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A Phase Change Material Technology Review Paper in Solar Energy Uses and Storage

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Abstract

The rapidly rising issue of declining the non-renewable resources available has focused the world attention on how renewable resources can be better used and harvested. Solar energy is one of the essential sources of renewable energy. Solar energy is a source of renewable energy for various applications in the world today. The present study is regarded as a summary of early studies on utilizing phase-change material in the use and storage of solar power. Due to its high thermal density, the isothermal nature and the easy power, the late thermosetting with the material is an advantageous way to store thermal energy. This paper summarizes how thermal energy can be efficiently stored via PCM in thermal energy storage systems of solar collectors. PCMs are isothermal, have higher density energy storage and are capable of operating in varying temperature environments. Therefore, an attempt was made in this paper to summarize an analysis of the various applications of phase change material (PCM), even solar collection device integrating PCMs.

Keywords: PCM; solar energy; solar collector; energy storage.

1. Introduction

Energy is the basis of all public uses worldwide. Different fields of life (e.g. electricity production, manufacturing, transport, domestic needs, etc.) are beginning to increase the resources required in the course of time. All human energy consumption has been catered for by fossil fuels [1]. Renewable energy will play an important role in the energy supply in the near future. In comparison to those for fossil fuels, renewable energy has big features.

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The sustainable use of renewable energy does not pollute the atmosphere, although the atmosphere does not suffer from sustainable fossil fuels and causes significant pollution [2]. The most available renewable energy sources are solar energy. The sun emanates thermal energy to the Earth, which forms 60 percent of its entire energy and reflects and absorbs the remaining energy in the atmosphere. The foundation of all known sources of energy , such as wind, fossil fuels and others, is solar energy. Solar energy can be transformed into electrical, thermal, photovoltaic and solar. The key solar energy issue is that solar energy is not always continuous and can be overcome by thermal storing [3,4]. The research presented provides an overview of the recent studies of solar storage by PCM. They discuss energy storage classification, phase change materials integrated in solar generation, solar water systems and solar heaters and end with the use of phase change material as a solar dryer. An associated study investigated the energy storage media of solar PCM dryers.

2. Typical Energy Storage

Energy storage aims at saving energy during its availability and using surplus for storage. The stored energy can be used during its absence later on. At the end of the day, the stored energy is used to balance consume energy and the supply energy. The stored energy can be in variant forms like storage electric energy, storage mechanical energy, and storage thermal energy.

a) **Sensible heat**: When a finite amount of heat of thermal energy is used to increase the temperature of a solid or fluid medium, a certain amount of sensitive heat is retained.

b**) Latent heat:** Latent heat storage is used to store thermal energy in the material. Latent heat is a calculation used to calculate the amount of heat provided or drawn from the material to change from one phase to another phase or vice versa.

c) **Both sensible and latent heat**: Using sensitive heat and heat storage latent.

3. Materials phase transition

All materials are materials for phase transformation. The key difference between these compounds is the temperature of the phase transition. At different temperatures, each material changes its phase. Moreover, the importance of latent heat and thermal conductivity is different for each material. Each PCM has its advantages and drawbacks and no typical material is available for PCMs. Furthermore, as shown in Figure (1), PCMs can be graded. Some PCMs that use latent heat for energy storage are then characterized [1]:

-- Physical thermal characteristics:

1) Agree to the use of the temperature adjustment for phase application.

2) Latent heat per unit weight is high.

3) They are of high thermal conductivity when solid and liquid.

4) The transition from phase to phase should be low in volume.

5) High volume over mass.

6) Low variety of density among changes in phases.

7) High-specific heat for use in critical heat storage processes.

-- **Proper chemistry**:

1) Later, several process series, chemical stability.

2) There is no phase separation or chemical dissolution.

3) After several process series, no shift in value.

4) No combustion liability, no degradation, no toxicity.

