J Ther Eng, Vol. 9, No. 5, pp. 1356–1371, September, 2023

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1377246

Review Article

Heat transfer enhancement and applications of thermal energy storage techniques on solar air collectors: A review

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ARTICLE INFO

Article history
Received: 11 March 2022
Revised: 04 June 2022
Accepted: 11 June 2022

Keywords:
Concentrating Collectors; Heat Transfer; Phase Change Material; Photovoltaic Thermal Collector

ABSTRACT

Solar air collectors have been used in a variety of industrial applications, prompting a study and summary of various studies on the topic. Solar collectors' exceptional energy conversion and storage outputs have piqued curiosity in the field of energy research. The current review study focuses on solar thermal application advancements and provides an overview of thermal energy storage devices and solar collectors. This paper presents and discusses a variety of solar collectors, both concentrating and non-concentrating. The energy storage media utilized in these plants, phase change material with melting temperatures exceeding 300°C, was examined. The goal of this study is to provide the necessary information for advanced investigations in the development of cost-effective high-temperature thermal storage systems. Finally, a summary of the presentation, as well as potential solar power plants are reviewed.

Cite this article as: Azeez K, Ahmed RI, Obaid ZA, Azzawi IDJ. Heat transfer enhancement and applications of thermal energy storage techniques on solar air collectors: A review. J Ther Eng 2023;9(5):1356–1371.

INTRODUCTION

Incident solar radiation can be used to produce renewable energy for large usage of solar air heater systems and these systems use this solar radiation to be transformed into heat to provide it for usage [1-4]. The key components for solar air heaters are the absorber plate, streaming air channels, insulator for the solar collectors (bottom and lateral edges) and translucent covers. The use of blowers is non-compulsory for an air provider source.

SOLAR COLLECTORS

Reliability and good performance of energy storage have contributed to the planning of thermal applications, which has expanded the emphasis of solar energy study. For solar energy applications in addition to direct electrical energy for photovoltaic applications, solar energy may be converted to the thermal energy of a working fluid. The uses of solar heating were engrossed by a solar collector that conveyed to the working fluid as heat. The heat transmitted by the fluids could be used to deliver tempered water

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This paper was recommended for publication in revised form by Regional Editor Omid Mahian

Published by Yıldız Technical University Press, İstanbul, Turkey

for heating and to support the heating storage trough that could be utilized for heating in case of sun absence. For photovoltaic PV applications, not only the solar radiation has been transformed into electrical energy, but also the excess of wasted heat output that has been extracted for heating using the PV board connected to the operating liquid-filled tube has been converted [5].

Concentrating Solar Collectors

Heliostat field collectors

Concentrating collectors that are generally furnished with solar tracking techniques have a concentration ratio much greater than that of non-concentration collectors. The concentrating collectors may benefit from higher temperatures of liquid; hence they can accomplish a greater thermal performance. One type of the concentrating collector is the Heliostat Field, which may also call as the central receiver, comprised of multiple flat mirrors heliostats. The whole array of mirrors/heliostats is essentially required to have a proper direction for reflecting incident rays of light of solar to a general tower since the sun varies its position during the day. An automatic control system is used to control the orientation of each unique heliostat that provided power by following the altazimuth technique. Similarly, an enhanced field layout design was required so as to put those heliostats with a substantial overall optical act.

In order to optimize the layout of the field, the YNES technique was stated by Wei et al [6]. The optimization of the heliostats field geometry can reflect the solar light to the main tower, wherever the heating energy and liquid heating up to a great temperature and higher-pressure steam, absorbed by the position of the steam generator. Sodium as a liquid, or molten salts (as potassium nitrates or sodium nitrates) may be the transfer of fluid heat through the steam generator, while high-temperature silicone oil combined with crushed rock, liquid sodium, or molten nitrate salt may be the thermal storage area [7]. The tower of the central solar collector can be divided into a cavity and an external form, using the type of central receiver. At Solar One, the receiver was of the external form as shown in Figure1.

It was installed up to the central tower; a contrast was carried out between 7 m receiver diameter combined of 25 layers. Six layers were preheated liquid and the rest for vapor output. Usually, the external receivers were tested with a diameter ratio of 1:1 to 2:1 in height. In general, the receiver area was organized as small as possible to minimize the loss of heat. Although that the receiver area's lower limit was tested by the optimal temperature operation of the tubing, the heat exchanger and the heat removal capacity of the fluid heat transport, with the intention of preventing the fluid heat transfer from being overheated. By using tubes with higher temperature tolerance or the capability of higher heat removal of the fluid heat transport, the receiver's lower limit region might decrease. The heat transfer fluid (HTF) comprises liquid/steam, liquid sodium and molten salts. The higher heat removal capacity of synthetic oils between water sodium and molten salt is more than vapor and preparation oils [8]. The heliostat field flux was displayed on the absorbing surfaces of the cavity walls in the devices (about 30% to 50% of the surface area of internal absorption [8]). For convective reduction and lack of radiation, the aperture size was reduced without blocking any of the solar flux going to the receptor. First of all, the drawback to the nature of the receiver was the heat flux, which could be absorbed into the receiver surface and transported by the transmission of fluid heat, stopping the receiver from overheating walls and the transfer of fluid heat inside them. Usually, the overall wall average flux over the absorber was half to one-third of the optimal values. The temperature gradients confined to the panel receiver and the heat cycles of the tube receiver were two other major consumptions that organized heat flux.

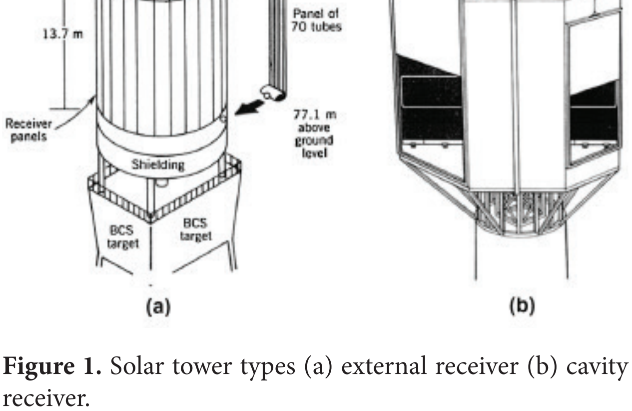

Figure 1. Solar tower types (a) external receiver (b) cavity receiver.

