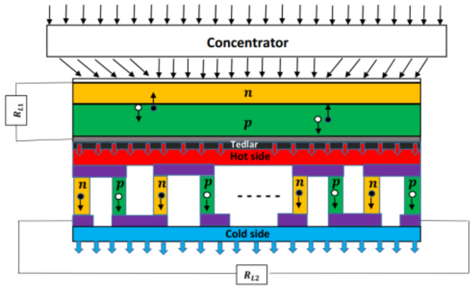
39	**Weixiong Wu [2019]** [34] / **China**	---------------		In this research, a flexible, stable, thermally shaped PCM compound consisting of PA and OBC and EG is applied
40	**Junbing Shi [2020]** [36]/ **China**	polyethylene glycol (PEG)		the latent heat of (PEG/N-ATP FSCPCM) increased At 87% of (PEG/attapulgite) it was close to latent heat.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

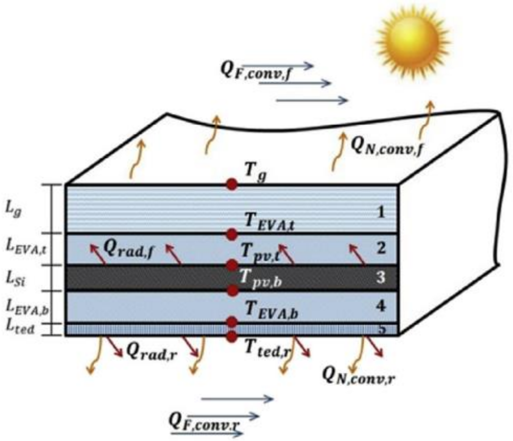
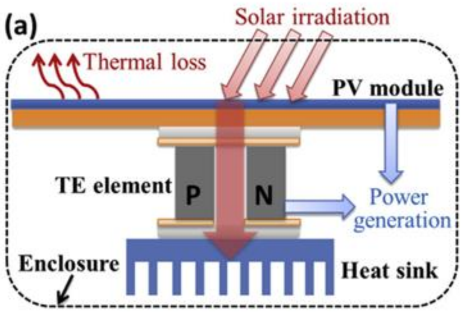
41	**Ruchira N. Wijesena [2020]** [37]/ **Colombo**	polyethylene glycol (PEG)		the stability of the shape of the compounds at 88% transmittance.
42	**Angela C. Evers [2020]** [42]/ **USA**	hydrated salt		The results showed that the PCM paraffin-reinforced insulation reduces the average peak temperature by up to 9.2%

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

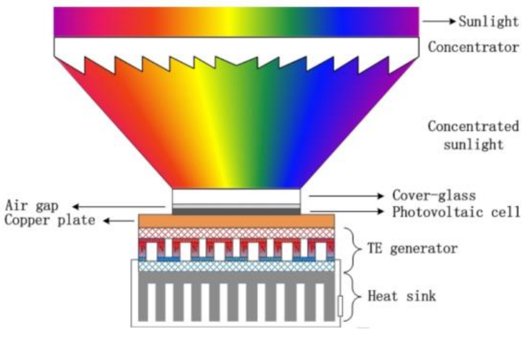
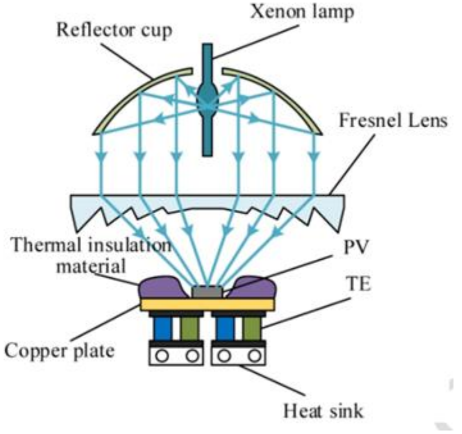
TE (thermal electric device)				
No	**Author (s) and work year / place**	**efficiency**	**Capture**	**Note**
43	**Ofer Beeri 2015** [45]/ **China**	32%		with a real possibility of exceeding 50% total efficiency.
44	**Yun Da 2015** [46]/ **China**	18.51%		to use the full spectrum of solar energy in hybrid systems (PV-TE).