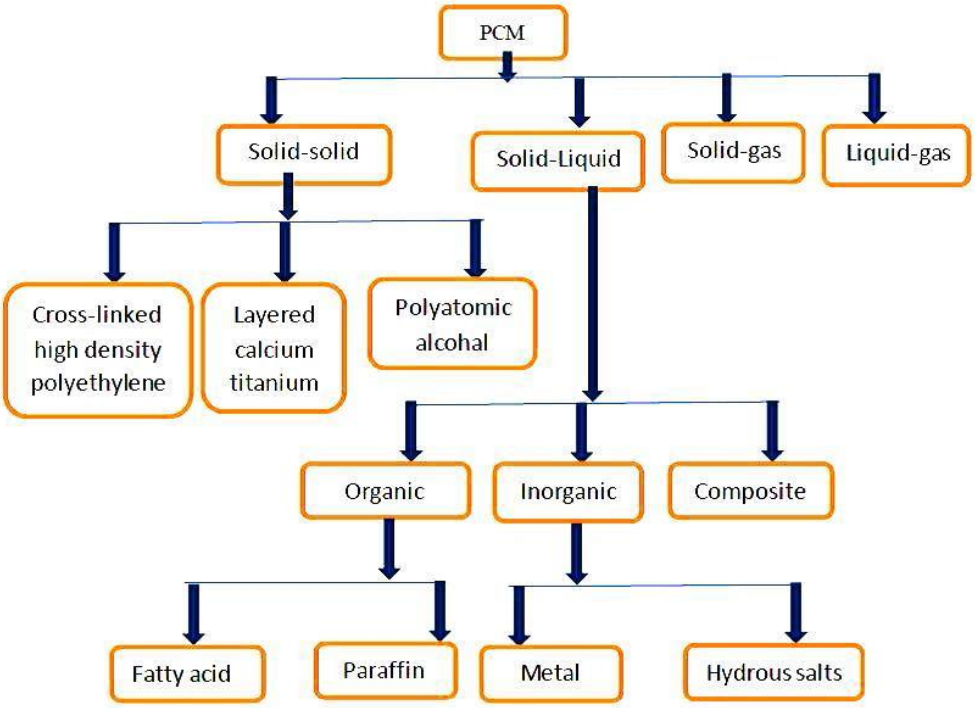

Figure 1: Classification of Phase Chance Material (PCM)[5]

4. Literature Reviews

Investigation of the above-mentioned vulnerabilities is continued in this field. Theoretical, numerical, and experimental, by using various Solar Collectors, are used in different models. The first type is by the use of solar collectors and the second type is through photocells since solar radiation can be transmitted through thermal or electrical energy. In order modeling of the method of heat transfer of the latent storage heat (LHS) system from a packaged spherical bed with PCM-filled capsules, Reference [6] a simplified, one-dimensional development transition models with a Limited divergence Strategy and mesh movement method to analyze working flow, mass flow and capsule temperature of fluids. A model in mathematics of the flat storage phase heat tank was developed in 2013 based on the theory of thermal transfer change by [7]. MATLAB has specified some major parameters with the iterative program in the heat storage flat-phase change tank, heat storage setup, inlet temperature, volume flow, the heat transfer effect PCM type. Shukla and his colleagues [8] theoretically studied PCM as a store for heat water by using sun-producing electricity. In the device study , i.e. solar, PCM and without water heating. In addition, the study dealt with the solar collector types as well as material storage types as sensitive and latent heat. The results show that PCM improves thermal efficiency. Reference [9] have developed and carried out CFD numerical simulation in two dimensions on a natural convection model for changes in porous media during the melting process. The numerical findings show that the natural convection at the melting region's top is large, and that the angle between the melting surface and melting time is rising. Esen and Ayhan[10] have compared the two models, One is in the tubes and the HTF flows parallel to it while the second is the PCM, and the HTF flows parallel. Similarly, they compare the other versions, as mentioned above. Due to fluent simulation, the former model is superior. Kürkü, and others [11] suggested a new approach to increase the thermal efficiency of the flat solar collector by installing two storage components in the collector frame in Figure (2). Both storage areas are made of galvanised steel plate and have upper and lower portions of paraffin wax and water. In December, testing was done in Turkey. The proposed design substantially enhances the characteristics of the heat transfer collector in terms of absorption and heat transfer coefficient. The system also lowered costs by almost 41.6% relative to the regular solar collector. In addition, several researchers have also examined the feasibility of incorporating phase Change material into solar collectors by adjusting phase Change material charakters, such as melting and thickness, or by analyzing optimum collector-design parameters.