Parabolic dish collectors

Parabolic dish collectors utilized the parabolic dish array of mirror shapes like the satellite dish to concentrate solar emission to the receiver situated at a dish face's general local location [9]. The convection heat transfer consisting of the receiver was heated to the functioning pressures and temperatures thus an engine receiver connection could produce electrical power [10]. Sterling and Brayton engines [11-12] were included in the engines under consideration. The number of sample dish engine systems in the range of (7-25) kW is positioned in various areas of the United States. The benefits of parabolic dish engine systems were as follows: low start-up losses, high optical performance and strong modularity that can be quickly ascended to meet the remote areas' required capacity were consolidated as too costly a power supply. For several applications, Solar Total Energy Project, proposed for America [13], the parabolic dish engine technologies were presented. STEP has a large solar parabolic dish system that operated in Georgia, Shenandoah, from 1983 to1990, containing 114 points. The system produced medium pressure vapor for the pressing of knitwear, high-pressure vapor for the generation of electricity and low-pressure vapor for the operation of the AC systems at a nearby knitwear factory.

Parabolic container collectors

With a rate of concentration of about 50 and container size, parabolic container collectors can concentrate the sunlight. Here, the focal line temperature could reach 300°C and up to 340°C. Parabolic mirrors were the key components of several collectors, each of which was capable of reflecting solar radiation parallel to its axis in symmetry to its general vital line. A black metal receiver was mounted at the focal line to trap the heat collection, which was a glass tube cover for heat loss reduction. The collectors of parabolic containers could be facing either in an east-west direction; the sun was also tracking from south to north or from east to west in a south-north direction, tracking the sun. Bakos [14] performed an experimental analysis to study the effect of the two-axis parabolic trough monitoring on the obtained sunlight, and a comparison was made of the situation using a constant surface orientation (tilted in the south direction at 40°). The measured solar heating collector on the tracking face has been shown to be important. The effect of the use of various forms of solar monitoring systems on current-voltage parameters and electricity of flat-plate photovoltaic (FPPV) was studied experimentally by Aballah [15] through four forms of comparison of electromechanical solar energy systems: one vertical axis, one west-east axis, and one south-north axis. The findings revealed that on a constant face, the ampere-volt metrics on monitoring faces were higher than that, with electricity energy rising up to 43.87%, 37.53%, 34.43%, and 15.69% for these categories. In addition, the peak tilt angle altered from 13° in summer to 61° in winter was analyzed by Kacira et al [16].

Non-Concentrating Collectors

Flat plate collectors

The flat plate solar collectors are often faced with direction and must also be faced correctly. A permanently incorporated flat solar plate collector for glass caps, absorber surfaces, insulation layers, recovery tubes and other auxiliary devices. The glass covers not only decreased convective losses from the plate absorber but also minimize the loss of emission induced by the greenhouse effect of the collector. High transmittance relative to solar heating from approximately 0.85 to 0.87 and the requisite low transmittance for long-wave solar radiation from 5.0 lm to 50 lm [17-18] was the reason for finding the appropriate material glazing such as the low iron glass. Thermal and optical properties effects on flat plate output solar collectors were performed by Hellstrom et al. [19]. The results showed that the efficiency increased by 5.6% at a temperature of 50°C when applying Teflon film as a second glass layer, while the total efficiency was given by 12.1 percent by a Teflon honeycomb installation to minimize convective loss. In addition, 6.5% of the production at 50°C working temperature was supplied with the glazing cover for the antireflection procedure. The plate absorber is coated with a blackened surface for the absorption of a greater amount of heat, yet the literature stated different color coatings [20-22].

The ideal selective surfaces are composed of a thin layer on the top that is absorbed with shortwave maximal solar strength and roughly converted to thermal radiation with a long wave and a lower layer with a low emittance with higher wave radiation and higher reflectance. Selective processing performance of certain suitable optical surfaces has usually been documented at a high cost; however, some low-cost production concepts have also been stated [23]. Similarly, the absorber losing heat must also decline the solar plate to improve thermal efficiency. It was studied by Francia [24] that the addition of a honeycomb composed of translucent material confronted with the air distance between the absorber and the glazing decreased the heat loss as well. In order to avoid the overheating system [25], the receiving heat from the plate absorber ought to be quickly transported to liquids. The solar receiver heat transfer with a porous medium was developed by Kumar and Reddy [26] and a substantial 64.3% improvement in heat transfer was achieved. Lambert et al, [27] investigated the effect of the flow oscillation that can greatly increase heat transfer once thermal diffusivities boost the fluids of the solar collector. A double pass structure was proposed to Ho et al. [28] to obtain solar and to gain from the best rate of heat transfer.

Hybrid PVT collectors

Heat and electricity can be transformed from solar radiation by utilizing Hybrid photovoltaic thermal collectors (PVT). A standard (PVT) collector was used in an optimum output PV module with a range of 5% to 20% besides a plate absorber to remove heat with a back-module PV. The PV module was concurrently cooled down to a proper temperature for high electrical performance by the elimination of plate heat; it produced surplus heat that could be used for low-temperature applications, such as adsorption cooling systems and hot water for washing and/or showering [29]. Much of the relevant research on PVT collectors has recently been applied to flat plate collectors. Several investigations have focused on tube lengths and absorber plate [30], fluid flow rates [31, 32], tanks sizes [33], PV cell packing factor [34], amorphous silicon [35, 36], metal fins [37], and various passage configurations [38]. For these collectors, the numerical approach was developed; the dynamic equilibrium between electrical and thermal outputs was studied [30, 32, 39, and 40]. In addition, and based on the Second Law of Thermodynamics, Joshi and Tiwari [41] applied to the energy analysis of the PVT collector.

The collectors of hybrids can separate into those that use liquid to extract the heat and still use the air. Because of its high heating capacity and good properties, water is a unique substance as an operating liquid in the hybrid

PVT collectors. A submerged water solar heating system was investigated by Tina et al [42] and the 4 cm layer thickness was concluded to reduce the thermal drift and the reflection of their system, reducing the activity of the PVT by 14%. At first, the sunlight was essentially absorbed by the infrared water and then, the full clarity of the water in the short wavelength region was correlated with the increased efficiency. The intensity of the long-wavelength can be absorbed by liquid for the production of heat and short-wavelength emission may also be utilized for the generation of electrical power by PV. Water's natural PV layout compatibility has been verified by [43-45]. The lowest curve, including the rear face's short circuit current Isc alone at different times of day the front panel's middle curve of Isc; the upper curve, reflects the PV module faces' complete Isc. They found that the electrical energy output of the PV module was greater by 38% than the available PVT system, with no rise in system cost.

SOLAR AIR HEATERS

It is possible to split solar air heaters into two major components. The first component was related to the air channel flow setup. In order to increase the system performance, flow arrangements of different air channels can be constructed. Under this topic, four configurations of air channels can be represented:

- Single air channel flow with a single pass
- Double air channel flow with a single pass
- Single air channel flow with a double pass
- Single air channel flow with a recycled double pass

The second component was linked to air channel layout. Different style variations may be used in solar collectors for that purpose. In the second category, three subtitles can be expressed: flat plate, expanded surface supported, and porous medium supported. Here, both the primary and subtitles have been clarified.

