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Thermal Energy Storage using Phase Change Materials and their Applications: A Review

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Abstract: This paper presents a review on thermal energy storage using Phase change material (PCM) and their applications. Latent heat thermal energy storage offers a huge opportunity to reduce fuel dependency and environmental impact produced by fossil fuel consumption. Solar energy is a renewable energy supply that can generate electricity, provide hot water, heat and cool a house and give lighting for buildings. In response to rising electrical energy costs, thermal storage technology has recently been developed. The selection of the substances to be used mostly depends upon the temperature level of the application. Phase change materials (PCMs) are one of the latent heat materials having low temperature range and high energy density of melting– solidification. Phase Change Materials (PCMs) are becoming more and more attractive for space heating and cooling in buildings, solar applications, off-peak energy storage, and heat exchanger improvements.
Keywords - Phase Change Material (PCM), renewable energy, Thermal Energy storage, Latent heat thermal energy storage.

I. Introduction

In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. One of the options is to develop energy storage devices, which are as essential as developing new sources of energy. The storage of energy in appropriate forms, which can conventionally be converted into the essential form, is a present day challenge to the technologists. One of prospective techniques of storing thermal energy is the application of PCMs. Solar energy is a significant alternative energy source for heating applications. The use of seasonal thermal energy storage can substantially decrease the cost of solar energy systems that can supply up to 100% of buildings energy requirements. Such system can save solar energy during the summer and retain the stored heat for use during the winter. The application needs huge inexpensive storage volumes and the most promising technologies were established underground, using ground heat exchangers. Although such systems were constructed and demonstrated, it is challenging to create them cost effective. It is significant to design considerations related to cost effectiveness and enhance the thermal performance of the ground storage and the connected systems. Integrated approach for evaluating the performance of all system components should be used during the design process and determination of system control strategies. This paper provides a review on Thermal Energy Storage (TES) using PCMs.

2. Classification of PCMs

In 1983 Abhat gave a useful classification of the substances used for TES as shown in Fig. 1 [1]. The use of a latent heat storage system using PCMs is a helpful approach of storing thermal energy and has the advantages of high-energy storage density because of the isothermal nature of the storage process. PCMs were mostly used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications [2-4]. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. There are a large number of organic and inorganic materials, which can be known as PCM from the point of view of melting temperature and latent heat of fusion. As no single material can have all the involved properties for an ideal thermal-storage media, one has to use the available materials for an adequate system design. In general inorganic compounds have almost double volumetric latent heat storage capacity (250–400 kg/dm^3) than the organic compounds (128–200 kg/dm^3). Some of the essential properties required for PCMs are (i) High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy. (ii) High specific heat that provides additional sensible heat storage effect and also avoid sub cooling.

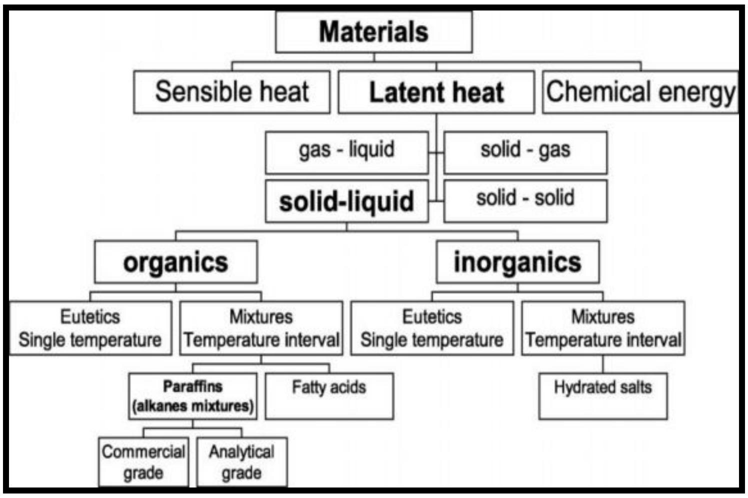

Fig.1. Classification of energy storage materials [1]

3. Thermal Energy Storage

Thermal energy can be stored as a change in internal energy of a material as sensible heat and latent heat. In Sensible Heat Storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

$$Q = \int_{T_i}^{T_f} mC_P dT = mC_{ap}(T_f - T_i) \qquad (1)$$

Where m is the mass of the substance, Cp is specific heat capacity of the substance, C_{ap} is the specific heat capacity of absorption, dT is the temperature difference, T_f is the final temperature and T_i is the initial temperature. The first two areas cover the two fundamental aspects to be studied in a thermal storage system, the material and the heat-exchanger, as is shown in Fig. 2.

