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A Review of Performance of Thermal Energy Storage System using PCM in Different Applications

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Abstract: This paper presents a review of thermal energy storage technologies with phase change materials (PCM). It has been reviewed that latent heat could store large amount of energy per unit mass. Moreover, latent heat storage could store fusion heat at a constant temperature which is the phase transition temperature of the phase change materials (PCM). There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. The review covers different methods of heat transfer enhancement techniques, encapsulation of phase change materials in Thermal Energy Storage System and solar system.

Keywords: Thermal Energy storage systems, PCM, Heat Transfer Enhancement, Solar System, Latent Heat.

INTRODUCTION

The continuous increase in the level of greenhouse gas emissions and the rise in fuel prices are the main driving forces behind the efforts for more effectively utilize various sources of renewable energy.The increasing of the population and development of the different countries converts the energy topic in one of the most important aspects of our times. The main target due to the limited life of conventional energy sources is the achievement of a sustainable energy mix where thermo solar energy plays an important role. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. The scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. It is an advanced energy technology that has recently attracted increasing interest for thermal applications such as space and water heating, cooling and air-conditioning. Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. They are highly valuable from an economic perspective. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost.

Phase Change Materials, commonly known as PCM are capable to store energy by changing from solid to liquid (melting) and releasing heat by changing from liquid to solid (freezing), as well to provide a large heat capacity over a limited temperature range.To reduce the reliance on burning fossil fuels for energy purposes, it is important to implement green energy strategies, systems and applications to develop a sustainable future. This is where alternative construction technologies and techniques, like PCM can be introduced to reduce the amount of energy consumption required for heating and cooling.

THERMAL ENERGY STORAGE METHOD

Thermal Energy Storage (TES) play an important role in the effective functioning of various systems, such as solar systems, power system, heating and cooling systems, and industrial waste heat recovery systems. There are three methods used and still being investigated in order to store thermal energy. One is the sensible heat storage (SHS), the other one is the latent heat storage (LHS) and the last one is the thermo-chemical storage.

***1. Sensible heat storage*.** Sensible Heat Storage (SHS) is based on raising the temperature of a solid or liquid to store heat and releasing it with the decrease of temperature when it is necessary. The volumes needed to store energy in the scale that world needs are extremely large. That is why the other two methods are being developed. The amount of heat stored depends on the specificheat of the medium, the temperature change and the amount ofstorage material [1].

$$Q = \int_{T_i}^{T_f} mC_p dT$$

$$= mC_p(dT_f - dT_i)$$

2. Latent heat storage. This method is based on the utilization of phase change materials (PCM). Thesematerials store heat when they go from solid to liquid, from liquid to gas or from solid to solid. Then they release energy when they have the reverse phase change. The storage capacity of the LHS system with a PCM medium [1] is given by

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{T_i} mC_p dT$$

$$Q = m[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)]$$

3. Thermo-chemical energy storage. In the Thermo-Chemical Energy Storage systems, the energy is absorbed and released while breaking or reforming molecular bonds in a completely reversible chemical reaction. In this case, the storage of heat depends on the amount of chemical material and endothermic heat of reaction.