Solar Air Heaters Classification According to Air Channel Flow Configuration

Experimental research was performed on solar air heaters using porous media [46]. They concluded that solar radiation and mass flow rate have an influence on the solar collector quality. The most popular and easiest type of solar air heater was the single air channel flow single pass, as depicted in Figure 2.

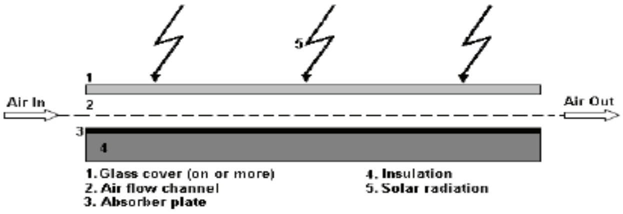

Figure 2. Shape of Single pass for single flow.

In general, for a great degree of solar absorption and as an absorber layer choice, a black plate was used. The air channel was sealed to prevent heat leakage to the atmosphere on the bottom and lateral sides. Polyurethane, glass wool and rock wool could be the most suitable insulation fabrics. The sun's light travel through the translucent shield and the absorber plate is absorbed. Since the bottom has been insulated, the temperature of the absorber plate has been raised. The heat was transmitted to the air that poured through the channel from the hot absorber layer. There was an inlet and outlet for the air to join and directly exit the pipe in the solar collector single airflow single pass. That's why several investigators have called this kind of solar air heater a "single flow single pass"[47-48].

A performance comparison between the double pass and single pass of flow solar air heater was studied and concluded that the double pass process improves the efficiency of the solar collector [48]. The double-flow solar air heater single pass was nearly identical to the single airflow single pass heater. The number of airflow channels was the primary distinction between them. As shown in Figure 3, there were two air channels in the single pass with a double-flow solar air heater. A solar absorber and a glass cover were part of the top channel. The second channel at the bottom of the first channel was composed of the same (top) absorber plate of insulation. As separated, the air has reached the collector; mid-way travels through the upper channel while the rest flows travel through the lower channel. The airflow reaches the channel with both channels and directly exits it. That was the reason why a "double-flow single pass" was described as this form of solar air listener. The heat transfer area is increased using a single pass with a double-flow solar air heater and the system's thermal efficiency could be better in comparison to a single pass with a single flow model for equal flow rate [49].

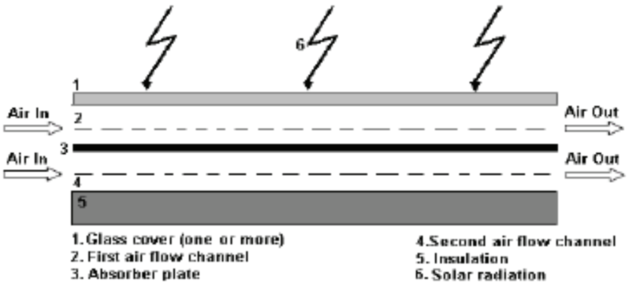

Figure 3. Single pass double flow with absorber separator.

The key purpose of using the double pass setting is to deduce the loss of heat from the facade of the collector to the surrounding region and also to increase the system's thermal performance [50]. The thermal performance of a double-pass solar air heater was experimentally constructed and produced by Gonzalez et al. [51] at INENCO theoretically developed a thermal model to explain its thermal behavior. The findings revealed an increase of a temperature of about 35 ° C with respect to the inlet air temperature, around 900 W / m^2 for solar radiation on the collector plane and concluded that the average daily productivity is 34%. Two coinciding airflow channels have been chosen in a solar air heater with double pass single flow. At the top of the channel, air flows, altered direction closed to the end of the channel, and reaches the lower channel with straight turns. This is the key reason why a “single flow double pass” is the principal reason for describing this form of solar air heater as each of them is demonstrated in Figure 4a. Here, two overlying airflow channels are present, glass split these channels and the absorber is mounted on the bottom side of the lower channel. In the second design, as seen in Figure 4b, the absorber plate is mounted as a separator between the upper and lower channels [52].

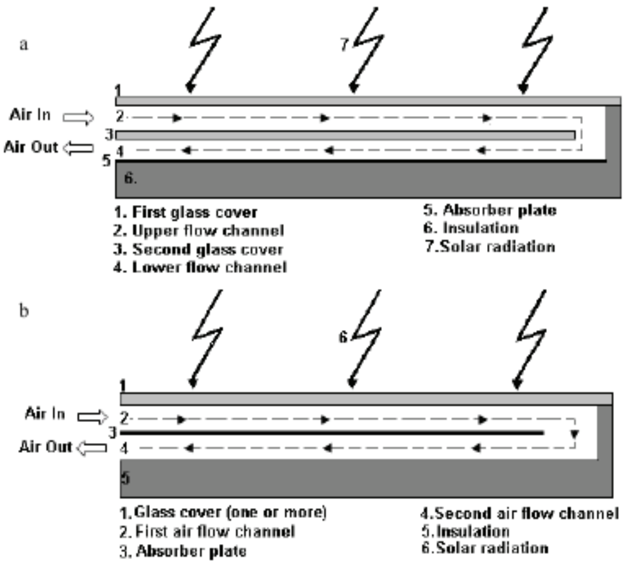

Figure 4. Solar heating of double pass single flow with (a) glass (b) absorber separators

Moreover, in the single air channel flow with recycled double pass solar air heater model, the use of recycled warm air will increase its performance and change the temperature of the air outlet [53-54]. If the output temperature differs from the desired temperature, the heated air will be partially circulated to provide the desired temperature at the exit.

Solar Air Heaters Classification According to Air Channel Design

Scientists have paid more consideration to study flat solar heating by means of practical process on the cost and performance analysis of two-pass solar heating [55]. A flat plate collector that is used for heating the air, is generally referred to as solar heating [56]. This flat plate come as the simplest form of solar air heater as depicted in Figure 5. It does consist of an absorber plate and a single or a couple of glass covers. Except for the glass shield, the solar heating sides need to be perfectly shielded to avoid heat loss. Here the air may flow either underneath the absorber plate or over it with various designs that can be developed such as single pass, double pass, double flow, or recycled flat plate solar air heaters. In general, the absorber plate has a smooth plate and does not have a fin, part of roughness, or barrier, and this sort of solar air heater is named as “Flat Air Channel” for this reason. The design of the flat air channel solar air heater is a simple low-cost design. This type of solar air heater performance is less than another version since no system or process is used to upsurge the channel heat transfer [56].