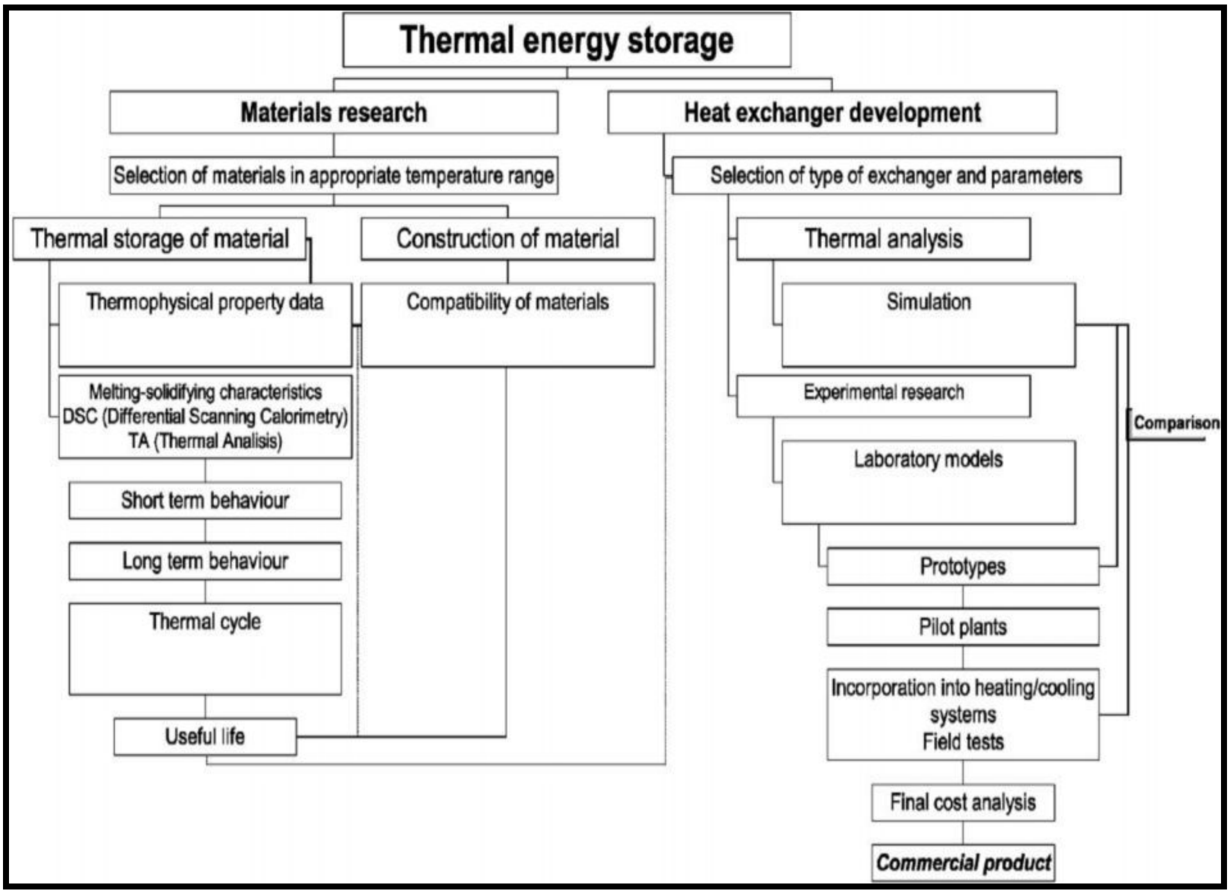

Fig.2. Areas of research in thermal storage systems [1]

3.1 Latent Heat Storage

Latent Heat Storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. The storage capacity of the LHS with a PCM medium is given by [4].

$$Q = \int_{T_i}^{T_m} mC_P dT + ma_m \Delta h_m + \int_{T_m}^{T_f} mC_P dT \quad (2)$$

$$Q = m\left[C_{sp}\left(T_m - T_i\right) + a_m \Delta h_m + C_{1p}\left(T_f - T_m\right)\right] \quad (3)$$