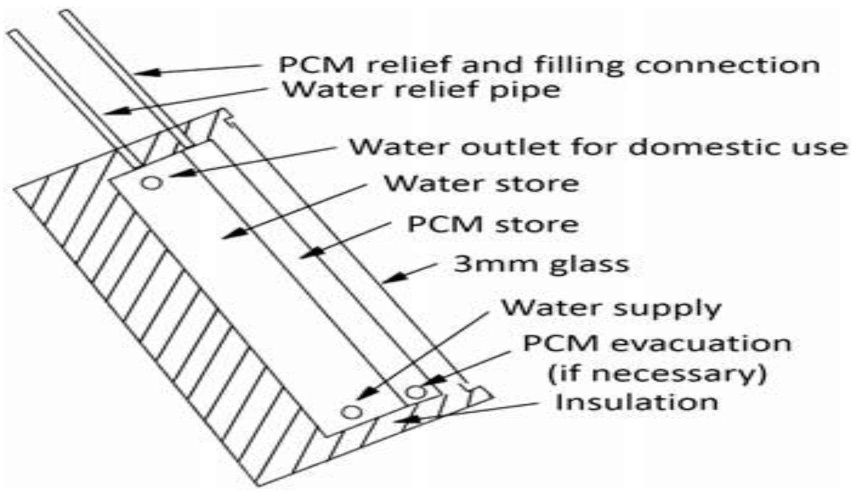

Figure 2: The diagram of the solar collector [11]. PCM, content for PCM.

