International Journal of Applied Engineering & Technology

RECENT DEVELOPMENTS & THE FUNCTION OF NANOFLUIDS IN PHOTOVOLTAIC (PVT) SYSTEM

Fahim Sheikh[1], P. M. Ardhapurkar[2] and S. P. Deshmukh[3]*
[1]Research Scholar and [3]Professor, Department of General Engineering, Institute of Chemical Technology, Mumbai
[2]Professor, Department of Mechanical Engineering, Mauli Group of Institution's college of Engineering and technology, Shegaon
[1]mec21fr.sheikh@pg.ictmumbai.edu.in,[2]pm.ardhapurkar@gmail.com and [3]sp.deshmukh@ictmumbai.edu.in

ABSTRACT
Using appropriate nanofluid characteristics (factors include high heat transfer rates, volume flow rates, fractional volumes, concentration ratios, etc.), this article conducts a thorough evaluation of nanofluids for use in PV thermal systems. The focus is on how nanomaterials influence the thermal cycle stability, viscosity, density, phase change temperature, sub cooling time, and duration, thermal conductivity (k), and latent heat of Phase change materials (phase change materials) across a range of operating temperatures. Researchers hope that by delving further into the theory and practice of PVT systems, this work can improve the thermal performance of systems that use nanomaterials and integrate them with phase change material or nano-phase change material. Using nanofluids with nano-phase change material improves how well the solar photovoltaic thermal system regulates heat, electricity, and total system efficiency.

Keywords: Nanofluids, Solar energy, Renewable energy, Solar Photovoltaic-thermal system, phase change material, Nano-enhanced Phase change materials.

Nomenclature Symbols	Abbreviations		
K	Thermal conductivity	lpm	Liters per minutes
η_{el}	Electrical efficiency	TE	Thermal energy
η_{ov}	Overall efficiency	FEM	Finite element method
$T_{PVmodule}$	PV module surface temperature	EG	Ethylene glycol
T_m	Melting temperature	SWCNT	Single-walled carbon nanotubes
M	Mass flow rate	MWCNT	Multi-walled carbon nanotubes
Q	Volume flow rate	PVT	Photovoltaic/thermal
η_{th}	Thermal efficiency	NP	Nanoparticle
ϕ_w	Weight fraction of nanoparticle	NF	Nanofluids
EE	Electrical energy	PV	Photovoltaic

INTRODUCTION
The ever-increasing demand for resources like power, water, housing, fuel, energy, and food is directly proportional to the rate at which the global population is expanding. Since solar radiation is abundant and readily available, solar energy (SE) has surpassed all other renewable energy sources in importance in meeting the world's growing energy demand. Because it guarantees several additional benefits, such as reducing fossil fuel usage and the risk of climate change, the SE is considered as possibly fruitful (1). Photovoltaic cells have numerous possible applications due to their clean, ecologically friendly, and adaptable nature as a power source. Among the numerous benefits of a solar system are its portability, low maintenance cost, long reliability, ease of installation, lack of fuel use, and absence of dangerous greenhouse gas emissions and groundwater contamination (2,3). When light from the sun hits the panels, the heat they absorb can reach deadly levels in warmer climates, particularly during the summer. Increases in ($T_{PVmodule}$) cause PV module thermal stresses, which reduce power output and shorten the panel's lifespan (4). A non-combustible fluid circulates underneath the panel, reducing the

temperature of the PV cells and increasing the system's thermal efficiency. Integrated solar thermal (PVT) systems can make both heat and power at the same time (5,6). Most fluids employed in PV thermal systems are inefficient because they can't store or transport heat effectively (7, 8). Therefore, Researchers are considering using fluids with higher heat capacities and better thermal conductivity. Drawing on a variety of studies that have been published in the medical literature. The most effective heat exchanger fluid for solar photovoltaic thermal systems has been determined to be nanofluids. Phase change materials mixed with nanoparticles have been said to work in solar photovoltaic thermal (PVT) systems (9, 10). The matter that changes phases People are looking into using paraffin wax for this purpose because it is cheap, safe for the environment, and can hold a lot of heat and energy over a wide temperature range (11). A drawback is that it becomes worse with time. Adding nanoparticles to the phase change material dramatically increases the total recovered heat energy and may significantly speed up the heat transfer rate (12). Adding nanoparticles to paraffin wax speeds up its exergy recovery and shortens its solidification time; yet, after 30 heating/cooling cycles, neither the fusion nor recrystallization of the wax changed. Additionally, it has been noted that the thermo physical characteristics of paraffin wax do not change even after subjected to five heat cycles (13). This research thoroughly examines the potential applications of solar photovoltaic thermal (PVT) systems, including nanofluids and nanos-enhanced phase transition materials. The heat, power, and cost efficiency of PVT systems are affected by several factors, including particle size, volume flow rate, volume fraction, and phase-change materials. A great deal of information is available on this topic.

2. Nanofluids

Nanofluids consist of dispersed nanoparticles in a base fluid, such as water, heating oil, ethylene glycol, or another substance. Varying from 1 to 100 nanometers in width, the nanoparticles [14–15]. Nanofluids can modify a system's capacity, specific heat, thermal conductivity, rate of heat transfer, and viscosity. Using highly thermally conductive nanofluids improves the system's efficiency by allowing for more heat to be transmitted [16–17].(1)Metal-based nanoparticles, (2) Carbon-based nanoparticles, and (3) Nanocomposites are the three main types of nanoparticles. Fig.1 displays the comprehensive categorization of nanoparticles [18,19]. Specifically, nanocomposites enhance the base fluid's thermophysical characteristics due to their exceptional heat-carrying and -transferring capabilities. The system's total thermal conductivity is much better, which lowers its running costs. This is because nanofluids have better thermophysical features [20]. Nanofluids are an exciting new technology that lowers cell temperature by soaking up all the extra solar energy that photovoltaic cells don't need. Consequently, nanofluids can also serve as an optical filter for photovoltaic cells [21,22,23]. When compared to other fluids, nanofluids have extremely high production and preparation costs, which provide a difficulty [24]. The instability of nanofluids and the significant decrease in system performance caused by nanoparticle aggregation are also highlighted in reference [25]. Experimental SEM investigation of CuO nanoparticle aggregation is shown in Fig. 2 [26,27].

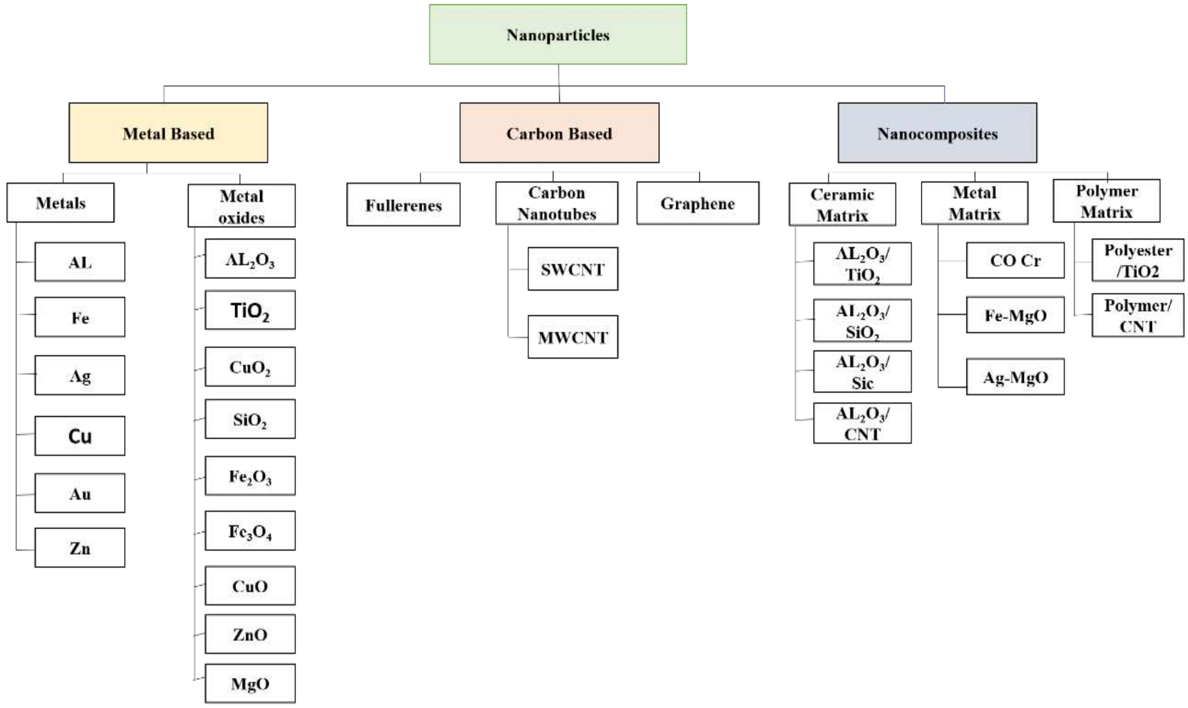

Fig.1: Nanoparticles and their categorization [19].

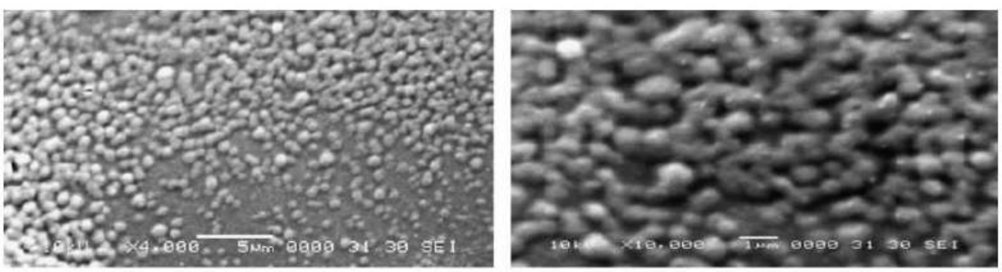

Fig. 2: Visualization of CuO nanoparticle Agglomeration through SEM [27].