45	**M. Benghanem 2016** [50]/ **Saudi Arabia**	6%		The effectiveness of solar cells increases by 0.5 percent every degree Celsius decrease in temperature.
46	**Ravita Lamba 2016** [47]/ **India**	5.8%		the hybrid system (CPV–TEG) using the MATALB program.

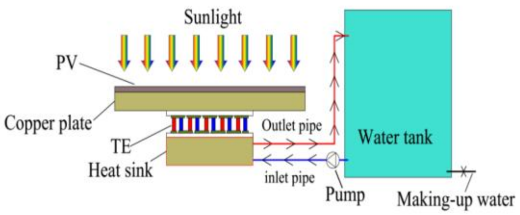
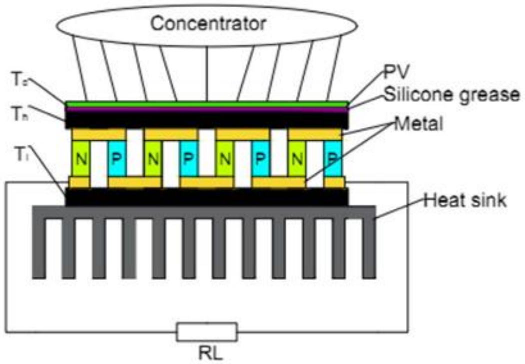
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

47	**Rezania 2016 [10]** [48] / **Denmark**	16.6%		A model of thermal photovoltaic hybrid panels (PV-TEG) was simplified.
48	**Wei Zhu 2016 [60]** [49]/ **China**	25%		the thermoelectric generator delivers an additional 648 J of electrical energy even when it is not in use.

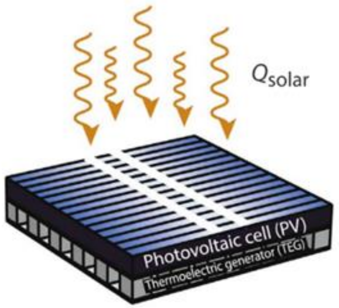
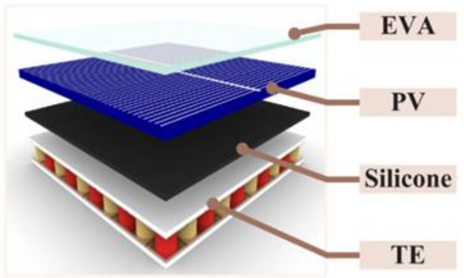
Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

49	**Dianhong Li 2017 [6]** [49]/ **China**	21.6 % 13.1%		using type (CIGS) it increased by 21.6 % and type (Thin flim sillcon) increased by 13.1%.
50	**Jin Zhang 2017 [7]]** [52]/ **China**	19.1%		The system is improved by controlling the water tools in the cooling blocks

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

51	**Ershuai Yin 2017 [4]** 51]/ **China**	16.75%		The efficiency ratio increased from 15.97 % to 16.75% .
52	**Guiqiang Li 2018 [5]** [55] **/ China**	11.6%.		the highest resistance obtained for cell (c-Si) is 0.75 ohms and for cell (GaAs) is 2 ohms .

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 1365 - 1400
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 31 May 2022

53	**R. Bjørk 2018 [3** [54]**]/ Denmark**	34%		PV of type (c-Si, a-Si, CIGS and CdTe).
54	**Yi-Peng Zhou 2020 [11]** [56]/ **China**	36.6%		system (PV-TE/T) increased by 11.6% for the tandem (PV-TE) system, and this percentage increased to 36.6%.

5. CONCLUSIONS

The state-of-the-art of PV-PCM-TE systems is examined in this study, with a focus on technical overview and material selection. Due to the latent heat storage capability of PCMs, attaching PCMs to the rear of a PV panel adds external cooling power to the PV. According to the energy balance study, the high thermal conductivity and energy density of PCMs, as well as good thermal contact between the PV panel and the PCMs, are critical for better system performance.. Even while new technologies based on PV-PCM systems, such as the PV/T-PCM, provide new techniques, it appears that extensive theoretical study in PV-PCM systems in different aspects has been undertaken. However, the path to practical application is still far away, with several difficulties unresolved.