Ahmet and his colleagues [12] studied theoretically the type of solar collectors whose area was 1.44 m^2. This collector comprises two parts. The first part has water. The second has PCM with a freezing and melting degrees of 45-50 ^{o}C which was paraffin wax. The results showed that hot water which we get from the system was more than 55^{o}C during a typical day time with a high sun radiation, in addition to a temperature of more than 30 ^{o}C during the night. The instantaneous thermal efficiency ranges between 20-80%. It was also found that this system reduces in cost and size of the system in Turkey. In order to experimentally investigate the output compared to the traditional SWH method, Khalifa and his colleagues [13,14]. An installed solar collector with a container containing a PCM as a TES media has been developed and installed. The tests took place in Iraq in winter. Six copper tubes 80 mm across external diameter equal to 15 mm and thickness equal to 1 mm were connected in series. In the rear layer of this collector, the waste heat was absorbered with a melting temperature of 46.7 degrees Celsius of 42.4 kg paraffin wax. In January and February, these tests were performed outdoors, and in Baghdad , Iraq, a half cloud day in March. The results showed that, depending on the environmental conditions, the instantaneous effectiveness of the solar collector variated from 45% to 54%. In addition, in January and February, the authors observed that the increases in PCM- and plate temperatures were virtually the same. In March, furthermore, the phase change material stored more heat and the average temperature of the plate was higher from midday to sunset. Finally, paraffin wax was found prosperous technology for increasing compact SWH systems thermal efficiency, which use heated material stored in solar collectors and rely on the environment . An experimental research by Al-Hiniti and his colleagues [15] examined the efficiency of solar water heating systems using phase changes content, PCM. A cylindrical storing tank containing paraffin wax PCM was used with a solar plate array packed in hot water. To conduct the initial heating, a heater was connected to the tank water. Work in this system was based with a closed loop on traditional natural circulation. The findings have shown that water temperature in the tank is 13-Celsius degree higher than traditional systems and higher than the ambient temperature, 30 ° C higher . El-Basuoni and his colleagues [16] suggested an experimental comparison of a urea-sodium acetate trihydrate (USAT) mixture with a melted urae solar flat plate – sodium acetate trihydrate – trihydrate conductor (USATL). In September, experiments were carried out in El-Minia, Egypt. The results demonstrated Reverse proportionality during USAT cooling process between release stream rate and download time. The results also showed a negligible effect on the total energy extracted from USAT. Furthermore, the finding of the USTL cooling process have shown a major impact on the energy derived from the discharge rate. Finally, the total solar system efficiency of the USATL system was greater than that of the USAT solar system. Reference [17] carried out an experimental and theoretical study of latent thermal heating for a heating system for water. The energy storage tank and auxiliary energy supply have been used to satisfy the heating requirement. Mean collector and heat-season storage efficiency values were 0.60 and 0.70, and the unit was fitted with a 30 m^2 water solar collector. Due to the cloudy conditions for many days, the solar charging fraction for the same PCM collector was not the same as the collector's and storage efficiencies and its maximum value for 0.30–0.35. Reference [18] designed system is a solar pump (30 meters square) connected to the cylindrical heat storage tank loaded onto the heating solar pump. phase change material with an embedded capacity of 1090 kg ($Ca_2Cl_2 \cdot 6H_2O$), which operates in Two Modi. First when the solar or the weak, cold water flows into the heating storage unit and second when a heated pump occurs. Zhang and his colleagues [19] performed experimentally study of a solar collector with and without heat shields. The study was evaluation and comparative for performance. The practical analysis showed that the evacuated solar collector was better with heat shield especially with high temperature conditions. The calculated efficiency of the solar collector was 54.70% with heat shield at high temperature 123.9 °C, its efficiency was found to be 31.49 % higher than the efficiency without heat shields. The heat loss coefficient of solar collector was counted and was found to be 50.8 % less than without heat shields and so the performance of the system has improved. Reference [20] have studied the design of latent heat storage with small polyethylene capsulated PCM spheres, which form porous media in the construction ventilation system duct. In this analysis, they assumed that ambient air was first heated on the solar roof and then latent stored and entered live spaces as preselected ventilation air and concluded that heat storage dimensions should be optimized during the season rather than the selected typical days. The solar roof measurement results suggest that the ambient air is cooled (3 – 4) K in a clear summer evening and that radiant cooling can be analyzed during the summer nights. Reference [21] studied phase change material (IGT) loading and discharge processes as storage and carried out maths. One main conclusion of the analysis, both from the perspective of first and second law, is, that the main benefit of phase-change storage material, in comparison to the size of packaged beds using a sensible heat-storage material, is enhanced storage