2.1. Stability of Nanofluids

Nanofluids outperform more traditional working fluids in terms of heat conductivity, as we've already established. Because the nanoparticles are dispersed and highly thermally conductive, the colloidal solution exhibits an extraordinarily high thermal conductivity. However, the base fluid may have superior heat conductivity. When nanoparticles settle down or clump together, they make nanofluids less able to transfer heat, making them less effective [28]. Therefore, improving nanofluid stability should be your first priority. Figure 3 shows how nanofluid stability is related to their thermal conductivity [29]. The stability of a nanofluid liquid solution depends on three things: instability in diffusion, chemical stability, and kinetic stability [30]. The ability of nanoparticles to clump together in a fluid is dependent on their dispersion stability. How the nanoparticles react with the liquid around them is what determines their chemical stability. For instance, chemical stability is not a concern when fabricating nanofluids at temperatures significantly lower than the reaction temperature. Nanoparticles in a base fluid experience kinematic stability, also known as Brownian motion, due to the dynamic motion. There are three types of nanofluid stability: dispersive, chemical, and kinetic. The temperature, viscosity, density of the fluid, and the type of surfactant can change all three [31]. This is why it's so difficult for scientists to guarantee that nanofluids will remain intact. Nowadays, scientists and researchers are working on new ways to determine how stable nanofluids are. (i)X-ray diffraction, (ii)zeta potential, (iii)scanning electron microscopy, (iv)differential scanning calorimetry, (vi)femtosecond Fourier transform infrared spectroscopy, and (vii)thermal gas analysis [32-

36]. As seen in Figure 4, TEM pictures of CuO nanoparticles are featured. Figure 4 clearly demonstrates the stability of the nanofluids by showing that the created CuO nanoparticles are uniformly distributed and exhibit minimal aggregation.

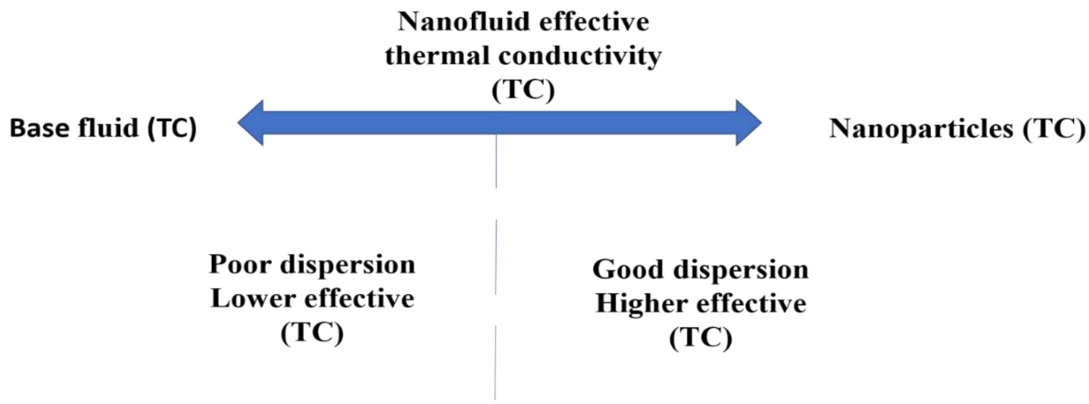

Fig. 3: Correlation between nanofluid stability and their thermal conductivity. [29].

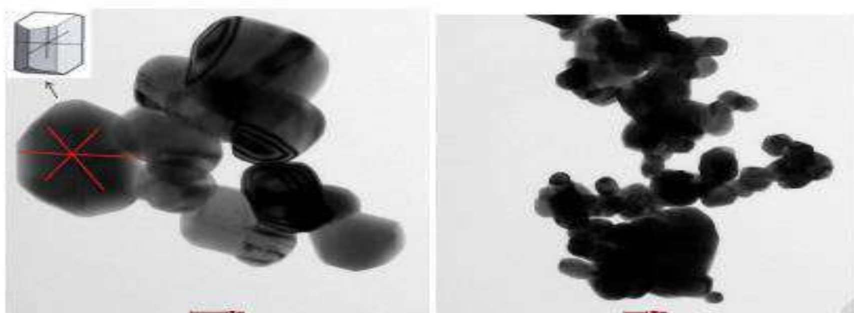

Fig. 4: TEM of CuO nanoparticles [37].

2.2. Nanofluid Preparation

Solid particles spread across a liquid medium (liquid) on a nanoscale scale create nanofluids. Nanofluid preparation may be done in either a one-step or two-step process. The two-step method has become the standard because it is cheap and easy to use. Figure 5 shows how the particles are made and then the base fluid spreads them out. The nanofluid would stand in for the water in a PVT system that uses them. In this case, the better heat transfer provided by a PVT detector is possible because these fluids have better thermophysical properties [38]. A rise in thermal and electrical efficiency is the result. Gathering the solid nanoparticles, which are usually a dry powder, is the first stage of the two-stage procedure. The next step is to use sonication or a magnetic mixer to mix the nanoparticles and base fluid. The produced nanoparticles agglomerate due to their high surface activity. It is advised to use a sonicator, like an ultrasonic probe, when mixing to prevent sedimentation and agglomeration, two unwanted consequences. In order to attain a steady, consistent, and uninterrupted suspension, Ultrasonic shakers or vibration must be used to sonicate the nanofluid solution for lengthy durations, usually 80 to 100 minutes. Adding surfactant, sometimes called a dispersant, to the nanofluid will make it more stable and improve its thermal conductivity [40]. Figure 6 shows the two-stage method's procedure, and Figure 7 shows a probe sonicator and an ultrasonic shaker. Sardarbadi et al. [41] studied how silica/water nanofluids could be used as a cooler to make a photovoltaic thermal unit (PVT) work better in terms of both heat and electricity.Doses of 1 weight percent and 3 weight percent of nanofluid were used in the study. They found that compared to a PVT system running on pure water, one using a 1 wt% silica/water nanofluid was 3.6% more efficient. The total efficiency is raised by 7.9 percent when a nanofluid is made by adding 3 weight percent silica to water. Results showed that increasing the concentration of the silica/water nanofluid from 1% to 3% improved the heat efficiency of the PVT system by 7.6% and 12.8%, respectively. Using three different nanofluids—one having just water, one with 1% silica and water, and a combination of the two—, researchers found that adding a collector to a PVT system raised the system exergy by 19.36%, 22.6%, and 24.3%, respectively. Hashim et al. [42] evaluated a hybrid solar thermal system's heat and power generation capabilities using an Al_2O_3/water nanofluid buffer. Nanofluids with 0.1 to 0.5 percent were used, and the mass flow rate was kept at 0.2 liters per second. Downgrading the PV system's temperature to 42°C raises the solar cells' efficiency by 12.1% at a concentration ratio of 0.3, but it drops to 11.3% at 52°C. The fluid dynamics of a photovoltaic system were studied by Khanjari et al. [43] using an Ag/H2O and Al2O3/H2O nanofluid. They found that the system's performance and heat transfer coefficient were both enhanced by adding more nanoparticles. The former significantly improves the system's electrical efficiency when comparing A_g/H_2O nanofluid to Al_2O_3/H_2O. Interactions between solar thermal photovoltaic systems and their environments have also been examined by the same author [44]. Although the thermal efficiency was mainly unaffected by changes in fluid intake temperature or sunshine intensity, the electrical efficiency of solar photovoltaic thermal systems declined with these variables. The researchers found that compared to normal water, the Al_2O_3/H_2O nanofluid utilized in the photovoltaic thermal system produced more efficient electricity. Michael et al. [45] tried a sun photovoltaic heating device using CuO and water nanofluids. The nanofluids made up only 0.05% of the total volume. In place of the Tedlar layer, a thin layer of copper is put on top of the silicon cells. Electrical and heat performance was checked on covered and unglazed solar PV thermal hybrid systems. Figure 8 shows how the experiments for this work were set up. This research discovered that heat efficiency rose by 45% and electrical efficiency fell by 3% when glazing and nanofluid were used as the "base fluid" instead of ordinary water. A solar photovoltaic system's performance was tested using paraffin wax as a phase transition material and Al_2O_3 as a nanofluid. They have prepared three distinct testing setups: (i) a control fluid containing no phase change material, (ii) a phase change material layer attached to the rear of the photovoltaic thermal system, and (iii) a hybrid of the two. They discovered a 13.2% increase in PVT system efficiency using the third configuration as compared to the reference configuration. By about 5.7%, the second configuration is more efficient.

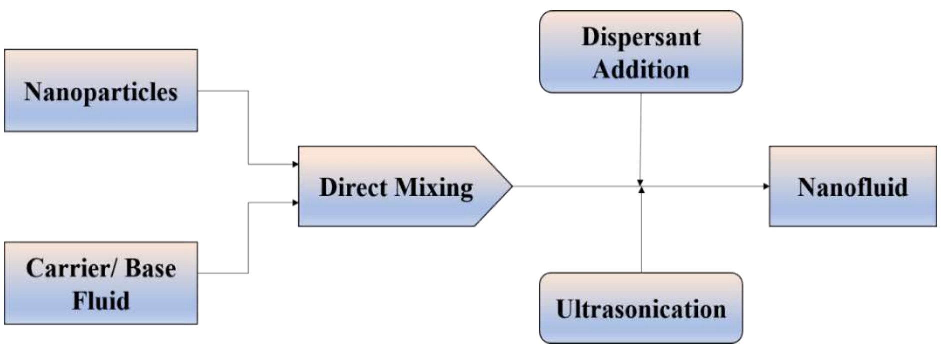

Fig. 5: Two-stage method methodology [38]

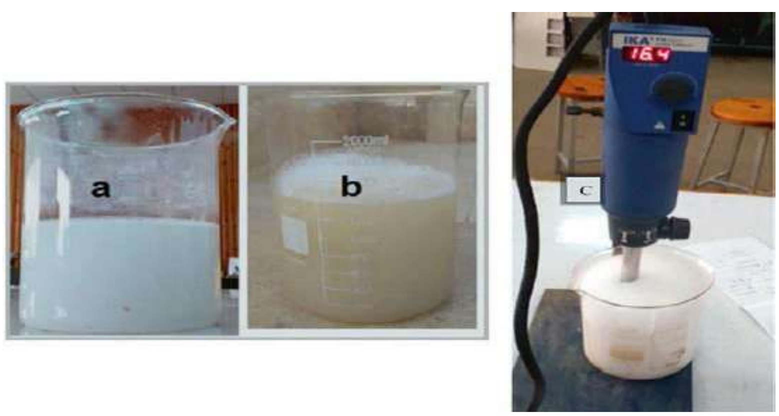

Fig. 6: Simulated, actual, and prepared silica nanofluid (a) before, (b) after, and (c) during an experiment. [39]

Fig. 7: Ultrasonic bath shaker [39]