Latent heat storage uses the latent heat of the material to store thermal energy. Latent heat is the amount of heat absorbed or released during the change of the material from one phase to another phase. The amount of thermal energy stored in form of latent heat in a material is calculated by

$$Q = m \times LH \quad (4)$$

Where **Q** is the amount of thermal energy stored or released in form of latent heat (kJ), **m** is the mass of the material used to store thermal energy (kg), and **LH** is the Latent heat of fusion or vaporization (kJ/kg). It is clear from above equation (4) that the amount of thermal energy stored as latent heat depends on the mass and the value of the latent heat of the used material. Materials used to store thermal energy in form of latent heat are called PCMs. Latent heat storage is particularly attractive since it gives a high-energy storage density and has the capacity to store energy at a constant temperature or over a limited range of temperature variation – which is the temperature that corresponds to the phase transition temperature of the material.

3.2 Heat Transfer Enhancement

There are various techniques to improve the heat transfer in a latent heat thermal storage. The uses of finned tubes with different configurations were proposed by different researchers [5-11]. The improvement in solidification rate in molten stage dispersed with large conductivity particles [12-15]. The use of thin aluminium plates filled with PCMs was developed by Tong *et.al.* [16]. A graphite-compound-material, where the PCM is fixed inside a graphite matrix was reported by several researchers [17-22]. The main advantage of such a material is the increase in heat conductivity in the PCM without much reduction in energy storage, where as the other advantages are the decrease in sub cooling of salt hydrates and the decrease of volume change in paraffins. The use of graphite as heat transfer development material has also been reported and developed brushes made of carbon fibres [23-25]. The feature of this method is that the volume fraction of the fibres is exactly controlled without any difficulty and that the fibres with low volume fraction are entirely dispersed in the PCMs. The developed composite based materials such as paraffin, styrene–butadiene–styrene triblock copolymer and exfoliated graphite are used for heat storage [26]. They reported that the composite paraffin undergoes solid–liquid phase change, and there is no leakage of it even in the state of melting.

4. Applications

A variety of cold storage tanks incorporated in air conditioning systems in buildings were studied [27–30]. Cold storage is also developed for other applications like vegetable cooling [31], pre-cooling inlet air in gas turbine [32], or temperature maintenance in room with computers or electrical appliances [33-38]. Another application of PCMs was its inclusion in solar cookers to extend their usage time [39]. The use of PCM storage for increasing thermal comfort in vehicles was implemented [40]. PCM storage was included in a paint-drying system to recover exhaust heat [41]. The use of PCMs in solar power plants was reported [42-44]. A new development was reported [45-47], where a combined configuration of one sensible heat storage module, like concrete, and of two PCM modules at each end is used. The use of PCMs for cold storage were 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 [48-50]. A PCM in the thermal diode can be used to increase the effectiveness of the heat sink [51, 52]. In order to reduce the solar gain in buildings, the possibility study was done 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 put a stop to the temperature of the internal ambient from decreasing [53-56].

When transporting food, in several cases the food temperature have to be kept above a certain temperature or if it is frozen food defrosting should be avoided. The location is similar when transporting temperature sensitive medications. This application had already been established in the market with many companies commercializing transport boxes for sensitive materials [57, 58]. The application of PCM to contain the maximum temperature of electronic components is very promising, especially as it act as passive elements and therefore do not need any additional source of energy [59–61]. When engines and hydraulic machines are started from low temperatures, energy consumption and abrasion are high. Therefore, numerous companies have already investigated and developed LHS for motor vehicles [62–66]. In this application, the heat store is heated up by the cooling fluid while the engine is running. When the engine is stopped, the heat is stored and can be used to preheat the engine on a new start. Using the heat store it is possible to reach an optimised working temperature within the engine in a much shorter time than without heat store [67].

4. Conclusion

This review paper is focused on the available thermal energy storage technology with PCMs with different applications. This paper presents the current research in this particular field, with the main focus being on the consideration of the thermal properties of various PCMs. These thermal 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, waste heat recovery systems. The paper mainly focused on PCMs based thermal energy storage system, which is more attractive and useful to the energy conservative system and covered current research papers in particular field.

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