One of the most significant challenges might be choosing the right type of phase transition material. Paraffin, slat hydrates, and eutectics all appear to be promising options, but each has its own set of advantages and disadvantages, including low heat conductivity and liquid leakage. Pure paraffin in a cuboid container with internal fins or nanoparticles for thermal conductivity increase is still the most popular method. Almost all research on PCMs focuses solely on the melting process, ignoring the solidification phase, resulting in erroneous conclusions. Furthermore, while determining the appropriate phase transition temperature for PCMs, both the PV temperature and the ambient temperature should be taken into account, guaranteeing the highest melting fraction during the day and the maximum solidification fraction at night.

References

[1] T. Eprijournal, "07 Alternative energy sources (solar energy)," *Fuel Energy Abstr.*, no. November, pp. 2000–2000, 2000.

[2] A. N. Al-Shamani *et al.*, "Nanofluids for improved efficiency in cooling solar collectors - A review," *Renew. Sustain. Energy Rev.*, vol. 38, pp. 348–367, 2014, doi: 10.1016/j.rser.2014.05.041.

[3] C. S. Rajoria, S. Agrawal, and G. N. Tiwari, "Exergetic and enviroeconomic analysis of novel hybrid PVT array," *Sol. Energy*, vol. 88, pp. 110–119, 2013, doi: 10.1016/j.solener.2012.11.018.

[4] M. Y. H. Othman, F. Hussain, K. Sopian, B. Yatim, and H. Ruslan, "Performance study of air-based photovoltaic-thermal (PV/T) collector with different designs of heat exchanger," *Sains Malaysiana*, vol. 42, no. 9, pp. 1319–1325, 2013.

[5] Y. Li, G. Zhang, G. Z. Lv, A. N. Zhang, and R. Z. Wang, "Performance study of a solar photovoltaic air conditioner in the hot summer and cold winter zone," *Sol. Energy*, vol. 117, pp. 167–179, 2015, doi: 10.1016/j.solener.2015.04.015.

[6] E. D. Rounis, A. K. Athienitis, and T. Stathopoulos, "Multiple-inlet Building Integrated Photovoltaic/Thermal system modelling under varying wind and temperature conditions," *Sol. Energy*, vol. 139, no. 1, pp. 157–170, 2016, doi: 10.1016/j.solener.2016.09.023.

[7] M. Gholampour and M. Ameri, "Energy and exergy analyses of Photovoltaic/Thermal flat transpired collectors: Experimental and theoretical study," *Appl. Energy*, vol. 164, pp. 837–856, 2016, doi: 10.1016/j.apenergy.2015.12.042.

[8] J. C. Mojumder, W. T. Chong, H. C. Ong, K. Y. Leong, and Abdullah-Al-Mamoon, "An experimental investigation on performance analysis of air type photovoltaic thermal collector system integrated with cooling fins design," *Energy Build.*, vol. 130, pp. 272–285, 2016, doi: 10.1016/j.enbuild.2016.08.040.

[9] R. Sellami and M. E. Slimani, "Study and modeling of energy performance of a hybrid photovoltaic / thermal solar collector : Configuration suitab ..."

[10] S. Tiwari and G. N. Tiwari, "Exergoeconomic analysis of photovoltaic-thermal (PVT) mixed mode greenhouse solar dryer," *Energy*, vol. 114, pp. 155–164, 2016, doi: 10.1016/j.energy.2016.07.132.

[11] A. Fudholi *et al.*, "Energy and exergy analyses of photovoltaic thermal collector with ∇-groove," *Sol. Energy*, vol. 159, no. November 2016, pp. 742–750, 2018, doi: 10.1016/j.solener.2017.11.056.

[12] S. Senthilraja, R. Gangadevi, R. Marimuthu, and M. Baskaran, "Performance evaluation of water and air based PVT solar collector for hydrogen production application," *Int. J. Hydrogen Energy*, vol. 45, no. 13, pp. 7498–7507, 2020, doi: 10.1016/j.ijhydene.2019.02.223.

[13] N. Xu, J. Ji, W. Sun, W. Huang, J. Li, and Z. Jin, "Numerical simulation and experimental validation of a high concentration photovoltaic/thermal module based on point-focus Fresnel lens," *Appl. Energy*, vol. 168, pp. 269–281, 2016, doi: 10.1016/j.apenergy.2016.01.077.

[14] M. Modjinou, J. Ji, J. Li, W. Yuan, and F. Zhou, "A numerical and experimental study of micro-channel heat pipe solar photovoltaics thermal system," *Appl. Energy*, vol. 206, no. May, pp. 708–722, 2017, doi: 10.1016/j.apenergy.2017.08.221.