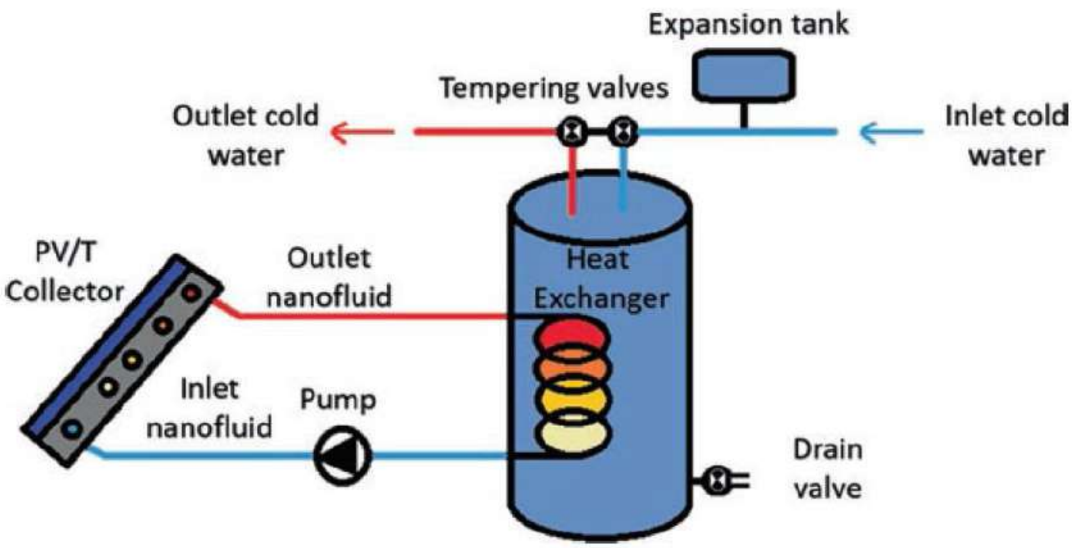

Fig. 8: Typical layout of a nanofluid-based PVT system [45].

3. Phase Change Materials (Pcms) & Their Classifications

PCM can change phase repeatedly while preserving their latent heat. More thermal energy (TE) may be absorbed and released during the melting and solidification processes of a material with a high latent heat-storing capacity [47].There are three types of phase change materials, distinguished by the temperature at which they undergo phase transition, the process by which they do so, and their chemical identity [48]. We classify PHASE CHANGE MATERIALs as either low (below 15 C), intermediate (between 15 and 90 C), or high (beyond 90 C) according to their phase transition temperatures. Solar thermal systems, the food industry, and air conditioning systems are a few examples of where low-temperature phase change materials are used [49]. Having said that, phase change materials' ability to function at moderate temperatures makes them very useful in the solar thermal, electrical, and biological sectors. The opposite is true for high-temperature phase change materials, which find application in both personal and military aircraft [50]. One way to classify phase change materials is by the type of phase transition they undergo; these can be solid-liquid, liquid-gas, or gas-solid [51]. Because the phase transition causes a slight change in volume and enthalpy, solid-liquid phase change materials have a wide range of potential uses. Figure 9 shows the three categories of phase change materials, eutectic, inorganic, and organic, and how they may transition through a solid-liquid phase. Paraffin and non-paraffin are the two most common kinds of biological materials. When paraffin wax crystallizes, it releases much latent heat due to its long, straight chain of n-alkanes. A longer chain has a higher melting point and a higher latent heat of melting. Instead, alcohols, esters, and fatty acids comprise non-paraffin substances. Subcooling causes certain materials to have high freezing and melting points. Organic phase change materials such as paraffin wax and fatty acid are ideal because of their low cost, high TES capacity, and lack of need for supercooling [52]. Compared to paraffin, inorganic phase change materials such as salt hydrates are more cost-effective and possess a higher k-value. The main issues with salt hydrates are phase segregation and supercooling [53]. The uniform composition of eutectic phase change materials causes their melting and solidification temperatures to be lower than those of their individual phase change material components [54]. Unlike inorganic phase change materials, which experience phase segregation during the transition, these phase change materials have extremely high melting temperatures. These materials have a greater volumetric heat storage capacity, which is an additional benefit, but they are more challenging to create than inorganic and organic phase transition materials. A list of some of the phase change materials used in TES, including both natural and artificial ones, as well as their melting points, latent heat capacities, and eutectic states. To assist define what constitutes a "good" phase change material; numerous experts have proposed criteria and factors 55, 56, and 57. The features depicted in Figure 10 are indicative of an ideal PVT configuration phase change material.

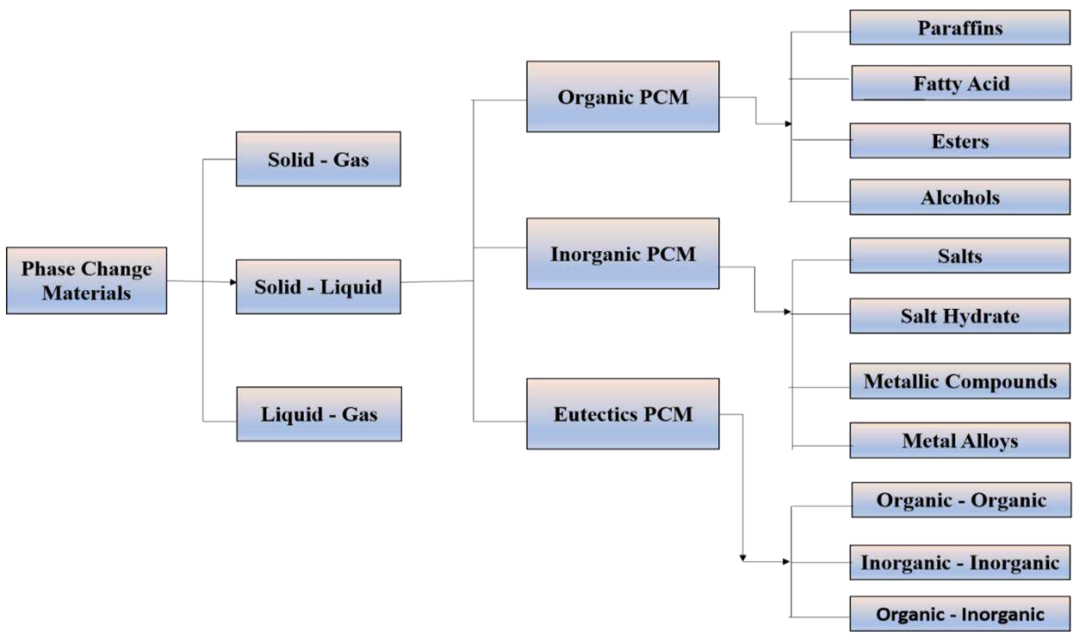

Fig. 9: Phase change material Categorizations.

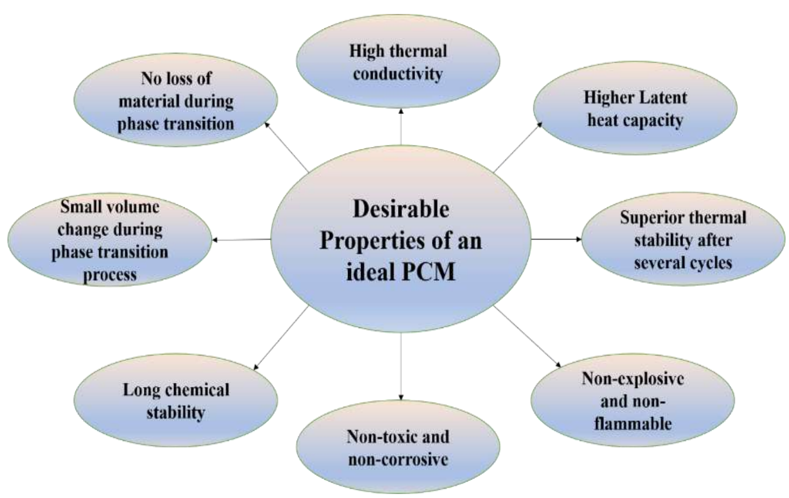

Fig. 10: Important features of a good PVT system configuration PHASE CHANGE MATERIAL

3.1 PVT System Based on PCM and NEPCM

There is a significant disparity between solar energy production and consumption, making storage mechanisms an essential component of solar energy systems. At night, when solar irradiation is at its lowest and heat demands are at their peak, this becomes much more apparent. You may prepare for nighttime power outages by charging your batteries during the day. A fantastic method for storing thermal energy is Phase change material (phase change material), which is known for its high efficiency and rapid charging and discharging capabilities. phase change material has great commercial potential and is also quite easy to get your hands on. By comparing their melting points, you can find the phase change material that is most suited to your needs. Systems characterized by high daytime temperatures and low nocturnal temperatures are necessary for materials that undergo rapid regeneration or recovery and solidification. A phase change material's mass, thermal capacity and thermal conductivity are crucial elements that significantly impact its phase change. There is a significant difference in the phases of personal condensates and the temperatures at which they undergo phase changes. Latent heat of fusion and very varied stage change temperatures characterize individual condensates [58]. Paraffin and non-paraffin oils, salt hydrates, and other inorganic compounds can be distinguished from organic materials. But the former is typically considered to be the best. The main drawbacks of paraffin include its poor heat conductivity [59,60] and the considerable volume change that happens when it melts. For this reason, several authors have proposed encasing these chemicals in nano-phase change or nano-enhanced phase change material. When it comes to heat transfer processes, these materials are invaluable since they boost phase change material recovery and thermal conductivity. The authors have achieved their goal of keeping PV modules at an appropriate temperature by utilizing phase change material. Stritih, et al. [61] investigated how well a solar array fitted with a power regulation module (RT28HC) using TRNSYS for theoretical and practical purposes. Research shows that using phase change material reduces the PV system's temperature by 35.6% compared to not using it. Using phase change material may boost electricity efficiency by 7.3%, according to the findings of the yearly simulations. To improve the thermal conductivity of the phase transition material, we followed the two-step process outlined by Karunamurthy and colleagues, which included dispersing paraffin and cupric oxide (CuO) nanoparticles [62]. The authors used an ultrasonic stirrer to combine their materials in seven different volumes, ranging in concentration from 0.01% to 0.15%. This material was utilized by an LTES system in a solar pond. It was demonstrated that the charging time of an LTES battery decreased as its volume fraction increased. Al-wali et al. [63] used nanofluids and nanophase change materials in a PVT collector. Sardarabadi et al. [64] also used a PVT collector with phase change material and nanofluids. Compared to the PV modules evaluated individually, the finished product is more efficient in terms of heat and electricity, according to both tests. "Increase efficiency" is defined as a percentage gain relative to a baseline PV module under same circumstances, even if the performance of a photovoltaic module is practically the same when its cooling is maintained, as it is under perfect testing settings.

