Investigation on Phase Change Materials

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Abstract— the use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. This paper also summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCMs for use in different

Index Terms— phase change materials, energy storage methods,physical properties, chemical properties,kinetic properties, pcm trombe wall, pcm wallboard.

1 Introduction

Energy storage is a key issue to be addressed to allow intermittent energy sources, typically renewable sources, to match energy supply with demand. There are numerous storage technologies that are capable of storing energy in various forms including kinetic energy, chemical solutions, magnetic fields, or other novel approaches.

PCMs absorb and emit heat while maintaining a nearly constant temperature. Within the human comfort range of 68° to 86°F (20° to 30°C), latent thermal storage materials are very effective. They store 5 to 14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock.

Thermal energy can be stored in well-insulated fluids or solids. It can be generally stored as latent heat-by virtue of latent heat of change of phase of medium. In this the temperature of the medium remains more or less constant since it undergoes a phase transformation. Phase change storages with higher energy den sities are more attractive for small storage.

Thermal storage capacity per unit mass and unit volume for small temperature differences is high
Thermal gradients during charging and discharging is small
Simultaneous charging and discharging is possible with appropriate selection of heat exchanger

The continuous increase in the level of greenhouse gas emissions and the climb in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. 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. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists. 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. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. For example, storage would improve the performance of a power generation plant by load leveling and higher efficiency would lead to energy conservation and lesser generation cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs). Unfortunately, prior to the large-scale practical application of this technology, it is necessary to resolve numerous problems at the re-

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search and development stage. Types of energy storage methods are given below.

2 Energy storage methods

The different forms of energy that can be stored include mechanical, electrical and thermal energy

2.1 Mechanical energy storage

Mechanical energy storage systems include gravitational energy storage or pumped hydropower storage (PHPS), compressed air energy storage (CAES) and flywheels. The PHPS and CAES technologies can be used for large-scale utility energy storage while flywheels are more suitable for intermediate storage. Storage is carried out when inexpensive off-peak power is available, e.g., at night or weekends. The storage is discharged when power is needed because of insufficient supply from the base-load plant...

2.2 Electrical storage

Energy storage through batteries is an option for storing the electrical energy. A battery is charged, by connecting it to a source of direct electric current and when it is discharged, the stored chemical energy is converted into electrical energy. Potential applications of batteries are utilization of off-peak power, load leveling, and storage of electrical energy generated by wind turbine or photovoltaic plants. The most common type of storage batteries is the lead acid and Ni–Cd.

2.3 Thermal energy storage

Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermo chemical or combination of these. An overview of major technique of storage of solar thermal energy is shown in Fig. 1

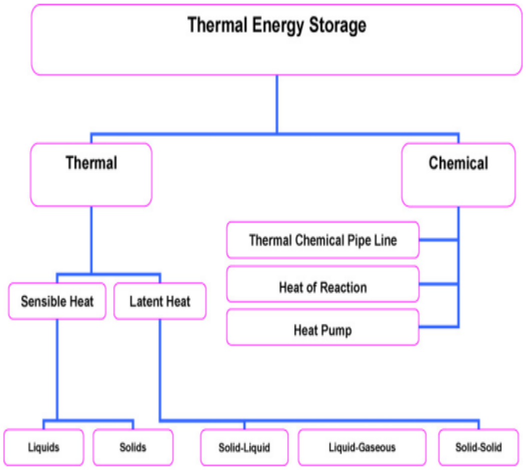

Fig. 1. Different types of thermal storage of solar energy.

3. LATENT HEAT STORAGE MATERIALS

3.1 PCM:

Phase change materials (PCM) are ‘‘Latent’’ heat storage materials. 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.’’ Initially, these solid–liquid PCMs perform like conventional storage materials, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. 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.

The PCM to be used in the design of thermal-storage systems should passes desirable thermo physical, kinetics and chemical properties which are as follows

3.1.1.Thermal properties

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

Selecting a PCM for a particular application, the operating temperature of the heating or cooling should be matched to the transition temperature of the PCM. The latent heat should be as high as possible, especially on a volumetric basis, to minimize the physical size of the heat store. High thermal conductivity would assist the charging and discharging of the energy storage.

3.1.2. Physical properties

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

Phase stability during freezing melting would help towards setting heat storage and high density is desirable to allow a smaller size of storage container. Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.

3.1.3. Kinetic properties

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

Supercooling has been a troublesome aspect of PCM development, particularly for salt hydrates. Supercooling of more than a few degrees will interfere with proper heat extraction from the store, and 5–10 8C supercooling can prevent it entirely..