[15] R. Liang, C. Zhou, Q. Pan, and J. Zhang, "Performance evaluation of sheet-and-tube hybrid photovoltaic/thermal (PVT) collectors connected in series," *Procedia Eng.*, vol. 205, pp. 461–468, 2017, doi: 10.1016/j.proeng.2017.10.411.

[16] H. Long, T. T. Chow, and J. Ji, "Building-integrated heat pipe photovoltaic/thermal system for use in Hong Kong," *Sol. Energy*, vol. 155, pp. 1084–1091, 2017, doi: 10.1016/j.solener.2017.07.055.

[17] A. L. Abdullah, S. Misha, N. Tamaldin, M. A. M. Rosli, and F. A. Sachit, "Theoretical study and indoor experimental validation of performance of the new photovoltaic thermal solar collector (PVT) based water system," *Case Stud. Therm. Eng.*, vol. 18, no. November 2019, p. 100595, 2020, doi: 10.1016/j.csite.2020.100595.

[18] X. Yang, L. Sun, Y. Yuan, X. Zhao, and X. Cao, "Experimental investigation on performance comparison of PV/T-PCM system and PV/T system," *Renew. Energy*, vol. 119, pp. 152–159, 2018, doi: 10.1016/j.renene.2017.11.094.

[19] T. Maatallah, R. Zachariah, and F. G. Al-Amri, "Exergo-economic analysis of a serpentine flow type water based photovoltaic thermal system with phase change material (PVT-PCM/water)," *Sol. Energy*, vol. 193, no. May, pp. 195–204, 2019, doi: 10.1016/j.solener.2019.09.063.

[20] H. Fayaz, N. A. Rahim, M. Hasanuzzaman, A. Rivai, and R. Nasrin, "Numerical and outdoor real time experimental investigation of performance of PCM based PVT system," *Sol. Energy*, vol. 179, no. July 2018, pp. 135–150, 2019, doi: 10.1016/j.solener.2018.12.057.

[21] A. Naghdbishi, M. E. Yazdi, and G. Akbari, "Experimental investigation of the effect of multi-wall carbon nanotube – Water/glycol based nanofluids on a PVT system integrated with PCM-covered collector," *Appl. Therm. Eng.*, vol. 178, 2020, doi: 10.1016/j.applthermaleng.2020.115556.

[22] H. Najafi and K. A. Woodbury, "Optimization of a cooling system based on Peltier effect for photovoltaic cells," *Sol. Energy*, vol. 91, pp. 152–160, 2013, doi: 10.1016/j.solener.2013.01.026.

[23] A. Kane and V. Verma, "Performance enhancement of building integrated photovoltaic module using thermoelectric cooling," *Int. J. Renew. Energy Res.*, vol. 3, no. 2, pp. 320–324, 2013, doi: 10.20508/ijrer.81220.

[24] J. Zhang, H. Zhai, Z. Wu, Y. Wang, and H. Xie, "Experimental investigation of novel integrated photovoltaic-thermoelectric hybrid devices with enhanced performance," *Sol. Energy Mater. Sol. Cells*, vol. 215, no. April, p. 110666, 2020, doi: 10.1016/j.solmat.2020.110666.

[25] T. Wang, S. Wang, and W. Wu, "Experimental study on effective thermal conductivity of microcapsules based phase change composites," *Int. J. Heat Mass Transf.*, vol. 109, pp. 930–937, 2017, doi: 10.1016/j.ijheatmasstransfer.2017.02.068.

[26] X. Liu and Z. Rao, "Experimental study on the thermal performance of graphene and exfoliated graphite sheet for thermal energy storage phase change material," *Thermochim. Acta*, vol. 647, pp. 15–21, 2017, doi: 10.1016/j.tca.2016.11.010.

[27] M. Li, Q. Guo, and S. Nutt, "Carbon nanotube/paraffin/montmorillonite composite phase change material for

thermal energy storage," *Sol. Energy*, vol. 146, pp. 1–7, 2017, doi: 10.1016/j.solener.2017.02.003.

[28] J. F. Luo *et al.*, "Numerical and experimental study on the heat transfer properties of the composite paraffin/expanded graphite phase change material," *Int. J. Heat Mass Transf.*, vol. 84, pp. 237–244, 2015, doi: 10.1016/j.ijheatmasstransfer.2015.01.019.