4. Nano-Enhance PCM

The low k value of phase transition materials has led scientists to classify them as insulators rather than metals. Because of their slow energy storage and release rates, low k materials are severely limited in their usage as PCMs. Using nano-phase change material—a hybrid of phase change and nanoparticles—is essential for achieving this goal). Metals (Cu, Fe, Ag, Al, and Au), oxides of metals (Al_2O_3, SiO_2, TiO_2, Fe_3O_4, CuO, and ZnO), graphene, graphite, and carbon nanotubes (single- and multi-walled) are among the many NPs that the scientific community has thoroughly investigated.In contrast, the thermo-physical characteristics of nano-enhance pcm and pcm are affected by the amount of NP doping in the former. Two methods exist for dealing with nano-phase transition materials. The one-step technique synthesizes the initial phase change material and distributes it using NP in a single phase. Storage, coloring, and transportation are thus rendered unnecessary by this method. Because it eliminates agglomeration and dispersion, this method is used in low-volume production [65]. Making Nano-phase change material requires two steps: first, making the powdered NP; and second, dissolving it in phase change material. There aren't many types of insulators, so the study only looks at the working fluids and heat absorbers. Figure 12 shows the most basic versions of the one-step and two-step approaches. The only way to ensure that the NP is uniformly distributed throughout the phase transition material is to stabilize and mix it.

Combining ultrasonic baths & magnetic stirring is required to mix nanomaterials into phase transition material bases. The two-step method saves money for large-scale manufacturing than the one-step method [66]. Among nephase change materials' numerous useful features are k and heat transmission, which allow solar photovoltaic (PV) systems to keep running at peak efficiency and at the optimal temperature [67].

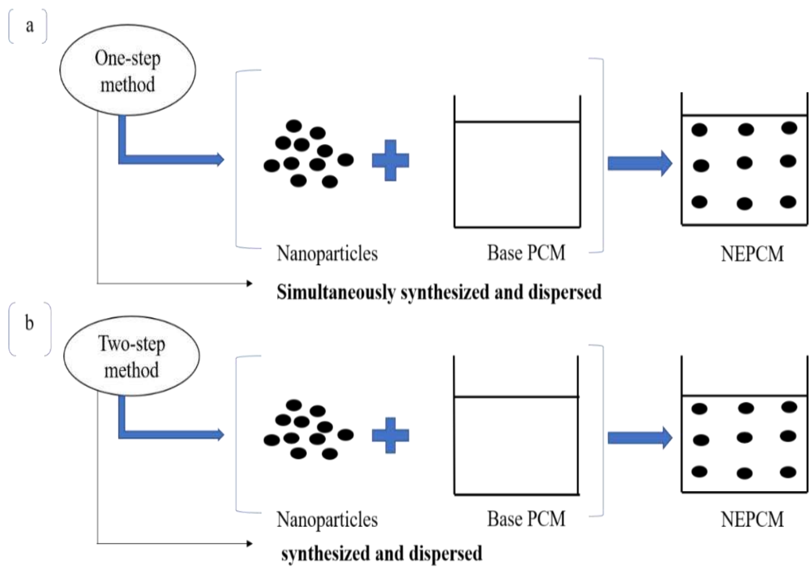

Fig. 12: (a) One-step process; (b) Two-step process

5. PVT Cooling System

Because heat transfer is the primary function of this collector type, optimizing and designing to maximize heat transfer efficiency is of the utmost importance. The absorber's working fluid, insulation, shape, and arrangement significantly affect how heat moves through it. The investigation focuses on the thermal absorber and operating fluids because of the limited number of insulator kinds. Because absorbers are custom-made for each operating fluid, several authors classify PVT systems according to this criterion. Various methods of PVT collector classification are illustrated in Fig.13. When determining the PVT type, the fluid type is an important consideration. Another important consideration when designing a PVT collector is the type of working fluid.

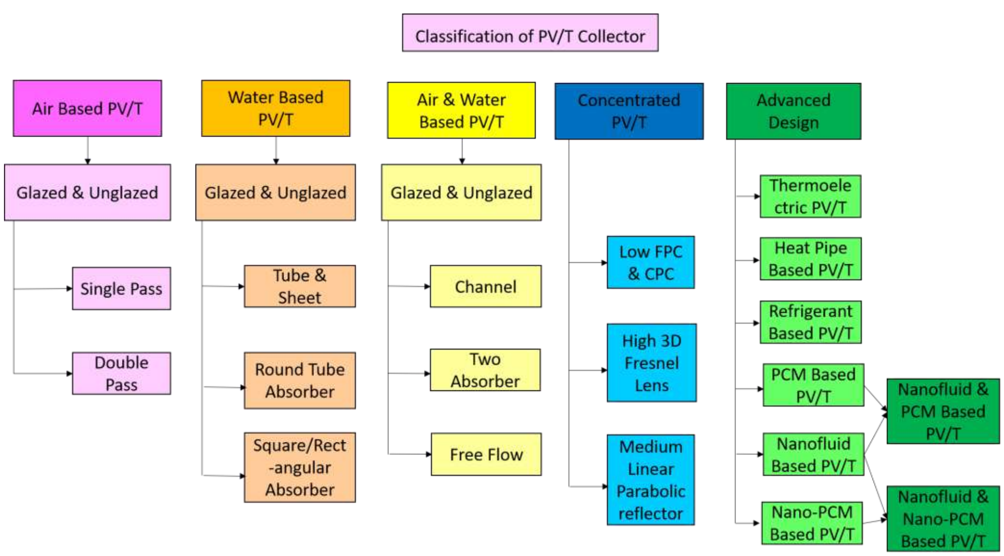

Fig. 13 Classification of PVT Collector

5.1 Photovoltaic Thermal System Cooling by Water

The new method is better than the old one because water takes heat away from the PV cell better than air. To develop the optimal design, researchers must consider the water's velocity, the absence of heat transmission, and the heavyweight. These factors necessitate substantial changes to the system designs. Kalogirou et al. used the modeling and computer program TRNSYS to look at how well a mixed solar photovoltaic water system worked in Nicosia, Cyprus, taking into account the weather (TMY). The photovoltaic (PV) system differed from the thermal system in that it used a cylinder to store hot water and several inverters instead of an array of differential thermostats, pumps, and batteries. The solar PV system is 31.7% more efficient than before it was installed (2.8% vs. 7.7%), and a mixed approach may meet 49% of the hot water needs of the average family each year. Over the course of the system's expected lifetime of 4.6 years, the owner can expect to save 790 Euros. A flat photovoltaic/thermal collector consisting of a single glass panel forms the basis of this novel apparatus. Chow [69] suggested a seven-node explicit dynamic model representing dynamic systems. Modeling the transient performance in terms of efficiency, heat and electrical current gains, and temperatures of multiple components is possible by combining the calculating the size variation of the control group using a supplementary transfer programme. This model made it possible to look at the hybrid collector's energy more completely. It also allowed adding adsorption and multidimensional thermal conductivity to the nodal method, which is used on PV modules. Dupeyrata et al. [70] used TRNSYS modeling to compare the output of one PV module with that of one solar thermal collector to figure out how well a water-cooled PVT system worked. For the sake of this comparison, we will assume that the two methods' climatic conditions and surface areas are identical. Traditional photovoltaic cells and solar water heaters worked together to achieve better results than either technology could on its own in some situations, where the amount of available solar collector area was a determining factor. Tset al. [71] conducted calculations to determine if a PVT system with liquid cooling could fulfill the energy and hot water requirements of an office building in Hong Kong. Experts determined combining PV cells with solar water heating devices was far more cost-effective than employing either technology alone. According to the study, the results were favorable even after accounting for maintenance expenses and additional components when employing PVT systems with a quick recovery time. For the most part of 2018, net worth was positive. The research shows that PVT systems can work in semitropical office buildings. Bigorajski and Chwieduk [72] investigated the Greek city of Patras as a possible location for PVT installations. The researchers looked at how efficient the system was using a mathematical model. A single-family home may theoretically heat its water using the system's generated heat and electricity. According to the analysis, the PVT system performs at peak efficiency in December and January when it produces more energy than heat. Low electrical efficiency was caused by the cooling fluid's high temperatures throughout the summer.

5.2 PVT-Phase Change Material System Based on Water

Water analysis of pcm was used to cool the module, and a serpentine-shaped flow route was extended to its rear by Maatallah et al. [73]. Fig.14 depicts the contents of an aluminum container, which included a serpentine copper tube, paraffin wax, and an aluminum absorber plate. The fluid dynamics used in this experiment ranged from 0.004 to 0.02 kg/s. In comparison to PV modules alone, PVT with phase change material achieves higher power and overall efficiency, according to the results. In most cases, these gains amount to 17.33% and 28.86%, after all. The proposed system outperformed the PV module in terms of lifespan efficiency by 27% and had a payback period that was 11.26% shorter. Malvi et al. [74] used phase change material to model energy balance and its impact on hybrid photovoltaic and solar thermal systems. One promising option is a hybrid PV/solar thermal system, which uses PV's effects on the UV and visible light spectrum. This was in contrast to the solar thermal system, which made use of solar infrared radiation and photovoltaic cell waste. Houses that utilize hybrid PVT panels to collect heat from phase change materials are nine percent more efficient than conventional PV panels. Browne et al. [75] examined the efficiency of conventional PV panels, a water-based PVT-PCMs, and traditional PVT panels. Using phase change material and water as coolants, Zhou et al. [76] statistically examined the PVT system and found that its heat-storage capacity increased by 33% in marine circumstances and by 100% in high-temperature environments. Su et al. [77] studied how well a PVT system that used phase change material worked.