capacity . Silva and his colleagues [22] the melting and solidification of paraffin wax in an upright rectangular container, experimentally and mathematically, and concluded that there were correlations can be used for a quick estimate of charge and discharge time, thus making them helpful in design of a latent thermal-energies stock of this kind. There was a fair amount of effort to study the increase in efficiency by the use of multiple phase change materials in various LHTS unit configurations. Reference [23] used three phase change materials from several melting points in the cylindrical capsules. Air was used as HTF. The three phase change materials have been used to melt and solidify both at the load and at the discharge of all three PCMs simultaneously, and a phase change process has begun at different times, as in one phase change material system. As phase change material in greenhouse heating for 7.2 m^2 ground surface, Reference [24] measured $CaCl_2 \cdot 6H_2O$ and polyethyleneglycol. They compared traditional greenhouses with greenhouses of type PCM. The greenhouse efficiency of a solar collector installed phase change material storage was 59%, and at night, when the external temperature fell to 0,6 µ C, 8 barrels C was maintainable inside the greenhouse. To create more accurate and sophisticated control for solar greenhouse systems, a microcomputer control system was developed . The efficiency of Shape Stabilized PhaseChange Materials (SSPCMs) with a peak-phase temperature of 30.5 ° C mounted around the refrigerator condensing tubes was investigated by Cheng and his colleagues [25]. It was found that the temperature of the mid-point and outlet condensers were reduced respectively by 2.3 ° C and 6.5 ° C and 12% energy was saved as opposed to a normal cooler. Riffat and his colleagues [26] performed an experimental study on cylindrical evacuated solar collector system, using water and paraffin wax in different percent's as PCM in order to know the thermal performance in this system. It was found that water in a partial filling 25.28% in the system gave a greater overall thermal efficiency compared with other cases: water with 100%, PCM with 22.43%, and PCM 56.7%. This is during the charging and discharging period when no energy input. The new design of the cooled trucks made up of an off-vehicle cooling unit and an on-vehicle PCM storage unit (melts at -26.7 °C) was developed by Liu and his colleagues [27], as indicated in Figure. 8. Compared with traditional systems without PCMs, energy consumption was decreased by up to 86.4 percent. Ahmed and his colleagues [43] proposed a new method for the reduction of heat transmission for trucks fitted with paraffin-based PCM isolating walls. By the addition of phase change material to the insulating foam on both walls, the overall heat transfer was averaged by 29.1 per cent and the daily heat flow to the cooled compartment by 16.3 per cent on average. The results of measuring a hut with PCM in its wall, ceiling and floor heating system, were numerically analyzed by [28]. With a melting temperature of between 27 and 29oC the inner wall was bordered with phase change material DuPont Sheets. phase change materials with lower melting temperatures in walls were found to be efficient in building comfort improvements and cost savings of 42 percent were achieved with corresponding energy savings of 32 percent . The effects of phase change material wallboards on summer thermal comfort on buildings were numerically investigated by Evola and his colleagues [29]. phase change material wallboards may be mounted on the interior surface of the partition walls to minimize the peak operating temperature by 1 °C. In addition, a major attenuation was observed in the swing of the divisions' regular surface temperature, as shown in figure. 15, with a peak surface temperature decreased in the second day from 29,7 °C to 28 °C, with a daily swing of 5,7 °C to just 2,9 °C . The efficiency of a solar thermo syphon heater with a built-in latent heat storage device through a phase change material has been examined numerically by [30]. The phase change material was found to have a melting temperature of 61 °C, 51 °C, 43 ° C and 32 °C. In comparison with and without a thermic energy store the author compared the solar heater efficiency. The numerical results show that the solar air heater used with a phase change material has better efficiency at melting temperatures of 51 ° C and 43 ° C. It also indicates that the air heater had a minimum thermal discharge of 0.01 kg s / h when the mass flow rate equal to 30 m / h while the temperature of melting in phase-change material was 43 ° C during the night. In addition, the average solar air heater performance was between 27 and 63.8 percent depending on the phase-changing material melting temperature. In an experimental study [31], carried out an extension of thermal energy storage operations to a solar water heating system. As shown in Figure (3), an open-air experiment has been performed with a flat platform solar collector integrated with paraffin wax as a phase change material. The used paraffin wax was melted and retained respectively at 60.45 degree Celsius and 58.84 degrees degree Celsius. Two cases were compared: with and without PCM. The results of this study showed that the efficiency of the system was 52 percent with a 10 ° angle and a mass flow rate of 0,5 kg / min. The efficiency of the system was however 51% with an inclination angle of 20 ° and a flow of 0.5 kg / min. Under slope angles (10 ° and 20 °) also provide hot water during the day with a temperature of about 38 ° C. The findings also showed that more solar radiation was obtained by the 10 ° inclination angle. This made it easier to melt the Phase change material.