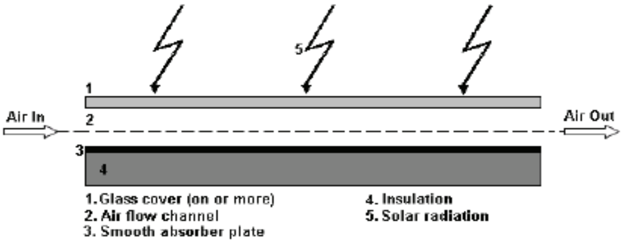

Figure 5. Solar air heater by flat plate [56].

Also, experimental and theoretical research has been performed on the thermal performance of the double pass solar air collector with a finned absorber (surfaced extended) [57]. The efficiency of the mass flow rate and solar intensity has been improved, but the efficiency has been dependent on the mass flow rate. Numerous designs have been examined to advance the low thermal performance of solar air heaters with flat air channels. The most critical factor that influenced the thermal efficiency of the solar air heaters was the type of absorber plate. Hence, a variety of absorber modifications were studied [58]. The surface area expansion of the absorber plate could be an effective procedure for increasing the efficiency of solar air heaters. The solar air heater surface area could be increased by adding fins, ribs, obstacles, or any other factor of roughness to the absorber plate, in other words by adding any other components that create roughness to the absorber layer. The solar air heater has a translucent mask, a roughened absorber plate, and insulation material that absorbs solar radiation with the help of an expanded surface of the air channel. In addition to extending the absorption field, the fins mounted or roughness portion to the absorber plate improved the mixing of air circulating in the channel and thereby enhanced the coefficient of heat transport.

Several studies have focused on improving the efficiency of air heaters by combining flat plate collectors with packed beds and energy storage systems using porous structures [59]. Single-pass solar heating and various porous media have been practically carried out [60]. Their findings showed that the solar heating efficacy of steel wool porous media was greater than that of glass wool and traditional air heaters. The porous media-aided solar air heater channel may be a helpful technique to maximize the temperature and thermal performance of the outlet air. It was also indicated that the use of a packed bed in solar air heater channel flowing increases the heat transport region and improves the air stream mixing process. The insulating material, the translucent shell, the porous media and the absorber plate used in these solar heaters are shown in Figure 6.

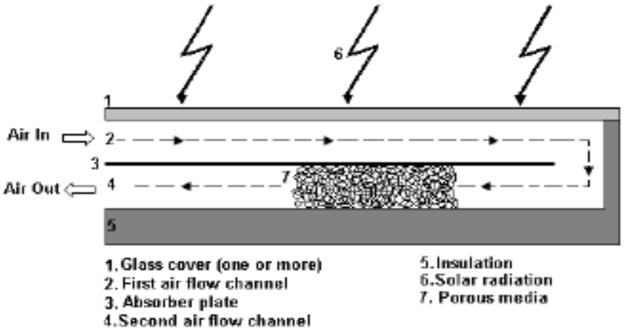

Figure 6. Solar air heater with assisted by porous media [60].

The solar air heater channel flow was introduced into the porous media. Hence, in interaction with the porous media that has been in contact with the absorber, the air flows through a pipe. Porous media heater assistance may well be built as a single pass, double pass, or recycled Nonetheless double pass systems are normally single flow. In order to accelerate the heat transfer between the air flows inside the pipe and porous media, the latter should be selected from high conductive materials. To signify a pressure, drop in the canal, the porosity of the porous media is an extremely significant factor. Although the declining porosity boosts the effective coefficient of heat transfer, it also improves the drop in pressure across the channel. Consequently, it indicated the importance to carry out studies on the features of porous media needed for the design of a device with a high rate of heat transfer and a low drop in pressure. Besides, it is evident that the thermal transition between the absorber and the airflow through the channel can be greatly increased with maximum porosity, thickness and position [61].

PERFORMANCE ENHANCEMENT METHODS

Heat Enhancement by High Conductive Materials

Combining materials with considerable thermal conductivity (sensitive heat step) via the phase change materials PCM. The PCM heat transfer storage device can be enhanced by the latent heat phase. The molten phase change materials were restrained and retained for the limited porosity found by the capillary forces and surface tension of the ceramic network, for phase change materials/ ceramic compound, and provided the use of possible direct link heat exchangers [62-66]. Petri et al [62] tested a porous media laboratory storage unit that comprised 2.22 kg of composite $BaCO_3$-Na_2CO_3 (800 °C melting point)/ MgO. Pellets of a cylindrical shape of a height of 1.5 cm and a diameter of 2 cm were used to compact the composite content. High stability of the $BaCO_3$-Na_2CO_3/MgO composite was demonstrated in the 200-cycling analysis. The use of carbonate (K_2CO_3-Na_2CO_3-Li_2CO_3)/MgO composite material as a heating storage medium to extend the cooling time in a double-wall reactor has been tested experimentally by Gokon et al. [67]. As an improvement of heat transfer, graphite was also carried out because of its strong thermal conductivity, low density and chemical resistance [68-70]. Depending on the graphite percentage, the thermal conductivity of the paraffin graphite composite can rise to 70 Wm^{-1} K^{-1}. The cost of the material can upsurge, and the space storage size may decline by increasing the fraction of graphite, the graphite quality may be limited [69]. The plastic lightweight capsules have been used for applications with low-temperature phase shift materials. The phase transition materials were often not economical to encapsulate, and the melt temperature was typically above 210°C. When the capsule is used to contain PCM, the original volume of the PCM may not go beyond 75% to survive the drop in pressure during the solidification and or melting period.

Extended Surface Area for Heat Transfer

Heat transfer distance into phase change materials can be reduced with the use of heat transfer extension surfaces such as capsules or finned tubes. These finned tube fin content can be aluminum, copper, graphite foil or steel. Table1 specified the related properties and costs for the various materials [70]. The volume-specific cost was an assessed quantity of cost, thermal conductivity, and density. It was demonstrated experimentally that graphite foil fin has the advantages over other materials, properties shown in figure 7, such as low density, good thermal conductivity, and great corrosion resistance against nitrite and nitrate salts at temperatures over 210°C.