Using the 1-D energy balance equation, we can see how changing the temperature and thickness of the phase change material layer impacts the other performance metrics of the PVT system, including power output and water flow rate. Results showed that the PVT system performed best with a 3.4-cm-thick layer of phase-change material set at 40 ^{o}c. At 30 ^{o}C, the participants' electrical energy consumption increased by 13.6% compared to the phase change material layer. Fayaz et al. [78] examined the efficiency of PVT and PVT-PCM using experimental and computational methods. The COMSOL Multiphysics software was used to do the numerical analysis. Making sure the water coming in stayed at a steady 27°C temperature and the flow rate between 0.5 and 3 lpm allowed experimental confirmation. The samples were kept in a controlled environment with artificial sunlight that was always 1000 W/m2. The highest level of performance for a PVT system using phase change material is 12.75 % based on tests and 12.59 % based on numerical calculations. According to the theoretical and practical tests, the PVT system's numbers are 12.28% and 12.4%, respectively. Browne et al. [79] assessed heat retention for three different systems: one using a simple PV module, one using a PVT-phase change material system with a heat exchanger, and one using a PVT system with a heat exchanger and a container. With the PVT-pcm, the water is heated to a higher temperature than with traditional heat exchanges. The water temperature increases by 5.5 ^{o}C when PVT is combined with phase change material, as opposed to when PVT is utilized alone. Adding pcm to the PVT system resulted in seven times greater heat energy collection from solar cells compared to the group that did not. Phase change materials have several domestic applications for the energy they store. Gaur et al. [80] used computers to analyze a PVT collection's electrical and thermal performance saturated with OM37, a bio-based phase transition material. A PVT system could do amazing things when it uses water as a coolant. The results showed that phase change material was the best choice when looking at how well the water-based PVT system worked in winter and during normal summer day exergy and η_{th}. Simon-Allue et al. [81] tried polymeric and aluminum parts in PVT systems with and without film and glass that touched the PV modules. Researchers discovered that adding or removing the glass greatly impacted heat performance but not so much electricity performance. Also, studies showed that aluminum did better than the plastic structure regarding heat performance. Fayaz et al. [82] used practical and theoretical methods to examine how well the PVT-phase change material system worked outside. A finite element method (FEM) study is used with the COMSOL Multiphysics program. A temperature of 32 ^{0}c for the water coming in, a range of 200 to 1000 W/m^2, and a flow rate of 0.5 lpm were all used in the study. An outdoor experiment with a water tank takes place in the ceiling. These studies show no changes between the numerical and experiment results. The suggested system gets an optimum η_{el} value of 13.98% in both computer and experimental tests. According to Kazemian et al. [83], they did experiments to see how well water and ethylene glycol worked as coolants for PVT modules (EG). One is a traditional PV system. On the other hand, four PVT systems use different cooling methods for their phase change materials: water, 50% EG, 100% EG, and 50% EG. When EG was used to cool PVT-phase change materials, they had smaller η_{ov} values than when water was used to cool them. The water-cooled PVT-phase change material system worked better than the others. Total energy output (TE) and energy efficiency (EE) were improved over a standard PV system, while the TPV module's temperature was reduced by 19.23%. Table.1 displays the results of previous studies on water-based PVT-pcm/Nano-enhance pcm.

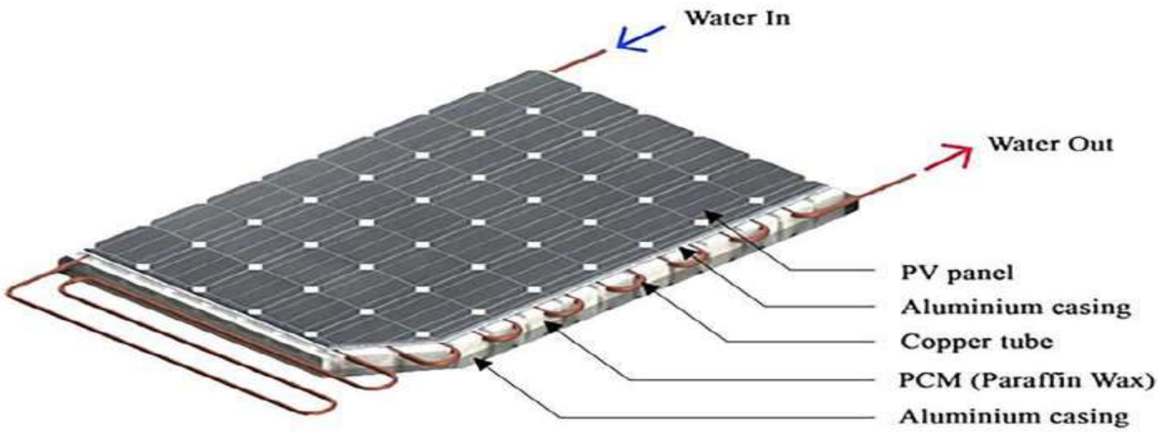

Fig. 14: PVT water-cooling system with PHASE CHANGE MATERIAL [73]

Table 1: An Overview of Water-Based PVT-pcm/Nano-enhances PCMs

Ref.	Type of study	phase change material used	Nanomaterial used for enhancement of phase change material	Application	Thermal power / efficiency	Electrical power/ efficiency	Overall efficiency/ Observation
Maatallah et al.	Experimental	RT30 (Tm = 57 ◦C)	NA	Household heating applications	26.87 %	17.33%	40.59%
Malvi et al.	Simulation	RT28 (Tm = 28 ◦C)	NA	Household heating applications	NA	NA	A typical increase of 9% in PV generation may be achieved by adding the appropriate phase change material to a system already configured to handle a 20°C rise in the average water temperature.
Browne et al.	Experimental	capric-palmitic (CP) (Tm = 22.4 ◦C)	NA	Household heating applications	NA	NA	The water in the PVT-phase change material system got almost 60 ^{0}c warmer than the water in the PVT system.
Zhou et al.	simulation	Not mentioned (Tm = 45 ◦C)	NA	Household purposes	NA	11.99%	Results showed that the PVT-phase change material system performed better when the mass flow rate increased, and the cooling water intake temperature decreased.
D. Su et al.	Mathematical	Organic PHASE CHAN	NA	Water heating	1096 W	13.6%	The photovoltaic-thermal solar collector maximises its overall energy

		GE MATE RIAL (Tm = 30 ◦C)					production by using a layer of phase transition material, 3.4 cm thick and having a melting point of 40 ^{o}c.
Fayaz et al.	Numeri cal and experim ental	Paraffin wax (Tm = 44 ◦C)	NA	Hot water applications	NA	12.91% numerically and 12.75% experimenta lly	The PVT system with phase change material integration achieved maximum efficiency levels of 12.91 percent and 12.75 percent, respectively. However, we obtained 12.4% from the calculations and 12.2% from the trials when using the PVT technique.
Browne et al.	Experi mental	capric: palmitic acid (75:25) (Tm = 17.7–22.8 ◦C)	NA	Household heating applications	NA	17.7 Wh is the maximum thermal power	The PVT-phase change material system's water output temperature is 5.5.0 degrees Celsius higher than the PVT system's water outlet temperature, making it stand out among other systems that use heat exchangers to cool water. You may put the energy you store in phase change material to use in other areas of your home, and research has shown that integrating it with a PVT system boosts TE extraction from solar cells by a factor of seven.
Gaur et al.	Numeri cal	phase change material OM37	NA	Hot water applications	9.26 kWh	16.87%	Based on the PVT calculated exergy and ηth, phase change material was shown to be more advantageous for both cold-weather and warm-weather seasons.
Simon-Allue et al.	Experi mental	organic RT50, inorgani c C48	NA	Water heating	63%	13.4%	While the amount of electricity produced is virtually the same, the system's thermal performance is drastically different. A higher TE for metal was found compared to polymeric configurations.
Fayaz	Numeri	A44	NA	Water heating	76%	13.98%	Numerically and

et al.	cal and experimental	paraffin wax (Tm = 44 ◦C)				numerically and 13.87% experimentally	experimentally, the PVT system's electrical performance is enhanced by 6.2 and 4.8%, while the PVT-phase change material system's performance is enhanced by 7.2 and 7.6%.
Kazemian et al.	Experimental	Paraffin wax (Merck, 107151) (Tm = 46–48 ◦C)	NA	Household heating applications	70.46 %	14.03%	The ɳov of PVT systems cooled by EG using organic paraffin wax is lower compared to those cooled by water using phase change material. When compared to traditional PV, TPVmodules have a temperature reduction of 19.23 ^{0}C.

5.3 PVT Cooling by Nanofluids

The results of cooling PVT systems with nanofluids to better transfer heat have been modeled and calculated. These studies, especially the most recent ones, help us make choice. Khandari et al. [84] explored the use of nanofluid as an alternative to water for cooling a PVT system. Use a nanofluid instead of water if you need a better thermal conductor. To describe the motion of nanofluid, alumina-water, and pure water, we used CFD. The level of nanoparticles containing water correlates with the efficiency of the PVT system being studied. Author discovered that the base fluid's heat transfer efficiency improved as the quantity of nanoparticles rose. Nanofluids made of alumina and water have a heat transfer coefficient 12.1% higher than plain water and 43.1% higher than Ag-water. Using alumina water instead of regular water increased the power output by 8-10%. When compared to plain water, the improvement with Ag-water could reach 28% to 45%. Rajab et al. [85] examined the potential effects of using nanofluids as heat transfer agents in a PVT system using a computer model based on FORTRAN. The results were compared to an early empirical model. Researchers have tested various nanoparticle types to see how they affect the electrical and thermal system performance. The intended PVT system was tested in three locations—Lyon, France; Mashhad, Iran; and Monastir, Tunisia—to observe the impact of weather on the findings. According to the research, utilizing water as the base fluid was more effective than ethylene glycol. Their device reaches its electrical and thermal performance limits by using a nanofluid made of copper and water. Also, thermal conductivity was increased with nanoparticle suspension concentrations ranging from 0% to 4%. According to the data, the electrical and thermal performance is highest in the coldest semiarid climate, which is located in Monastir, Tunisia. Adriana studied the thermophysical features of three oxide-based nanoparticles [86].To get a better grasp on what Al_2O_3, TiO_2, and SiO_2 do in water, numerical studies were carried out. Scientists found that introducing nanoparticles altered the thermophysical properties of every material they tested, and that doing so increased the materials' thermal conductivity by 12% or more. The nanofluid's thermal conductivity and Reynolds number were enhanced by a rise in nanoparticle concentration, raising the convection heat transfer coefficient.

5.4 NF-based PVT-PCM System

Sardarabadi et al. [87] investigated the efficacy of a PVT-phase change material system chilled with ZnO-water NF. This experiment used paraffin wax instead of phase change material (PCM). The electrical exergy efficiency was 23% higher and the performance was 13% better than that of traditional PV modules when using the proposed phase change material/NF hybrid system. Hosseinzadeh et al. [88] experimented with a PVT-phase change material system chilled by ZnO-water NF to determine its efficiency. The proposed PVT-phase change material cooled with NF outperformed the control system thermodynamically.In comparison to conventional photovoltaic (PV) and water-based PVT-phase change material cooling systems, the proposed system improved energy efficiency by 65.71 percent and exergetic efficiency by 13.61%. Hassan et al. [89] examined how graphene water could handle heat and control temperature in a PVT-phase change material system.The experimental parameters were v=0.05%,0.1%, and 0.15% and Q=20,30, and 40 lpm. Figure 14(a) and (b)* provide visual aids. The Al box and Cu tube transfer the molten phase change material (RT35HC) to the serpentine flow channel networks located on the module's back.The graphene-water cooled PVT-system achieved the highest EE, TE, and ov at Q = 40 lpm and ɘv = 0.1%, as shown by the findings. The percentages were as follows: 14.0%, 45.8%, and 60.3%.