$$Q = a_r m \Delta h_r$$

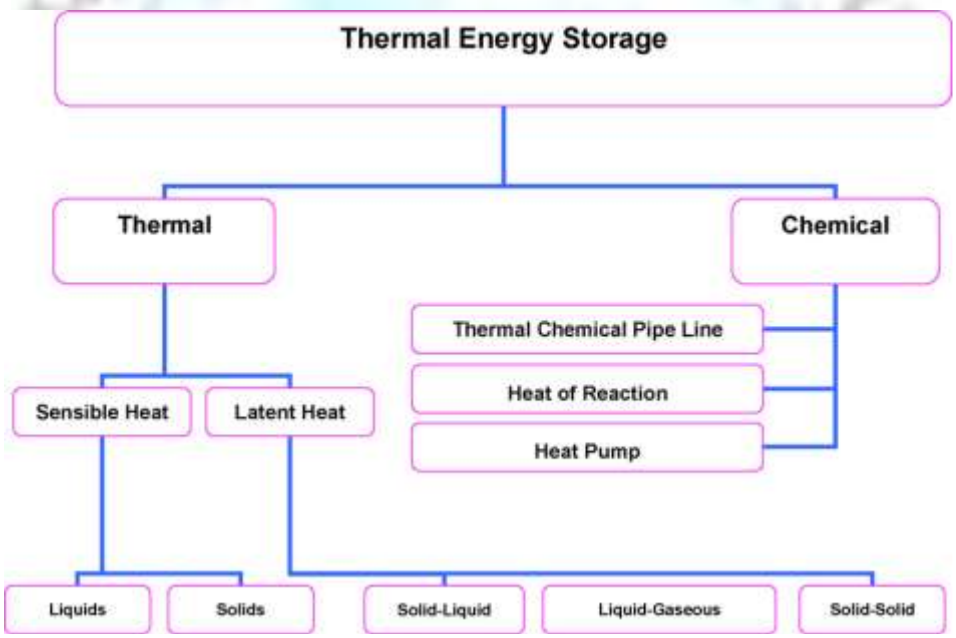

Fig.1. Different types of thermal storage of solar energy

PHASE CHANGE MATERIALS

Phase change material (PCM) utilizes the latent heat of the melting/solidification process to store energy. They are characterized by high volumetric storage density and a small temperature interval for thermal energy extraction and regeneration [2]. Latent heat storage through PCMs has the advantage of compactness because the fusion heat of PCMs is quite larger than their specific heats. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or ‘‘Phase.’’ PCMs are here divided into two main families: organic and inorganic [3]. Organic materials can be further classified into paraffin and non paraffin such as esters, fatty acids, alcohols and glycols. Inorganic materials are subdivided into salt hydrates and metallics. In 1983 Abhat [4] gave a useful classification of the substances used for thermal energy storage (TES).Among the most thorough references related with phase change materials, one can cite Abhat [4], Lane [5,6] and Dincer and Rosen [7].A large number of PCMs are known to melt with a heat of fusion in any required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic considerations and easy availability of these materials has to be kept in mind.

Thermal properties

(i) Good heat transfer.
(ii) High latent heat of transition.
(iii) Suitable phase-transition temperature.

Physical properties

(i) Favorable phase equilibrium.
(ii) High density.
(iii) Small volume change.
(iv) Low vapor pressure

Kinetic properties

(i) No supercooling.
(ii) Sufficient crystallization rate.

Chemical properties

(i) Long-term chemical stability.
(ii) Compatibility with materials of construction.
(iii) No toxicity.
(iv) No fire hazard

Economics

(i) Abundant.
(ii) Available.
(iii) Cost effective.

Table 1: PROPERTIES OF SOME PARAFFIN’S

Paraffins	Freezing Point/ Range (^oC)	Heat of Fusion (kj/kg)
6106	44	189
P116	45-48	210
5853	48-50	189
6035	58-60	189
6403	62-64	189
6499	66-68	189

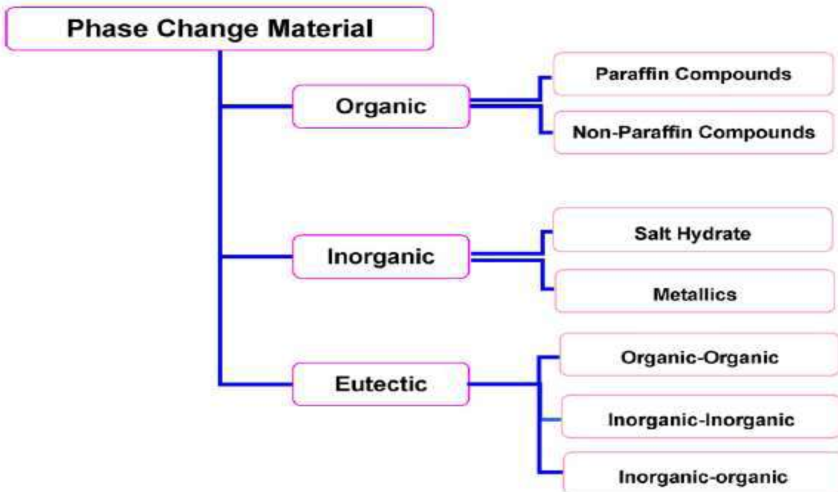

Fig. 2: Classifications of PCM

APPLICATIONS

1. Building applications. Themal storage in buildings using PCMs was one of the first applications studied, together with typical storage tanks. The firsts application of PCMs described in the literature was their use for heating and cooling in buildings, by Telkes in 1975 [8], and Lane in 1986 [5]. In 1975 the use of building structural components for thermal storage was pointed out already by Barkmann and Wessling [9], and later by other authors [10,11,12]. An interesting possibility in building applications is the impregnation of PCMs into porous construction materials, such as plasterboard, to increase thermal mass [13–15].The use of PCMs to store coolness have been developed for air conditioning applications, where cold is collected and stored from ambient air during night, and its relieved to the indoor ambient during the hottest hours of the day. This concept is known as free-cooling [16,21–23]. In order to diminish the solar gain in buildings, Ismail et al. [17,18] studied the possibility of using a window with a PCM curtain. This window is double sheeted with a gap between the sheets and an air vent at the top corner; the gap can be filled with PCM that upon freezing would prevent the temperature of the internal ambient from decreasing. Similarly, Merker et al. [19,20] have developed a new PCM-shading system to avoid overheating around the window area.

2. Solar water heater. Solar energy is not available at all times, and therefore solar installations require an intermediary storage of the energy for heating or warm water. PCM based system will offer the following benefits over a conventional system: Low volume in comparison to water storage systems and a higher efficiency due to a lower temperature difference between loading and discharging of the energy. Latent heat storage can also be implemented in conventional heating systems. Phase Change Material based solar water heater will also give a better controlled water temperature. Solar water heater is getting popularity [22], [23] since they are relatively inexpensive and simple to fabricate and maintain. Bhargava [24] utilized the PCM for a solar water heater and concluded that the efficiency of the system and the outlet water temperature during the evening hours increases with the increase in the thermal conductivity of the solid-liquid phases of the materials. Hot water can be obtained throughout the day if water pipes are placed near the surface of the storage material.