Figure 3: Phase change material integrated solar water heater system [31].

To validate the PCM-integrated solar air heating system and ensure comfort in winter, a numerical simulation was carried out by [32]. The author used a blend of salt and paraffin wax as a pcm in this work. Different temperatures of the melting points in a PCM: 19 ° C, 21 ° C and 23 ° C were performed. The rates of mass air flow often range from 10 m2 / h, 15 m2 / h, and 20 m2 / h. The numerical analysis showed that the thermal storage unit performs better when the temperature in the melting pot of the PCM is equal to winter-month medium comfort. Therefore, if the melting point temperature of a Phase change material deviates from the comfort temperature, the thermal storage output will be retracted. Reference [33] has theoretically and experimentally studied phase-change material PCM as storage medium for solar single basin still for optimum efficiency. Two types of PCM were used: paraffin wax and stearic acid. Considering the theoretical aspect, Matlab programming has been used to incorporate energy and exergy equations for thermodynamics first and second law, and equations have therefore been solved and the distribution temperature has been set. The work took place in five cases: in different PCM types, with varying depths for water and certain parameters such as solar radiation , ambient temperature, dew point and relative humidity influencing distillate development and device performance. The findings demonstrated that the use of paraffin wax results in greater day efficiency compared to 16 percent stearic acid. An increase in PCM thickness leads to productivity growth. With rising depth of saline water in the still basin, this productivity decreases. Solar radiation has a greater influence on device efficiency. With rising dew-point and relative humidity, the still productivity decreases. Strong agreement emerges when comparing the outcomes . In order to run a simulation for various latent cascade (CLHS) configurations, Reference [34] used a numeric model to use the "Dymola / Modelica" Standard Library in Tech Thermos. Some assumptions were made for simplifying the model: the material of phase change was intended to be a lumped mass with the same temperature distribution. Normal convection for the simulation was also believed. The results of the experiments were the desired results, and their model was validated . Cheralathan and his colleagues [35] have developed a simulation for studying the transient output of a phase change, material-based cool thermal storage (CTES) system consisting of a cylinder storage tank full of encapsulated PCMs in spherical containers integrated with the ethylene glycol chiller plant [35]. Water-soluble 30 wt. As the HTF and distilled water, the percentage of ethylene glycol was used as Phase change material with heterogeneous nucleation agents. Energy charging for this capacity was found to need less storage energy for storage systems designed for higher Stanton numbers (> 0.5) and higher porosities (> 0.49), whereas systems designed for higher Stefan numbers (> 0.4) and higher porosity (> 0.60) have lower energy. It was found that Therefore, moderate stefan number values (0.2-0.4), porosity (0.40-0.49) and higher numbers (0.7-1.0) should be selected for better and faster energy storage. In order to determine the technological feasibility of using an automotive cooling thermal accuser containing advanced PCM material, Kim and his colleagues [36] submitted a FORTRAN code numerical analysis. The innovative idea of automotive cooling is to store a great deal of thermal energy in the heat build-up and thus to minimize the total size of the cooling system. It has a latent temperature of 339,8 kJ / kg with a melting point of 118 ° C; erythritol was used as a PCM. This cooling technique was found to reduce the inventory size of coolant by 30 percent, thereby minimizing the period of coolant warming during the cold start and thus the harmful emissions . Al-Hinti and his colleagues [37] performed an experimental water efficiency analysis for the use of traditional solar water heating systems with phase-change material storage. The aim of this study is to compare the use of water alone and water for thermal storage using paraffin wax. In small cylindrical aluminum tubes, paraffin wax at a temperature melting of 52 ° C, latent heat 230 kJ / kg and a thermal conductivity of 0,25 W / m. K is used as a PCM. The Hashemite University in Jordan, locating 32.1 ° N/ 36.2 °, €and the world average maximum radiation horizontally was 750 W / m2 during April, performed experiments during the first – 24 April 2008 sessions. The results have shown that when the water within the tank reaches 50-55 ° C, the use of this phase-change material design offers a gain of 13-14 ° C over 14 hours after the termination of the input energy under the same natural circulation conditions relative to conventional sensitive storage systems. Whereas water and PCM are used only as storage medium and water and a short forced circulation cycle have had a small effect on system performance. The experimental analysis of the solar-contained collector in combination with PCM was carried out by [38] to improve the thermal efficiency of the system. Paraffin wax was used as PCM. The solar collector includes pipes for water transmission and the PCM transmission. Different water flow rates were obtained for 8.3-21.7 kg / min, so useful heat gain Qu was obtained. The results show that the average coefficient of heat transfer, which increases sharply as the thickness of the PCM coated layer increases because all these events develop strongly during the loading time. During the discharge time, the heat produced increased as the water flow rate increased.