Table 1. Properties of fin materials as specified by [70]

properties	Aluminum	Carbon steel	Stainless steel	Copper	Graphite
Thermal conductivity (W/m.K)	200	30	21	349	150
Density (kg/m^3)	2700	7811	7800	8811	999
Volume specific cost	7000	15,000	20,000	40,000	10,000

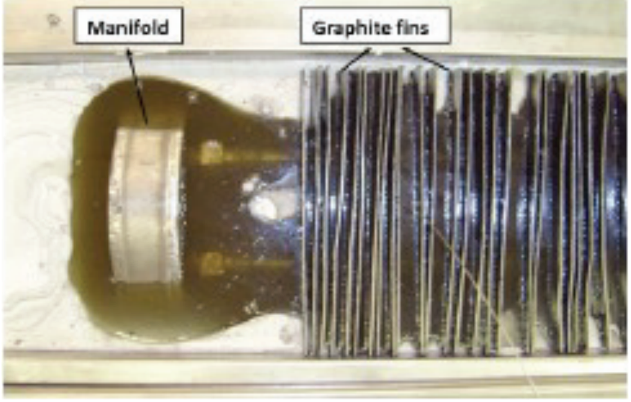

Figure 7. Graphite fins a storage unit and manifold [70].

Heat Transfer Enhancement by Intermediate Medium

Figure 8 as duplicated from [71], describes reflux heat transfer storage and demonstrates the integration of the principle of heat storage with intermedia-high conductive fluid. The principle depends on the evaporation of reflux condensation in the intermediate heat transfer fluid that occurs. The entire storage facility features a storage unit for phase change materials, and heat exchangers for charge/discharge externally linked to PCM at the top and bottom of the storage unit. The liquid intermediate heat transfer fluid was shielded by the heat exchanger charge. The liquids heat transfer fluid reverted to the gravity source tank. A hot PCM allows liquid HTF to evaporate, flowing into the top heat exchanger during the discharge process and the transport of vapor energy to the working liquid. Adinberg et al [71] effectively demonstrated the definition. As phase shift components, sodium chloride and sodium metal were used experimentally as the intermedia heat-transfer region for temperature preservation of 700 °C. The alloy of Zinc/Tin (80/30) and a eutectic mixture of biphenyl oxide and biphenyl were tested to create super-heated vapor with a temperature range of 340-399 °C [71] as the phase shift materials-heat transfer fluid method.

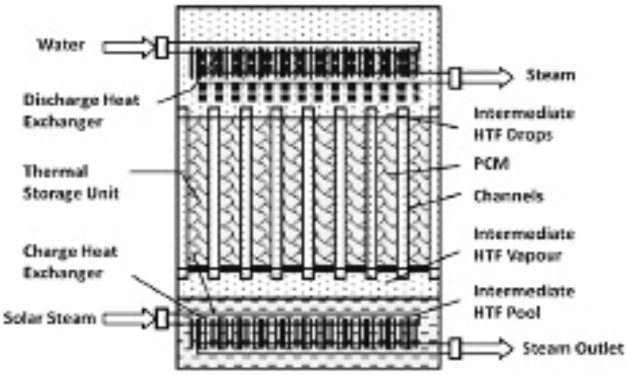

Figure 8. The concept of heat transfer reflux storage [71].

Heat Transfer Enhancement using Heat Pipes

It became brightly clear that the heat pipes have strong efficient thermal conductivity and can integrate the heating energy between the PCMs and the HTFs via the PCM storage systems. Figure 9 introduces a PCM collection device for heating by using heat pipes to boost heat transport [72]. Through the condensation and evaporation of heat pipe operating liquid occurring at the heat pipe ends, the heat pipes may convey heat between PCMs and HTFs.

Heat Transfer Enhancement with Multiple PCMs

Multiple PCMs with varying melting temperatures have been implemented by thermal storage systems to improve heat transfer technology. Fewer modules comprising of different phase change materials and different melting temperatures were secured in series in the phase change materials framework. Multiple phase shift materials have been used to increase thermal performance for latent storage systems. Choosing the right PCM was critical and the materials for phase change were relatively suitable. In shell-tube units, several PCMs ought to be in the direction of the flow as the melting temperature rises during the discharge process and decreases during the charging process [74]. The heat transfer rate was dependent on the temperature differential between the PCM and the HTF in the storage

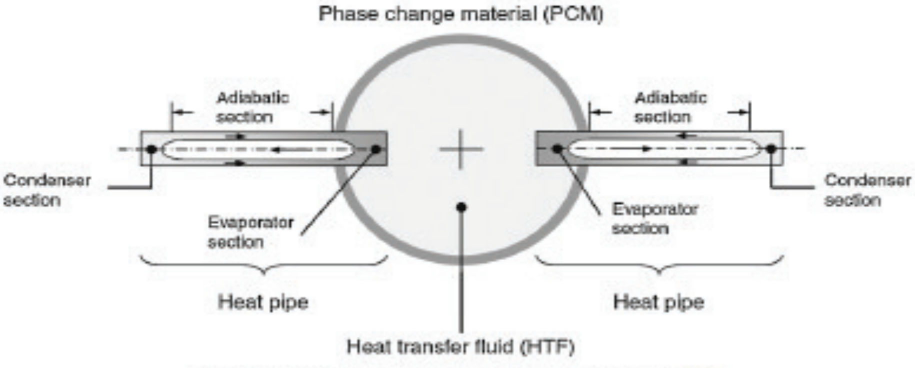

Figure 9. Heat transfer among phase change materials and heat transfer fluids using heat pipes [73].

unit. If PCM were used for a single-phase transition, this disparity steadily decreases in the direction of fluid flow heat transfer, and the consequences of the rate of reduction in heat transport. If the encapsulated phase change materials were submerged in a wide storage vessel in order to ignore the temperature difference of the heat transfer fluid with the flow direction, the multiple phase change materials may be configured as a flow direction in the radial direction rather than in the axial direction [74] in order to extract optimum achievement.

The melting mechanism of a cylindrical thermal storage capsule was experimentally observed by Wang et al. [74], packed with three-phase change materials, with phase change materials with the lowest melting point in the middle and other PCMs intended to raise the melting point from the center to the outside. For the same capsule with only phase shift materials2, the thermal efficiency was measured for the same contrast. Results found that in the three-phase change materials capsule, melting time was 36-41 percent smaller than the materials capsule for single-phase change. The thermal performance measurement of a thermal storage device using three-phase shift materials and loaded with air streaming through a number of cylindrical capsules was carried out by [75-77]. The findings revealed that the rate of heat transfer in all charging and discharge processes improved by approximately 10 percent compared to units including materials with one phase transition.

A related conclusion found that the efficiency of a thermal porous storage device based on five materials for phase change was 12% to 25% higher than those material systems for single-phase change [78-79]. Michels and Paal [80] have initiated a study to develop and validate a vertical shell and tube thermal storage device with three materials for high-temperature phase $NaNO_3$ (as a third PCM), eutectic KNO_3/KCl (as a second PCM) and shift-KNO_3 (as a first PCM). This system was adapted to the individual used for solar power plants using parabolic troughs. Michels and Hahne [81] cleared the reason that multiple phase change materials storage units have given a higher use of possible PCM. Likewise, a multiple PCMs storage unit offers a more uniform heat transfer fluid outlet temperature [82-84] and a greater energy performance [85-86].