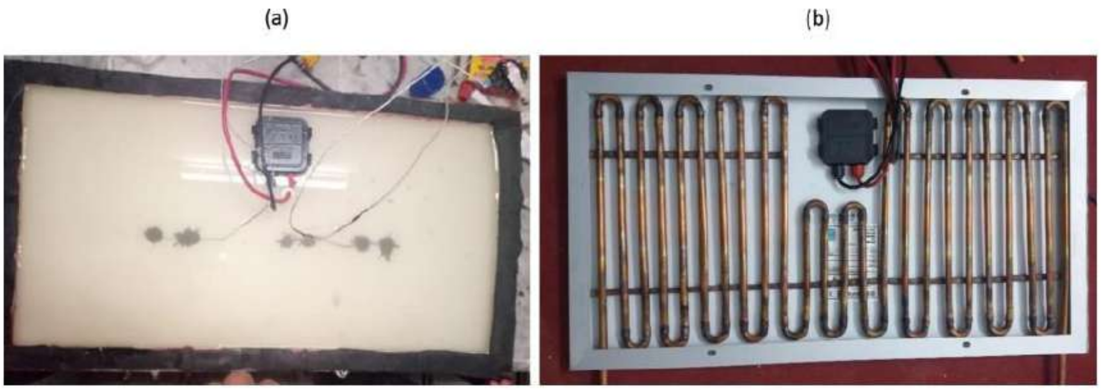

Fig. 15(a) Paraffin wax poured into an aluminum container as it melted; (b) a phase change material box lined with a network of serpentine copper tubes. [89]

5.5 NF-based PVT-NEPCM System

Sarafraz et al. [90] studied the effects of adding Nano boost phase change material and NF water on the electrical and thermal performance of PVT systems. The suggested system has a TE of 276.3 W/m2 and an EE of 307.9 W/m2. As the concentration of nanomaterials in the suggested PVT system increased, the overall power production went up. However, the pumping power needed to keep the working fluid moving went up as well. Because of this, the thermal-electrical power equivalence shrank. Al-Waeli et al. [91] used a mathematical model and experimental verification to examine the efficacy of a PVT system with a SiC-water coolant and paraffin wax, also known as a phase transition material. In contrast to the mathematical models' predictions of 13.7% for el and 72.0% for th, the actual findings showed el at 13.2% and th at 71.3%. Kazemian et al. [92] integrated an Al_2O_3-water cooled PVT system, which was then numerically investigated as parts of nano- enhance pcm. Adding Al_2O_3 nanoparticles to the PCM and coolant did not improve the effectiveness of the coolant NP dosage. The PVT system achieved outstanding results when combined with nano-phase change material and NF water, producing 377.87 W/m2 of thermal power and 136.93 W/m2 of electrical power. Table 2 summaries the research on NF-based PVT-phase change material/nano enhance phase change material systems.

Table 2: An Overview of Research Done on PVT-pcm/nano-enhance pcm Systems in NF.

Ref.	Type of study	phase change material used	Nanomaterial used for enhancement of phase change material	Nanomaterial used in cooling fluid	Thermal power/ efficiency	Electrical power/ efficiency	Overall efficiency/ Observations

Sardarabadi et al.	Experimental	Paraffin wax (Merck) (Tm = 42–72 ◦C)	NA	ZnO (ϕw = 0.2)	48%	13%	This system has almost 23% more overall exergy efficiency than a regular PV system.
Hosseinzadeh et al.	Experimental	Paraffin wax (Merck, 107151) (Tm = 46–48 ◦C)	NA	ZnO (ϕw = 0.2)	51.66%	14.05%	The total energetic efficiency for the suggested system was 13.61 percent, and the measured total energy efficiency was 65.71 percent.
Hassan et al.	Experimental	RT35HC (Tm = 35◦C)	NA	graphene nano powder (ϕ_v = 0.05, 0.1 and 0.15)	20.8%	14.5%	At Q = 40 lpm and ϕv = 0.1%, the graphene water-cooled PVTphase change material system had the highest EE, TE, and ov values, at 20.8%, 14.5%, and 14.1%, respectively.
Sarafraz et al.	Experimental	Paraffin wax (Tm = 49 ◦C)	MWCNT ((ϕw = 0.1)	MWCNT / WEG50 (ϕw = 0.2)	44%	45%	The EE reached 307.9W/m2, and the TE reached 276.3W/m2 when NF and NE phase change materials were added to the proposed PVT system, respectively. Results showed that overall power generation in the suggested PVT system rose with increasing nanomaterial concentration. On the other hand, more power was needed to circulate the working fluid.
Al-Waeli et al.	Mathematical & experimental	Paraffin wax (Tm = 40 ◦C)	SiC (ϕw = 0.1%)	SiC (ϕw = 3%)	72% experimentally	13.7% experimentally	Based on the results, it was found that ηel and ηth accounted for 13.2% and 71.3% in the mathematical models, respectively, whereas 13.7% and 72.0% were derived from the experiments.
Kazemian et al.	Numerical	Organic Rubitherm series (RT35)	Al2O3	Al2O3 (ϕw = 1%)	377.87 W/m2	136.93 W/m2	With nano-phase change material integrated and Al2O3-water cooling, the suggested PVT system reached 377.87 W/m2 of thermal power and 136.93 W/m2 of electrical power.

CONCLUSIONS

A concise synopsis of current research on solar energy systems is presented in this review article. This review paper has come to the following conclusions.Because PV changes the visible and ultraviolet portions of the sun spectrum, hybrid PVThermal systems are an exciting new development in renewable energy. The solar thermal system, on the other hand, made use of PV's wasted energy and the sun's infrared spectrum. Having two distinct systems for electrical and thermal components is therefore less efficient than a PVT system.

- Lessening the enhancement in backside temperature of PV modules under solar irradiation is achieved by incorporating the phase change material layer into PVT systems as opposed to PVT without the phase change material layer.
- To improve electrical efficiency, nanofluid is utilized to cool the PVT system's cell. This is done by improving the base fluid's thermal conductivity.
- Nanofluids are more effective as coolants for low discharge because they allow for an adequate interchange of wall-to-atmosphere heat transfer.
- The k of the smaller nanomaterial in phase change material is greater than that of the bigger nanomaterial because of the stronger contact forces. By incorporating nanomaterials into phase change material, the k is enhanced, and the latent heat is primarily reduced. The latent heat of melting and solidification also drops as the hybrid nanocomposite concentration rises.

FUTURE SCOPE:

A great deal of investigation is needed to improve the thermal conductivity, heat transfer rate, absorption, volume fraction, particle size, and other characteristics of nanofluids. While many studies have attempted to determine how nanoparticles affect the efficiency of PVT systems that incorporate phase change material/nephase change material, the results have been mixed. Consequently, the following areas can be explored further in future research:

- Solar PVT systems can benefit from using hybrid nanofluids instead of simple nanofluids.
- By combining nanofluids with Phase change materials, system performance can be enhanced.
- To compare the practical and theoretical results, CFD/COMSOL simulations can be run.
- To improve the performance of various solar photovoltaic heating systems, further theoretical and experimental research into the use of nanofluid is necessary.

  A thorough analysis of the effects of hybrid and magnetic NF on the performance of the PVT-nephase change material system is necessary.
- Technical, economic, and environmental considerations must be taken into account while evaluating the reliability of the PVT system integrated with nephase change material utilizing the NF.
- The PVT system can apply optimization approaches to verify the system's viability using nanofluid.

REFERENCE

[1] G. Alva, Y. Lin, G. Fang, An overview of thermal energy storage systems, Energy 144 (2018) 341–378, https://doi.org/10.1016/j.energy.2017.12.037.

[2] P.K.S. Rathore, S.S. Das, D.S. Chauhan, Perspectives of solar photovoltaic wate pumping for irrigationin India, Energy Strategy Reviews 22 (018) 385–395, https://doi.org/10.1016/j.esr.2018.10.009.

[3] A.P. Gonzalo, A.P. Marugan, F.P.G. Márquez, Survey of maintenance management for photovoltaic power systems, Renew Sustain Energy Rev 134 (2020), https://doi.org/10.1016/j.rser.2020.110347 110347.

[4] M.M. Islam, A.K. Pandey, M. Hasanuzzaman, N.A. Rahim, Recent progresses and achievements in photovoltaic-Phase change material technology: a review with special treatment on photovoltaic thermal-Phase change material systems, Energy Convers. Manag. 126 (2016) 177–204, https://doi.org/10.1016/j.enconman.2016.07.075.

[5] F. Shan, F. Tang, L. Cao, et al., Performance evaluations and applications of photovoltaic–thermal collectors and systems, Renew Sustain Energy Rev 33 (2014) 467–483, https://doi.org/10.1016/j.rser.2014.02.018.

[6] V.V. Tyagi, S.C. Kaushik, S.K. Tyagi, Advancement in solar photovoltaic/thermal (PVT) hybrid collector technology, Renew Sustain Energy Rev 16 (2012) 1383–1398, https://doi.org/10.1016/j.rser.2011.12.013.

[7] S.R. Reddy, M.A. Ebadian, C.X. Lin, A review of PV–T systems: thermal management and efficiency with single phase cooling, Int J Heat Mass Trans 91 (2015) 861–871.

[8] A.H. Besheer, M. Smyth, A. Zacharopoulos, et al., Review on recent approaches for hybrid PVT solar technology, Int J Energy Res 40 (2016) 2038–2053, https://doi.org/10.1002/er.3567.

[9] N. Kukreja, S.K. Gupta, M. Rawat, Performance analysis of Phase change material using energy storage device, Mater. Today: Proc. 26 (2) (2020) 913–917.

[10] K. Khanafer, K. Vafai, A critical synthesis of thermophysical characteristics of nanofluids, Int. J. Heat and Mass Transfer 54 (19–20) (2011) 4410–4428, https://doi.org/10.1016/j.ijheatmasstransfer.2011.04.048.

[11] A.H.A. Al-Waeli, M.T. Chaichan, K. Sopian, H.A. Kazem, H.B. Mahood, A. A. Khadom, Modeling and experimental validation of a PVT system using nanofluid coolant and nano-phase change material, Sol. Energy 177 (2019) 178–191, https://doi. org/10.1016/j.solener.2018.11.016.

[12] Jegadheeswarana S, Pohekara S D, Kousksoub T. Conductivity particles dispersed organic and inorganic Phase change materials for solar energy storage–an exergy based comparative evaluation. In: 2011 2nd International Conference on Advances in Energy Engineering (ICAEE2011), Energy Procedia 2012; 14: 643–648.