Lamberg and his colleagues [39] conducted an experimental study validating a FEMLAB software numerical model which predicts the compliance of different materials for phase changes during the process of solidification and melting. The Enthalpy method and the Efficient Heat Capacity method have been tested in two numerical methods. To perform experimental work on these two PCM storage tanks were planned and developed. Store 1 without improved structures of heat transfer during Store 2 with improved heat transfer (e.g. fins used). Storage 2 Paraffin grade of technology has been used as PCM. The result showed that all of the numerical results offered good estimations of melting and freezing processes, while the most accurate way of comparing the results to the experimental results was the efficient heat capacity way with a small temperature range (e.g., alternating H = 2 ° C). Therefore, the ease of adjusting the geometry and parameters of the storage system allows the customized PCM storage systems to be faster built particularly for various electronic applications . Reference [40] has carried out experimental studies to explore the probability of increasing paraffin enthalpy melting and solidification by ionomer sulfonation. The sulfaxes at three different mole percentages were two different forms of paraffin (docosane and hexacosane, respectively with melting points of 317.15 and 329.45 K). Fourier transform infraround (FT-IR) spectroscopy proved the sulfonation of paraffin samples. Adiabatic Bombs The calories of the differential scanning system used to calculate melt enthalpys and docosane solidification, hexacosane (HSC) and their sulfonated derivatives were used to determine paraffin sample sulfonation amounts. The sulfonation technique is achieved by the formation of acetyl sulfonate from paraffin 1, 2-dichloroethane solution, from sulfuric acid and acetate anhydride. DSC thermal analysis demonstrate that sulfonated paraffin samples absorb and release more energy than the samples used in this study for melting and solidifying pure paraffin. In addition , the difference in sulfonated docosane and hexacosane melting and freezing points was not important. Sulfonation has therefore been found to be an effective means of increasing paraffin LHTES power. In Tyagi and his colleagues [41], an experimental study has performed thousand rapid thermal-cycle testing of inorganic salt as a latent heat storage material to establish the shift in the latent fusion heat and melting temperature of the calcium chlorite hexahydrat (CaCl26H2O). It is important to evaluate the effect of thermal cycling and the reliability of changing melting tempers through a DSC. After repeated rapid thermal cycles the experimental results demonstrated better performance of thermal properties (i.e. latent thermal fusion and melting). $CaCl_2.6H_2O$ was found to melt between constant temperature ranges and latent fusion heat variations during the thermal cycling process. An example is the improper crystallisation of the PCM, since the experiment was performed using small quantities of PCM, few milligrams, for variation of the latent fusion heat and the melting temperature . Singh and his colleagues [42] have proposed a study to investigate the impact of the operating parameters of a packaged bed solar energy storage device with large sized storage materials in various shapes on the heat transfer and pressure drop characteristics. Nusselt number and friction factor correlations have been established in the form of the Reynolds numbers, sphericity and void fraction. There was a strong agreement between the test results and the correlations' expected results. Thus, the thermal and hydrodynamic efficiency of a bunk bed used for a latent thermal energy storage device consisting of packaging material with various shapes and bed porosities in the range of parameters examined can be predicted using these interconnections . In presence and lack of thermal storage, Saravanakumar and his colleagues [43] investigated the efficiency of the flat plate SAH. They have developed mathematical models and used finite differences. implicitly to solve the flat plate SAH energy equation. In addition, the storage-performance collector was about 5-10 percent higher than the non-storage collector. The most recent studies focused on integrated PCM air heating systems, as it offers a high energy storage capacity as against responsive heat storage and the optimal solar air heater thermal efficiency . Karthikeyan and Velraj were investigating a numerical and experimental study of an encapsulated PCM bunker spherical inserted into the jar in the cylinder storage [44]. In order to test the PCM temperature distribution they used the enthalpy model and specifically finite difference technique. During the loading and discharge phases, the same energy gain was also shown to be 0.015 kg / s. The concept was suitable for air-PCM heat storage and drying applications in solar space heating systems . The analysis of the PCM-based solar system was numerically predicted by [45]. It was shown to improve thermal conductive properties using aluminum foam injected into PCM paraffin wax. The findings investigated the impact on both the rise in heat transfer and the PCM fusion / freezing rate of aluminum foams in paraffin wax. The use of PCM aluminum foams also has been shown to be absolutely meltable in a short time although PCM purity can not fully melt . The performance of the experimentally manufactured solar air heater with phase-change material and paraffin wax was tested by Kabeel and his colleagues [46].They analyzed the (V corrugated) and flat plate-SAH thermal output presented without and with phase change material. The finding show that the V was on-the-ground SAH with PCM was 12% better than the other without phase change material and 15% and 21.3% more powerful than flat flat phase change material -SAHs air-MFR of 0.062 kg / s with and without phase change material. In this case the performance was 12% higher. In 3.5 hours at night, the (V- corrugated) platform-SAH outlet temperature was also observed to exceed 1.5–7.2 °C during roundabout 3.5 hours**.**

5. Conclusions

From the previous theoretical and experimental researches, one can notice that there is an increase in the number of researches who used the PCM with different types and in different solar collectors in order to investigate and achieve a better thermal performance. This uses the incorporation of the PCM into the solar collector and the implementation of the PCM as a latent storage tank. In the solid phase, most PCMs have very low thermal conductivity. However, various techniques may improve the thermal characteristics of the commercial PCMs available. In the light of the increased thermal power storage density of those materials as opposed to heat-sensitive storage materials, the recent research has concluded that PCMs are a storage material. The results of this review show that the PCM, which has large latent heat and a large heat transfer surface, is essential for improved thermal efficiency of the solar collector.

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