3. Solar air heater. Morrison, Abdel Khalik and Jurinak in their different studies [25,26] evaluated the performance of air-based solar heating systems utilizing phase change energy storage unit. The main objectives of their work were: (i) to determine the effect of the PCM latent heat and melting temperature on the thermal performance of air-based solar heating systems and (ii) to develop empirical model of significant phase change energy storage (PCES) units. The main conclusion was that the PCM should be selected on the basis of melting point rather than its latent heat and also found that air-based system utilizing sodium sulfate decahydrate as a storage medium requires roughly one-fourth the storage volume of a pebble bed and one half the storage volume of a water tank. Recent research involving hybrid systems and shape-stabilized phase-change material was found to yield improved thermal comfort in the winter. Zhou et al. [27] indicate that 47% normal-and-peak-hour energy savings, and 12% overall energy consumption reduction were observed.

4. Automobiles. PCM is already used today in a latent heat battery offered by BMW as optional equipment in its 5 series. The principle is quite simple, the storage material is connected to the radiator and stores excess heat when the motor runs at operating temperature. This heat is then available at the next cold start to heat up the motor quickly (better gas mileage) and for the interior (driving comfort). Due to the latent heat battery's excellent insulation, it can maintain the energy for 2 days at an outside temperature of – 20°C. As an extension to this application, PCM can also be used in tail-pipes (exhaust) of vehicles. This will maintain the catalytic converter at its design temperature, reducing excessive Hydro-carbon emissions during vehicle start up.

5. Floor and ceiling. Farid and Kong [28] constructed slabs containing encapsulated PCMs in spherical nodules. The plastic spheres contained about 10% empty space to accommodate volume expansion. Athienithis and Chen [29] investigated the transient heat transfer in floor heating systems. Savings up to 30% were reported. Space heating systems that incorporate PCMs located in the ceilings were also developed.

6. Green houses. Another application that has a major impact on power demand is the use of PCMs in green houses for storing the solar energy for curing and drying process and plant production. It is important to maintain temperatures in a small range to enable plants cultivated in a green house to flourish. However, due to large temperature swings in daytime and nighttime temperatures, most green houses need air- conditioning and/or heating. Phase Change Material installed in floor of such green houses will eliminate or reduce the dependence on air-conditioning/heating.

7. Off-peak electricity storage. Telkes [30], Herrick [31] and Gawarn and Scroder [32] studied latent heat storage system for air conditioning. Inorganic hydrous salts were used as storage material. However these studies were focused more on the development of new heat storage materials. Lane [33] suggested some PCMs for cooling and dehumidification. The PCM is frozen during off peak hours and coolness is withdrawn as needed during the day. Recently Department of Atomic Energy, Govt. of India sanctioned a R&D project to develop latent heat storage materials for the temperature range 5–158 for the storage of the coolness using off-peak power and to develop the pilot plant for the same [34]

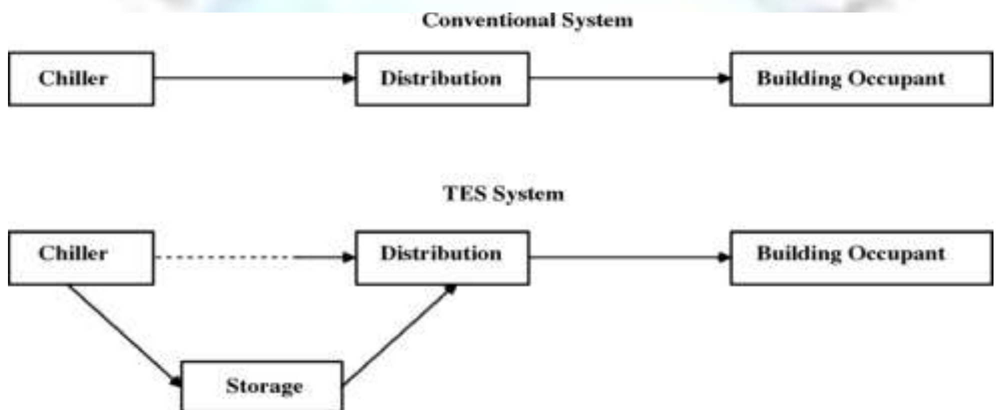

Fig. 3: Major system cooling components.

CONCLUSION

The trend for low cost, light weight construction increases the need for alternative and cost effective methods of providing thermal properties for different applications. This review paper is focused on the available thermal energy storage technology with PCMs with different applications. Those technologies is very beneficial for the humans and as well as for the energy conservation. The heat storage applications used as a part of solar water-heating systems, solar air heating systems, solar cooking, solar green house, space heating and cooling application for buildings, off-peak electricity storage systems. In a near future, PCMs will be more and more incorporated in global energy management solutions as the stress for innovative low environmental-impact technologies, the overall negative effect of energy consumption on the environment, and the cost of energy will all necessarily increase.

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