METHODS OF ENERGY STORAGE

Energy storage can be classified into many versions such as Mechanical, Latent Heat and Phase Change Material. Here a deliberated explanation is shown in the following sections.

Mechanical Energy Storage

Thermal storages

Thermal energy as a mechanical storage may store as variation in the internal energy of a material as latent heat, sensible, thermochemical, or multiple types of combinations.

Thermochemical storages

Thermochemical energy storages are related to the energy absorbed and released in reforming and breaking molecular bonds in a completely reversible chemical reaction. Solid–solid phase change materials have given the greater design flexibility and advantages of less stringent container requirements [87]. Many types of materials were a solution of organic solid as depicted in detail in Table 2.

Table 2. Type of organic solid solution [87]

Organic Solid Solution Types	Melting Point	Latent Heat of Fusion
pentaerythritol	188 °C	323 kJ/kg
pentaglycerine	81 °C	216 kJ/kg
Li_2SO_4	578 °C	214 kJ/kg
KHF2	196 °C	135 kJ/kg

Adding these materials to the Trombe wall might enhance the efficiency more than plain concrete. The system is complex and impractical and has made large volume changes [88]. Transformations of the solid-liquid have less latent heat in comparison to liquid-gas. Though, those transformations are related to small changes (equal to or less than 10%) in volume. The solid-liquid phase showed the economic attraction for use in thermal energy storage systems. Phase change materials themselves will not be used as a medium of heat transfer. A separate heat transfer medium should be built with the heat exchanger between the transfer energy from the source to the phase change materials and from phase change materials to the load. Utilizing of heat exchanger has to be designed specially, for a view of the low thermal diffusivity of phase change materials. The volume changes of the phase change materials on melting could be essentially special volume containers proposed for wholes phase change materials. Every latent heat energy storage system, therefore, holds virtually these components:

- A suitable phase change material with its melting point in the used temperature range,
- An appropriate heat exchange surface,
- A proper container well-matched with the phase change materials.

The latent heat thermal energy storage system development was involved to understand the three important topics:

- PCM,
- Heat exchangers and
- Container materials.

Electrical storages

The battery's energy storage stored the electrical power. The battery is charged by connecting it to a direct electrical current source and discharged when the chemical energy storage is transformed into electrical power. The battery applications were using optimum energy, leveling load and storage of electrical power generated by photovoltaic plants or wind turbines. In general, most types of batteries are lead-acid and Ni-Cd.

Latent Heat Storages

Thermal properties

In a phase change material PCM selected for experimental applications, the working temperature of the cooling or heating must be coordinated with the PCM transition temperature. It may be able to lower the physical dimensions required to store latent heat, especially on a volumetric basis. Good thermal conductivity materials could support the process of charging and discharging or of the storage of energy.

Physical properties

Phase equilibrium favorite, changing small volume, high density, and low steam pressure. Phase stability at melting freezing might be assisted towards setting thermal storage and good density which allowed a smaller storage container size. A small volume of phase changes transformation and small steam pressure at temperatures working for reduction problem of containment.

Kinetic properties

The Latent Heat Storages kinetic properties included the no supercooling and sufficient crystallization rate. The supercooling was a PCM troublesome of aspect development, salt hydrates particularly. Supercooling of a few degrees of temperature can interfere with suitable heat extraction from the store and 5 to 10 °C supercooling may prevent it.

Chemical properties

The Latent Heat Storages chemical properties represented a lengthy stable chemical term, collecting with construction materials, no hazard firing and no toxicity [90]. The phase change materials may experience degradation by loss of hydration liquid, chemical decomposition and inconsistency with materials construction. The phase change materials must nontoxic, non-explosive for safety and nonflammable.

Economics

The economics have included abundant, available and effective costs. Low cost and Large-scale obtainability of materials with PCM have been also very important. Based on those simple models, the economic evaluation results show that the capital cost of using PCM-1 is 9.479-14.211$/kWhth, and the capital cost of using PCM-2 is 21.648-22.967$/kWhth, respectively. Compared to the commercial solar thermal power tower system with the thermal energy storage cost 26.22$/kWhth, using shell-and-tube type LHTES is economically competitive. The capital cost of using KOH as the PCM in shell and tube LHTES working in parabolic trough solar thermal power plant is 17.745-23.744$/kWhth. Compared to a two-tank molten salt indirect thermal storage system with the capital cost of 52$/kWhth, using shell-and-tube type LHTES is also economically competitive [91].

Phase Change Materials Classification

PCMs (eutectic, inorganic and organic) are accessible in all prerequisite temperature ranges. There were many inorganic and organic chemical materials, which may be defined as phase change materials from the temperature melting point view and fusion latent heat. Nonetheless, the melting point in the working range, the majority of PCMs do not satisfy the criteria required for an adequate storage media as pre-deliberated. Generally, inorganic compounds have at least double volumetric latent thermal storage capacity from 250 kg/dm^3 to 400 kg/dm^3 than organic compounds from 128 to 200 kg/dm^3. For their chemical behavior, each subgroup's properties, which affected the design of latent heating energy storage systems utilizing phase change materials of the sub-group, were overview in detail below.

Organic phase change materials

The organic PCMs were classified as non-paraffin and paraffin. Organic materials have consisted of congruent melting means melting and freezing repeatedly without consequent degradation and phase segregation of their latent heat of fusion, self-nucleation means they crystallize with little or normally non-corrosiveness and no supercooling [92]. Many straight-chain mixing CH_3–(CH_2)–CH_3 has consisted of Paraffin. The crystallization of the (CH_3) chain releases a big amount of latent heat. Both the latent heat and melting point of fusion improve with the length of the chain. They were chemically inert and stable below 500°C. This showed little volume changes on melting which had low steam pressure in melt form, as the Paraffin properties of system-utilizing paraffin's always had a very big cycle of freezing melt. Paraffin mixtures are not completely refined oil [93]. Quite a lot of promising characteristics of paraffin are arising such as good nucleating properties and like congruent melting. Numbers of the adverse properties have been shown by Seeniraj et.al, [86].

The most numerous of the PCM with highly diverse properties are the non-paraffin organic. All those materials would have properties unlike the paraffin's, which have similar properties. This has the largest category of candidate materials for PCM storage. An extensive survey of the organic materials and identifying the esters number, fatty acids, alcohols, and glycols suitable for thermal storage has been performed. The organic materials were sub-groups such as fatty acids and other non-paraffin organic. These materials were flammable and might not expose to flames, oxidizing agents, or excessively high temperatures. Few non-paraffin were described in [94].