[13] Sobolciaka P, Mrlíka M, AlMaadeeda MA, Krupa I. Calorimetric and dynamic mechanical behavior of Phase change materials based on paraffin wax supported by expanded graphite. Thermochim Acta 2015; 617:111–9.

[14] W.H. Azmi, K.V. Sharma, R. Mamat, G. Najafi, M.S. Mohamad, The enhancement of effective thermal conductivity and effective dynamic viscosity of nanofluids– a review, Renew Sustain Energy Rev 53 (2016) 1046–1058, https://doi.org/10.1016/j.rser.2015.09.081.

[15] S.M.S. Murshed, C.A. Nieto de Castro, Conduction and convection heat transfer characteristics of ethylene glycol based nanofluids – a review, Appl Energy 184 (2016) 681–695.

[16] M. Gupta, V. Singh, R. Kumar, Z. Said, A review on thermophysical properties of nanofluids and heat transfer applications, Renew Sustain Energy Rev 74 (2017)638–670.

[17] N.A.C. Sidik, S. Samion, J. Ghaderian, Y. MNAWM, Recent progress on the application of nanofluids in minimum quantity lubrication machining: a review, Int, J Heat Mass Transf 108(Part-A) (2017) 79–89.

[18] P.K. Nagarajan, J. Subramani, S. Suyambazhahan, R. Sathyamurthy, Nanofluids for solar collector applications: a review, Energy Procedia 61 (2014) 2416– 2434, https://doi.org/10.1016/j.egypro.2014.12.017.

[19] P.K. Nagarajan, J. Subramani, S. Suyambazhahan, R. Sathyamurthy, Nanofluids for solar collector applications: a review, Energy Procedia 61 (2014) 2416–2434, https://doi.org/10.1016/j.egypro.2014.12.017.

[20] O. Arthur et al., An investigation into the thermophysical and rheological properties of nanofluids for solar thermal applications, Renew Sustain Energy Rev 55 (2016) 739–755, https://doi.org/10.1016/j.rser.2015.10.065.

[21] T.B. Gorji, A.A. Ranjbar, A review on optical properties and application of nanofluids in direct absorption solar collectors (DASCs), Renew Sustain Energy Rev 72 (2017) 10–32.

[22] S.H.A. Ahmad, R. Saidur, I.M. Mahbubul, F.A. Al-Sulaiman, Optical properties of various nanofluids used in solar collector: a review, Renew Sustain Energy Rev 73 (2017) 1014–1030.

[23] A.S. Abdelrazik, F.A. Al-Sulaiman, R. Saidur, R. Ben- Mansour, A review on recent development for the design and packaging of hybrid photovoltaic/ thermal (PVT) solar systems, Renew Sustain Energy Rev 95 (110–129) (2018), https://doi.org/10.1016/j.rser.2018.07.013.

[24] J. Lee, I. Mudawar, Assessment of the effectiveness of nanofluids for singlephase and two-phase heat transfer in micro-channels, Int. J. Heat Mass Transfer 50 (3–4) (2007) 452–463.

[25] R.A. Taylor, P.E. Phelan, R.J. Adrian, A. Gunawan, T.P. Otanicar, Characterization of light-induced, volumetric steam generation in nanofluids, Int. J. Therm. Sci. 56 (2012) 1–11.

[26] S. Dagher, Y. Haik, A.I. Ayesh, N. Tit, Synthesis and optical properties of colloidal CuO nanoparticles, J. Lumin. 151 (2014) 149–154, https://doi.org/ 10.1016/j.jlumin.2014.02.015.

[27] S.R. Reddy, M.A. Ebadian, C.X. Lin, A review of PV–T systems: thermal management and efficiency with single phase cooling, Int J Heat Mass Trans 91 (2015) 861–871.

[28] M. Borzuei, Z. Baniamerian, Role of nanoparticles on critical heat flux in convective boiling of nanofluids: Nanoparticle sedimentation and Brownian motion, Int J Heat Mass Transf 150 (2020), https://doi.org/10.1016/j.ijheatmasstransfer.2019.119299 119299.

[29] S. Almurtaji, N. Ali, J.A. Teixeira, A. Addali, On the Role of Nanofluids in Thermal-Hydraulic Performance of Heat Exchangers—A Review, Nanomaterials (Basel) 10 (4) (2020) 734, https://doi.org/10.3390/nano10040734.

[30] S. Mukherjee, P.C. Mishra, P. Chaudhuri, Stability of Heat Transfer Nanofluids—A Review, Chem Bio Eng Rev 5 (2018) 312–333, https://doi.org/10.1002/cben.201800008.

[31] N. Ali, J. A. Teixeira, A. Addali, A review on nanofluids: fabrication, stability,and thermophysical properties, J. Nanomaterials, 2018; 2018: Article ID 6978130, 33 pages. https://doi.org/10.1155/2018/6978130

[32] A. Asadi, I.M. Alarifi, V. Ali, H.M. Nguyen, An experimental investigation on the effects of ultrasonication time on stability and thermal conductivity of MWCNT-water nanofluid: Finding the optimum ultrasonication time, Ultrason. Sonochem 58 (2019), https://doi.org/10.1016/j. ultsonch.2019.104639 104639.

[33] S. Aberoumand, A. Jafarimoghaddam, Experimental study on synthesis, stability, thermal conductivity and viscosity of Cu–engine oil nanofluid, J.Taiwan Inst. Chem. Eng. 71 (2017) 315–322.

[34] Y. Hwang, J.K. Lee, C.H. Lee, Y.M. Jung, S.I. Cheong, C.G. Lee, B.C. Ku, S.P. Jang, Stability and thermal conductivity characteristics of nanofluids, Thermochim. Acta 455 (2007) 70–74.

[35] S. Ilyas, R. Pendyala, N. Marneni, S. Lim, Stability, rheology and thermal analysis of functionalized aluminathermal oil-based nanofluids for advanced cooling systems, Energy Convers. Manag 142 (2017) 215–229.

[36] R. Ranjbarzadeh, A. Moradikazerouni, R. Bakhtiari, A. Asadi, M. Afrand, An experimental study on stability and thermal conductivity of water/silica nanofluid: Eco-friendly production of nanoparticles, J. Clean. Prod. 206 (2019) 1089–1100.

[37] S. Amalraj, P.A. Michael, Synthesis and characterization of Al2O3 and CuO nanoparticles into nanofluids for solar panel applications, Results Phys. 15 (2019), https://doi.org/10.1016/j.rinp.2019.102797 102797.

[38] N.A.C. Sidik, I.M. Adamu, M.M. Jamil, G.H.R. Kefayati, R. Mamat, G. Najafi, Recent progress on hybrid nanofluids in heat transfer applications: a comprehensive review. Int. Commun. Heat Mass Transfer 78, 68–79 (2016)

[39] W. Yu, H. Xie, A review on nanofluids: preparation, stability mechanisms, and applications. J. Nanomater. **2012**, 1 (2012)

[40] X.F. Li, D.S. Zhu, X.J. Wang, N. Wang, J.W. Gao, H. Li, Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H2O nanofluids. Thermochimica Acta **469**(1–2), 98–103 (2008)

[41] M. Sardarabadi, M. Passandideh-Fard, S. Zeinali Heris, Experimental investigation of the effects of silica/water nanofluid on PVT (photovoltaic thermal units), Energy 66 (2014) 264–272.

[42] A. R. A. Hashim, A. Hussien, and A. H. Noman, Indoor investigation for improving the hybrid photovoltaic/thermal system performance using nanofluid (AL2O3-water), Engineering and Technology Journal, 2015: 33(4) Part A Engineering;889–901. https://www.iasj.net/iasj/download/ 0c74153bc434bcb2

[43] Y. Khanjari, F. Pourfayaz, A.B. Kasaeian, Numerical investigation on using of nanofluid in a water-cooled photovoltaic thermal system, Energy Convers Manag 122 (2016) 263–278.

[44] Y. Khanjari, A.B. Kasaeian, F. Pourfayaz, Evaluating the environmental parameters affecting the performance of photovoltaic thermal system using nanofluid, Appl Therm Eng 115 (2017) 178–187.

[45] J.J. Michael, S. Iniyan, Performance analysis of a copper sheet laminated photovoltaic thermal collector using copper oxide - water nanofluid, Sol. Energy 119 (2015) 439–451.

[46] S.A. Nada, D.H. El-Nagar, H.M.S. Hussein, Improving the thermal regulation and efficiency enhancement of phase change material integrated PV modules using nano particles, Energy Convers. Manage. 166 (2018) 735–743.

[47] B. EanestJebasingh, A.Valan Arasu, A comprehensive review on latent heat and thermal conductivity of nanoparticle dispersed Phase change material for lowtemperature applications, Energy Storage Mater. 24 (2020) 52–74, https://doi.org/10.1016/j.ensm.2019.07.031.

[48] H. Nazir, M. Batool, F.J. Bolivar Osorio, M. Isaza-Ruiz, X. Xu, K. Vignarooban, Recent developments in Phase change materials for energy storage applications: a review, Int. J. Heat Mass Tranf. 129 (2019) 491–523, https://doi.org/10.1016/j. ijheatmasstransfer.2018.09.126.

[49] S.D. Sharma, H. Kitano, K. Sagara, Phase change materials for low temperature solar applications, Res. Rep. Fac. Eng. Mie Univ. 29 (2004) 31–64.

[50] F. Agyenim, N. Hewitt, P. Eames, M. Smyth, A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS), Renew. Sustain. Energy Rev. 14 (2010) 615–628, https://doi. org/10.1016/j.rser.2009.10.015.

[51] E. Alehosseini, S.M. Jafari, Nanoencapsulation of Phase change materials (phase change materials) and their applications in various fields for energy storage and management, Adv. Colloid Interface Sci. 283 (2020), 102226, https://doi.org/10.1016/j. cis.2020.102226.

[52] Y. Zhang, L. Wang, B. Tang, R. Lu, S. Zhang, Form-stable Phase change materials with high phase change enthalpy from the composite of paraffin and crosslinking phase change structure, Appl. Energy 184 (2016) 241–247, https://doi.org/ 10.1016/j.apenergy.2016.10.021.

[53] B. Carlsson, G. Wettermark, Heat-transfer properties of a heat-of-fusion store based on CaCl2·6H2O, Sol. Energy 24 (1980) 239–247, https://doi.org/10.1016/ 0038-092X(80)90480-6.

[54] A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, Review on thermal energy storage with Phase change materials and applications, Renew. Sustain. Energy Rev. 13 (2009) 318–345, https://doi.org/10.1016/j.rser.2007.10.005.