[29] X. Xiao, P. Zhang, and M. Li, "Preparation and thermal characterization of paraffin/metal foam composite phase change material," *Appl. Energy*, vol. 112, pp. 1357–1366, 2013, doi: 10.1016/j.apenergy.2013.04.050.

[30] P. Lv, C. Liu, and Z. Rao, "Experiment study on the thermal properties of paraffin/kaolin thermal energy storage form-stable phase change materials," *Appl. Energy*, vol. 182, pp. 475–487, 2016, doi: 10.1016/j.apenergy.2016.08.147.

[31] Y. Zhang, L. Wang, B. Tang, R. Lu, and S. Zhang, "Form-stable phase change materials with high phase change enthalpy from the composite of paraffin and cross-linking phase change structure," *Appl. Energy*, vol. 184, pp. 241–246, 2016, doi: 10.1016/j.apenergy.2016.10.021.

[32] Z. Li *et al.*, "Preparation of novel copper-powder-sintered frame/paraffin form-stable phase change materials with extremely high thermal conductivity," *Appl. Energy*, vol. 206, no. September, pp. 1147–1157, 2017, doi: 10.1016/j.apenergy.2017.10.046.

[33] Q. Sun, Y. Yuan, H. Zhang, X. Cao, and L. Sun, "Thermal properties of polyethylene glycol/carbon microsphere composite as a novel phase change material," *J. Therm. Anal. Calorim.*, vol. 130, no. 3, pp. 1741–1749, 2017, doi: 10.1007/s10973-017-6535-6.

[34] W. Wu, W. Wu, and S. Wang, "Form-stable and thermally induced flexible composite phase change material for thermal energy storage and thermal management applications," *Appl. Energy*, vol. 236, no. November 2018, pp. 10–21, 2019, doi: 10.1016/j.apenergy.2018.11.071.

[35] C. Li, Q. Li, and Y. Ding, "Investigation on the thermal performance of a high temperature packed bed thermal energy storage system containing carbonate salt based composite phase change materials," *Appl. Energy*, vol. 247, no. November 2018, pp. 374–388, 2019, doi: 10.1016/j.apenergy.2019.04.031.

[36] J. Shi and M. Li, "Synthesis and characterization of polyethylene glycol/modified attapulgite form-stable composite phase change material for thermal energy storage," *Sol. Energy*, vol. 205, no. May, pp. 62–73, 2020, doi: 10.1016/j.solener.2020.05.064.

[37] R. N. Wijesena, N. D. Tissera, V. W. S. G. Rathnayaka, H. D. Rajapakse, R. M. de Silva, and K. M. N. de Silva, "Shape-stabilization of polyethylene glycol phase change materials with chitin nanofibers for applications in 'smart' windows," *Carbohydr. Polym.*, vol. 237, p. 116132, 2020, doi: 10.1016/j.carbpol.2020.116132.

[38] J. P. Kotzé, T. W. Von Backström, and P. J. Erens, "High temperature thermal energy storage utilizing metallic phase change materials and metallic heat transfer fluids," *J. Sol. Energy Eng. Trans. ASME*, vol. 135, no. 3, pp. 1–6, 2013, doi: 10.1115/1.4023485.

[39] W. Q. Li, Z. G. Qu, Y. L. He, and Y. B. Tao, "Experimental study of a passive thermal management system for high-powered lithium ion batteries using porous metal foam saturated with phase change materials," *J. Power Sources*, vol. 255, pp. 9–15, 2014, doi: 10.1016/j.jpowsour.2014.01.006.

[40] P. Zhang, Z. Meng, H. Zhu, Y. Wang, and S. Peng, "Experimental and Numerical Study of Heat Transfer Characteristics of a Paraffin/Metal Foam Composite PCM," *Energy Procedia*, vol. 75, pp. 3091–3097, 2015, doi: 10.1016/j.egypro.2015.07.637.

[41] Y. B. Tao, C. H. Lin, and Y. L. He, "Preparation and thermal properties characterization of carbonate salt/carbon nanomaterial composite phase change material," *Energy Convers. Manag.*, vol. 97, pp. 103–110, 2015, doi: 10.1016/j.enconman.2015.03.051.

[42] A. Hussain, C. Y. Tso, and C. Y. H. Chao, "Experimental investigation of a passive thermal management system for high-powered lithium ion batteries using nickel foam-paraffin composite," *Energy*, vol. 115, pp. 209–218, 2016, doi: 10.1016/j.energy.2016.09.008.