Inorganic phase change materials

The inorganic materials were classified as salt hydrate and metallic. The inorganic PCM did not super cool significantly and the heat of fusion did not degrade with cycling [88].

The hydrates salt is considered an alloy of inorganic salts and liquid forming a general formula of classical crystalline solid $AB\acute{A}nH_2O$. The hydrated salt normally was melting to a salt hydrate with scarcer liquid moles, for the melting point the crystals hydrate divided into anhydrous salt and liquid, or to a lower hydrate and liquid. A single problem with most hydrates salt was that of incongruent melting. This due to the released liquid of crystallization was not sufficient to dissolve all the solid phases introduce. The reason for the density difference is the lower hydrate (or anhydrous salt) settles down to the bottom of the container. Numbers of hydrates salt also were poor nucleating properties resulting in supercooling of the water before crystallization happened. They were not corrosive, compatible with plastics and only slightly toxic. Numbers of salt hydrates were sufficiently cheap for the utilizing for storing [95]. Three behavior types of salts melted may define: congruent, incongruent and semi congruent melting. The main problem of utilizing hydrates salt, like phase change materials, which were judged proper for utilization in thermal storage, melt incongruently. There was also another general problem with hydrates salt was supercooling. At the fusion temperature, the nucleation rate was commonly too low. To benefit from a reasonable nucleation rate, the solution was to be supercooled and hence heating instead of being discharged at fusion temperature was discharged at a very lower temperature.

The metals with low melting temperature and eutectics metal were introduced. So far, these metallic were not practically considered for phase change materials technology due to the weight penalties. Although the volume was a measure of consideration, they were likely candidates due to the fusion's high heat per unit volume. These metallic were high thermal conductivities, so fillers with added weight penalties were not demanded. Moreover, the utilization of metallic poses a number of uncommon engineering complications. The main difference between the metallic and other phase change materials was their good thermal conductivity. Hence, some of the features of the metallic material are as follows:

- Low heat of fusion per unit weight,
- High thermal conductivity,
- High heat of fusion per unit volume,
- Relatively low vapour pressure
- Low specific heat.

Eutectics

Eutectic refers to a melting composition comprising two or more components in which each component melts and freezes in a consistent manner, resulting in a crystallization of a combination of the component crystals [96]. Some segregation phase change materials compositions have rarely been inaccurately defined the eutectics, since they were minimum melting. Due to the components experiencing a paratactic reaction during phase transition; yet, they must more properly be noun peritectic. Consequently, the mixture of tetradecane freezing point is 5.3°C whereas for the hexadecane is (17.9°C) [97].

Phase change materials application

The appropriate phase change materials choice for each application requires the phase change materials to have melting temperature within the range of practical application. Numbers of application fields were reported for phase change materials. It seems that most research on PCMs was conducted within the temperature range from zero to 65°C proper for domestic cooling-heating [98].

PCM containers

The phase change materials have been chosen depending mainly on the temperature application range, the subsequent main significant parameters for considering were the geometry of the phase change materials container and the heating and geometrical factors of tanks necessary for a taken quantity of phase change materials. Every single parameter od which has a direct effect on heat transfer enhancement of phase change materials and ultimately influences melting time and efficiency of phase change materials storage unit. In order to confirm the long-term thermal efficiency of any phase change materials system, the shape and size of the phase change materials tanks should be related to the melting time of phase change materials and daily insolation for the same position. This might be true only if the solar air collector was the source of energy. Phase change materials were placed in long thin heat pipes [99], cylindrical tanks [100] and rectangular tanks [101].

Phase change materials heat transfer enhancement techniques

The low thermal conductivity of phase change materials has led to slow charging and discharging rates; therefore, the heat transfer augmentation methods were found for many LHTES applications. Many researchers were focused on the heat transfer enhancement techniques in phase change materials which consist of finned tubes of various configurations, bubble agitation, and insertion of a metal matrix into the PCM, using PCM dispersed with high conductivity particles, microencapsulation of the phase change materials or shell-tube [102]. Figure 10 shows the plan of the general enhanced heat transfer techniques performed. The majority of the heat enhancement techniques were based on the fins embedded applications in the PCM. The reason for the simplicity, ease in fabrication and low construction cost was followed by the metal matrix impregnation through the PCM utilizing good materials conductivity such as carbon fiber, multitudes and brushes.

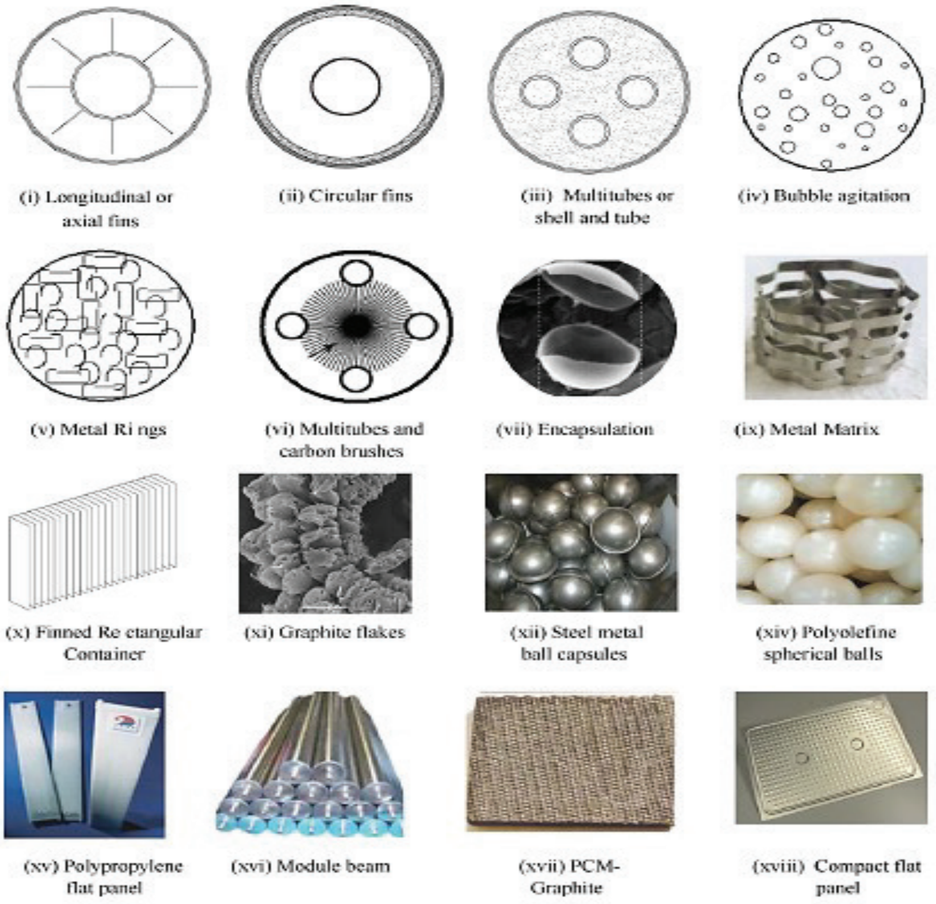
(i) Longitudinal or axial fins
(ii) Circular fins
(iii) Multitubes or shell and tube
(iv) Bubble agitation
(v) Metal Rings
(vi) Multitubes and carbon brushes
(vii) Encapsulation
(ix) Metal Matrix
(x) Finned Rectangular Container
(xi) Graphite flakes
(xii) Steel metal ball capsules
(xiv) Polyolefine spherical balls
(xv) Polypropylene flat panel
(xvi) Module beam
(xvii) PCM-Graphite
(xviii) Compact flat panel