[55] K.Y. Leong, M.R. Abdul Rahman, B.A. Gurunathan, Nano-enhanced Phase change materials: a review of thermo-physical properties, applications and challenges, J. Energy Storage 21 (2019) 18–31, https://doi.org/10.1016/j.est.2018.11.008.

[56] G. Wei, G. Wang, C. Xu, X. Ju, L. Xing, X. Du, Y. Yang, Selection principles and thermophysical properties of high temperature Phase change materials for thermal energy storage: a review, Renew. Sustain. Energy Rev. 81 (2018) 1771–1786, https://doi.org/10.1016/j.rser.2017.05.271.

[57] A. Kumar, A.K. Tiwari, Z. Said, A comprehensive review analysis on advances of evacuated tube solar collector using nanofluids and phase change material, Sustain. Energy Technol. Asses. 47 (2021), 101417, https://doi.org/10.1016/j.seta.2021.101417.

[58] M.M. Farid, A.M. Khudhair, S.A.K. Razack, S. Al-Hallaj, A review on phase change energy storage: materials and applications. Energy Conver. Manage. **45**(9–10), 1597–1615 (2004)

[59] L. Colla, L. Fedele, S. Mancin, L. Danza, O. Manca, Nano-phase change materials for enhanced energy storage and passive cooling applications. Appl. Therm. Eng. **110**, 584–589 (2017)

[60] A.S. Abdelrazik, F.A. Al-Sulaiman, R. Saidur, R. Ben-Mansour, A review on recent development for the design and packaging of hybrid photovoltaic/thermal (PVT) solar systems. Renew. Sustain. Energy Rev. **95**, 110–129 (2018)

[61] R. Stropnik, U. Stritih, Increasing the efficiency of PV panel with the use of phase change material. Renew. Energy **97**, 671–679 (2016)

[62] K. Karunamurthy, K. Murugumohankumar, S. Suresh, Use of CuO nano-material for the improvement of thermal conductivity and performance of low temperature energy storage system of solar pond. Dig. J. Nanomater. Biostruct. **7**(4), 1833–1841 (2012)

[63] M. Sardarabadi, M. Passandideh-Fard, M.J. Maghrebi, M. Ghazikhani, Experimental study of using both ZnO/water nanofluid and Phase change material (phase change material) in photovoltaic thermal systems. Solar Energy Mater. Solar Cells **161**, 62–69 (2017)

[64] A.H. Al-Waeli, K. Sopian, M.T. Chaichan, H.A. Kazem, A. Ibrahim, S. Mat, M.H. Ruslan, Evaluation of the nanofluid and nano-phase change material based photovoltaic thermal (PVT) system: an experimental study. Energy Conver. Manage. **151**, 693–708 (2017)

[65] H.M. Ali, H. Babar, T.R. Shah, M.U. Sajid, M.A. Qasim, S. Javed, Preparation techniques of TiO2 nanofluids and challenges: a review, Appl. Sci. 8 (4) (2018) 587–616, https://doi.org/10.3390/app8040587.

[66] K.P. Venkitaraj, S. Suresh, B. Praveen, A. Venugopal, S.C. Nair, Pentaerythritol with alumina nano additives for thermal energy storage applications, J. Energy Storage 13 (2017) 359–377, https://doi.org/10.1016/j.est.2017.08.002.

[67] F. Hassan, F. Jamil, A. Hussain, H.M. Ali, M.M. Janjua, S. Khushnood, M. Farhan, K. Altaf, Z. Said, C. Li, Recent advancements in latent heat Phase change materials and their applications for thermal energy storage and buildings: a state-of-the-art review, Sustain. Energy Technol. Asses. 49 (2022), 101646, https://doi.org/ 10.1016/j.seta.2021.101646.

[68] S.A. Kalogirou, Use of TRNSYS for modelling and simulation of a hybrid PV–thermal solar system for Cyprus. Renew. Energy **23**, 247–260 (2001)

[69] T.T. Chow, Performance analysis of photovoltaic–thermal collector by explicit dynamic model. Sol. Energy 75(2), 143–152 (2003)

[70] P. Dupeyrata, C. Ménézo, S. Fortuin, Study of the thermal and electrical performances of PVT solar hot water system. Energ. Buildings 68, 751–755 (2014)

[71] K.-K. Tse, T.-T. Chow, Y. Su, Performance evaluation and economic analysis of a full scale water-based photovoltaic/thermal (PVT) system in an office building. Energ. Buildings **122**,42–52 (2016)

[72] J. Bigorajski, D. Chwieduk, Analysis of a micro photovoltaic/thermal (PVT) system operation in moderate climate. Renew. Energy **137**, 1–10 (2018). https://doi.org/10.1016/j. renene.2018.01.116

[73] T. Maatallah, R. Zachariah, F.G. Al-Amri, Exergo-economic analysis of a serpentine flow type water based photovoltaic thermal system with Phase change material (PVT-phase change material/water), Sol. Energy 193 (2019) 195–204, https://doi.org/ 10.1016/j.solener.2019.09.063.

[74] C.S. Malvi, D.W. Dixon-Hardy, R. Crook, Energy balance model of combined photovoltaic solar-thermal system incorporating Phase change material, Sol. Energy 85 (2011) 1440–1446, https://doi.org/10.1016/j.solener.2011.03.027.

[75] M.C. Browne, K. Lawlor, A. Kelly, B. Norton, S.J.M. Cormack, Indoor characterization of a photovoltaic/thermal Phase change material system, Energy Procedia 70 (2015) 163–171, https://doi.org/10.1016/j.egypro.2015.02.112.

[76] Y. Zhou, X. Liu, G. Zhang, Performance of buildings integrated with a photovoltaic-thermal collector and Phase change materials, Procedia Eng. 205 (2017) 1337–1343, https://doi.org/10.1016/j.proeng.2017.10.109.

[77] D. Su, Y. Jia, Y. Lin, G. Fang, Maximizing the energy output of a photovoltaic–thermal solar collector incorporating Phase change materials, Energy Build. 153 (2017) 382–391, https://doi.org/10.1016/j. enbuild.2017.08.027.

[78] H. Fayaz, N.A. Rahim, M. Hasanuzzaman, R. Nasrin, A. Rivai, Numerical and experimental investigation of the effect of operating conditions on performance of PVT and PVT-phase change material, Renew. Energy 143 (2019) 827–841, https://doi.org/10.1016/j.renene.2019.05.041.

[79] M.C. Browne, B. Norton, S.J. McCormack, Heat retention of a photovoltaic/ thermal collector with phase change material, Sol. Energy 133 (2016) 533–548, https://doi.org/10.1016/j.solener.2016.04.024.

[80] A. Gaur, C. Menezo, S. Giroux-Julien, Numerical studies on thermal and electrical performance of a fully wetted absorber PVT collector with phase change material as a storage medium, Renew. Energy 109 (2017) 168–187, https://doi.org/10.1016/j. renene.2017.01.062.

[81] R. Simon-Allue, I. Guedea, R. Villen, G. Brun, Experimental study of Phase change material influence on different models of photovoltaic-thermal collectors, Sol. Energy 190 (2019) 1–9, https://doi.org/10.1016/j.solener.2019.08.005.

[82] H. Fayaz, N.A. Rahim, M. Hasanuzzaman, A. Rivai, R. Nasrin, Numerical and outdoor real time experimental investigation of performance of phase change material based PVT system, Sol. Energy 179 (2019) 135–150, https://doi.org/10.1016/j. solener.2018.12.057.

[83] A. Kazemian, M. Hosseinzadeh, M. Sardarabadi, M. Passandideh-Fard, Experimental study of using both ethylene glycol and Phase change material as coolant in photovoltaic thermal systems (PVT) from energy, exergy and entropy generation viewpoints, Energy 162 (2018) 210–223, https://doi.org/10.1016/j.energy.2018.07.069.

[84] Y. Khanjari, F. Pourfayaz, A.B. Kasaeian, Numerical investigation on using of nanofluid in a water-cooled PV thermal system. Energ. Conver. Manage. 122, 263–278 (2016)

[85] O. Rejeb, M. Sardarabadi, C. Ménézo, M. Passandideh-Fard, M.H. Dhaou, A. Jemni, Numerical and model validation of uncovered nanofluid sheet and tube type photovoltaic thermal solar system. Energ. Conver. Manage. 110, 367–377 (2016)

[86] M.A. Adriana, Hybrid nanofluids based on Al2O3, TiO2 and SiO2: Numerical evaluation of different approaches. Int. J. Heat Mass Transfer 104, 852–860 (2017)

[87] M. Sardarabadi, M. Passandideh-Fard, M.J. Maghrebi, M. Ghazikhani, Experimental study of using both ZnO/water nanofluid and Phase change material (phase change material) in photovoltaic thermal systems, Sol. Energy Mater. Sol. Cells 161 (2017) 62–69, https://doi.org/10.1016/j.solmat.2016.11.032.

[88] M. Hosseinzadeh, M. Sardarabadi, M. Passandideh-Fard, Energy and exergy analysis of nanofluid based photovoltaic thermal system integrated with Phase change material, Energy 147 (2018) 636–647, https://doi.org/10.1016/j. energy.2018.01.073.

[89] A. Hassan, A. Wahab, M.A. Qasim, M.M. Janjua, M.A. Ali, H.M. Ali, T.R. Jadoon, E. Ali, A. Raza, N. Javaid, Thermal management and uniform temperature regulation of photovoltaic modules using hybrid Phase change materials-nanofluids system, Renew. Energy 145 (2020) 282–293, https://doi.org/ 10.1016/j.renene.2019.05.130.

[90] M.M. Sarafraz, M.R. Safaei, A.S. Leon, I. Tlili, T.A. Alkanhal, Z. Tian, M. Goodarzi, M. Arjomandi, Experimental investigation on thermal performance of a PVT-phase change material (photovoltaic/thermal) system cooling with a phase change material and nanofluid, Energy 12 (2019) 1–16, https://doi.org/10.3390/en12132572.

[91] A.H.A. Al-Waeli, M.T. Chaichan, K. Sopian, H.A. Kazem, H.B. Mahood, A. A. Khadom, Modeling and experimental validation of a PVT system using nanofluid coolant and nano-phase change material, Sol. Energy 177 (2019) 178–191, https://doi. org/10.1016/j.solener.2018.11.016.

[92] A. Kazemian, M. Khatibi, S.R. Maadi, T. Ma, Performance optimization of a nanofluid-based photovoltaic thermal system integrated with nano-enhanced Phase change material, Appl. Energy 295 (2021), 116859, https://doi.org/ 10.1016/j.apenergy.2021.116859.