[43] M. S. Yousef, H. Hassan, S. Kodama, and H. Sekiguchi, "An experimental study on the performance of single

slope solar still integrated with a PCM-based pin-finned heat sink," *Energy Procedia*, vol. 156, no. September 2018, pp. 100–104, 2019, doi: 10.1016/j.egypro.2018.11.102.

[44] A. C. Evers, M. A. Medina, and Y. Fang, "Evaluation of the thermal performance of frame walls enhanced with paraffin and hydrated salt phase change materials using a dynamic wall simulator," *Build. Environ.*, vol. 45, no. 8, pp. 1762–1768, 2010, doi: 10.1016/j.buildenv.2010.02.002.

[45] O. Beeri, O. Rotem, E. Hazan, E. A. Katz, A. Braun, and Y. Gelbstein, "Hybrid photovoltaic-thermoelectric system for concentrated solar energy conversion: Experimental realization and modeling," *J. Appl. Phys.*, vol. 118, no. 11, 2015, doi: 10.1063/1.4931428.

[46] Y. Da, Y. Xuan, and Q. Li, "From light trapping to solar energy utilization: A novel photovoltaic-thermoelectric hybrid system to fully utilize solar spectrum," *Energy*, vol. 95, pp. 200–210, 2016, doi: 10.1016/j.energy.2015.12.024.

[47] R. Lamba and S. C. Kaushik, "Modeling and performance analysis of a concentrated photovoltaic-thermoelectric hybrid power generation system," *Energy Convers. Manag.*, vol. 115, pp. 288–298, 2016, doi: 10.1016/j.enconman.2016.02.061.

[48] A. Rezania, D. Sera, and L. A. Rosendahl, "Coupled thermal model of photovoltaic-thermoelectric hybrid panel for sample cities in Europe," *Renew. Energy*, vol. 99, pp. 127–135, 2016, doi: 10.1016/j.renene.2016.06.045.

[49] W. Zhu, Y. Deng, Y. Wang, S. Shen, and R. Gulfam, "High-performance photovoltaic-thermoelectric hybrid power generation system with optimized thermal management," *Energy*, vol. 100, pp. 91–101, 2016, doi: 10.1016/j.energy.2016.01.055.

[50] M. Benghanem, A. A. Al-Mashraqi, and K. O. Daffallah, "Performance of solar cells using thermoelectric module in hot sites," *Renew. Energy*, vol. 89, pp. 51–59, 2016, doi: 10.1016/j.renene.2015.12.011.

[51] D. Li, Y. Xuan, Q. Li, and H. Hong, "Exergy and energy analysis of photovoltaic-thermoelectric hybrid systems," *Energy*, vol. 126, pp. 343–351, 2017, doi: 10.1016/j.energy.2017.03.042.

[52] J. Zhang and Y. Xuan, "Performance improvement of a photovoltaic - Thermoelectric hybrid system subjecting to fluctuant solar radiation," *Renew. Energy*, vol. 113, pp. 1551–1558, 2017, doi: 10.1016/j.renene.2017.07.003.

[53] T. Cui, Y. Xuan, E. Yin, Q. Li, and D. Li, "Experimental investigation on potential of a concentrated photovoltaic-thermoelectric system with phase change materials," *Energy*, vol. 122, pp. 94–102, 2017, doi: 10.1016/j.energy.2017.01.087.

[54] R. Bjørk and K. K. Nielsen, "The maximum theoretical performance of unconcentrated solar photovoltaic and thermoelectric generator systems," *Energy Convers. Manag.*, vol. 156, no. September 2017, pp. 264–268, 2018, doi: 10.1016/j.enconman.2017.11.009.

[55] G. Li, X. Chen, and Y. Jin, "Analysis of the primary constraint conditions of an efficient photovoltaic-thermoelectric hybrid system," *Energies*, vol. 10, no. 1, pp. 1–12, 2017, doi: 10.3390/en10010020.

[56] Y. P. Zhou, M. J. Li, Y. H. Hu, and T. Ma, "Design and experimental investigation of a novel full solar spectrum utilization system," *Appl. Energy*, vol. 260, no. November 2019, p. 114258, 2020, doi: 10.1016/j.apenergy.2019.114258.