Figure 10. PCMs heat transfer enhancement methods.

Characterizing the melting effect and PCMs solidification rates

The phase change materials systems design was related to correctly forecasting the thermal efficiency of the phase change materials system. Depending on both numerical and experimental studies carried out to test the energy characteristics of LHTES systems, different correspondences were allied linking thermal efficiency and dimensionless numbers in given parametric domains. Non-dimensional numbers were practiced in modeling phase change materials systems to the knowledge gained from these studies may extend beyond its acquisition source. In between the thermal efficiency parameters for which developed correlations and the melted volume fraction, temperature profile, melting rate and melting time. Although the significant available literature on quantifying solidification and melting rates, there was no attempt to correlate the available data. There are two main reasons why individual authors utilized different PCM with distinct heat transfer parameters. For the event where the identical phase change materials were utilized, the investigators employed various dimensionless factors ranges and introduced making it hard to cross-correlate among the characteristics affecting the heat transfer in specific phase change materials. Certain investigators introduced their findings without utilizing nondimensional parameters which makes it so difficult for extending the knowledge to applications beyond the original source.

The problems of heat transport analysis of PCM processes were complex cause the solid-liquid boundary travels depended on the speed [103]. There was much research were focused on LHTES problems. The PCM solutions problems included analytical, numerical, and experimental utilizing one, two- or three-dimensional problems for solving energy governed equations. Commissioning the enthalpy method has an advantage mentioned as the removal of satisfying conditions at the PCM front which many researchers facilitated the implementation of the theoretical algorithm. Results from the numerical methods mentioned that a good form for solving the PCM problem has been offered however, most of the accessible solutions to PCM apply to one and /or two-dimensional systems cause to the complication of the equations intricate in the PCM. The problem of latent heat phase change was supposed to be conduction controlled whereas free convection in the phase of liquid was studied in the analysis by other investigators, making the PCM to be more complex.

The reason to heat transfer accompanied is the problem arise by changing of phase would classified as: conduction

PCMs controlled and conduction/convection PCMs controlled. The conduction assumption was the major heat transfer mechanisms into the phase change materials were supposed to ignore the melt convection heat transfer. Under the convection heat transfer PCM controlled, the general assumption has been the phase change materials which at the temperature of melting. Models were not able for guessing exactly the melting rates nor tracking the intricate movement of the solid-liquid interface along the times into PCM [104].

CONCLUSIONS

With the emphasis on heat transfer enhancement and application of thermal energy storage techniques, couples of the major subsystems are reviewed such as;

- Heating energy storage
- Solar collectors
- Solar thermal applications.

Several solar collectors of concentrated and non-concentrated forms are discussed and showed that the PVT solar collectors result in the uppermost performance for non-concentrating collectors. Here, in order to resolve the poor heat transfer for these applications, heat transfer augmentation is required. Graphite composites and metal foams have been tested to be the best resources for this reason. Generally, a small graphite fraction of the composite is desirable in order to achieve high storage densities and keep costs low. The present state of existing solar power plants is being revised, with new improvements being proposed for future studies. All materials with melting temperatures exceeding 310°C were involved in the high-temperature phase transition. The promising compounds included eutectic salt, pure inorganic salts, eutectic metal alloys and metals. Pure inorganic salts and eutectic salts are concentrated on low-cost chlorides, nitrates and carbonates. It tests the measurement of the thermal properties of different materials for phase transition.

Heat storage technologies are utilized in any type of application for instance in solar air heating systems, solar water heating systems, solar greenhouse systems, solar cooking systems, home space cooling and heating applications, off-peak energy storage systems and waste heat recycling systems. The melt fraction analyses of the limited known phase change materials used for various heat exchanger container materials in many storage device applications are also introduced in this review article. Research and development are focused on both the resolution of the materials and concerns of particular phase change and the analysis of the features of new materials.

The current review paper indicates that the multiple heat transfer solution approaches conducted by different investigators have been used. The theoretical, numerical analysis and experimental work have been conducted on innovative materials thermophysical properties with phase change. For melting temperatures in the range of 300-550 °C, the fusion latent heats of more future phase shift materials in binary and ternary chloride eutectic salts are five pure inorganic salts dependent on hydroxides and nitrates. Researchers have also discovered high latent fusion heat, much of which was over (250 kJ kg^{-1}). One component of designing a high-temperature phase shift thermal storage device has been the identification of acceptable phase change materials. The increase in system thermal efficiency is because of the low thermal conductivity of salts which is a difficult factor. The thermal efficiency enhancement techniques used in phase shift high-temperature thermal storage systems.

For future work, the improvement of the thermal cycling behavior and the adaptation of the characterization procedure in order to exclude the heterogeneity effects of the composites have to be considered. This should give a good understanding of how the thermal conductivity values depend on thermal cycling and the direction of measurement.

NOMENCLATURE

$BaCO_3$	Barium carbonate
CH_3	Methanide
FPPV	Flat-Plate Photovoltaic
HTF	Heat transfer fluid
$K2CO_3$	Potassium carbonate
KHF_2	Potassium bifluoride
$Li2CO_3$	Lithium carbonate
Li_2SO_4	Lithium sulfate
MgO	Magnesium oxide
Na_2CO_3	Sodium carbonate
PCM	Phase Change Material
PTC	Parabolic Trough Collector
PVT	Photovoltaic Thermal Collectors
Tetradecane	Tetradecane $C_{14}H_{30}$
Hexadecane	Hexadecane $C_{16}H_{34}$
YNES technique	Method of data analyze from full and partial factorial design experiments

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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