3.1.4.Chemical properties

(i) Long-term chemical stability.

(ii) Compatibility with materials of construction.

(iii) No toxicity.

(iv) No fire hazard.

PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non-toxic, non- flammable and non-explosive for safety.

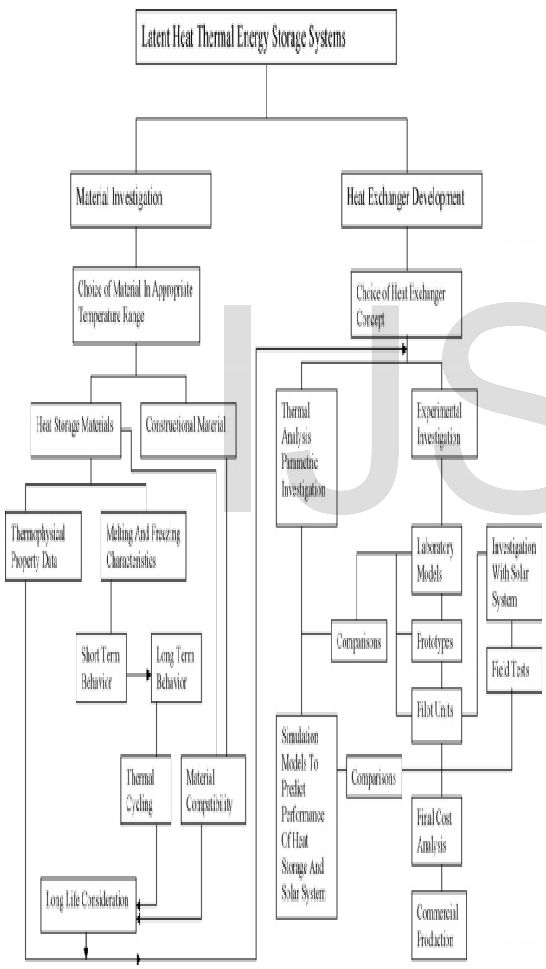

Fig. 2. Flow chart showing different stages involved in the development of a latent heat storage system.

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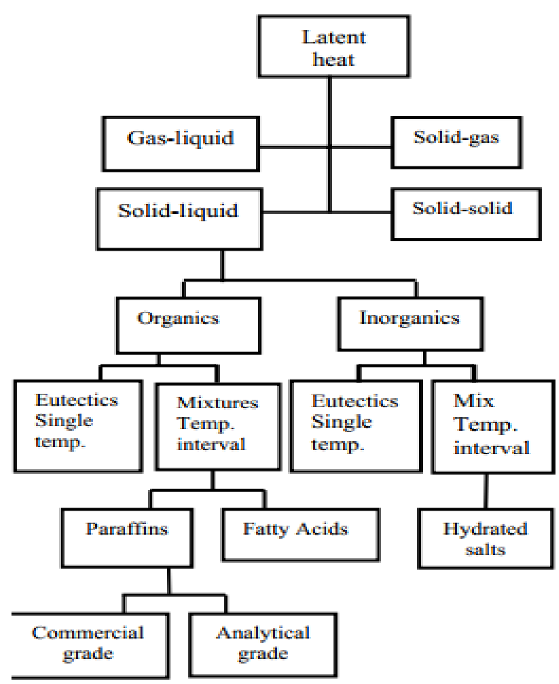
3.2.PCM Classification and Properties

In 1983, Abhat gave the general classification of energy storage material. The properties of different PCM's (Organic, Inorganic, Fatty acids) like density, specific heat, thermal conductivity and melting temperature.

Some of the important properties required for PCM are

- ❖ High latent heat of fusion per unit mass, so that a lesser amount of material stores a given amount of energy.
- ❖ High specific heat that provides additional sensible heat storage effect and also avoid sub cooling
- ❖ High thermal conductivity so that the temperature gradient required for charging the storage material is small
- ❖ High density, so that a smaller container volume holds the material
- ❖ A melting point in the desired operating temperature range.
- ❖ The phase change material should be non-poisonous, non-flammable and nonexplosive.
- ❖ No chemical decomposition, so that the (LHTS) system life is assured.
- ❖ No corrosiveness to construction material
- ❖ PCM should exhibit little or no super cooling during freezing.



Classification of PCM

PCMs have not always resolidified properly, because some PCMs get separated and stratify when in their liquid state. When temperature dropped, they did not completely solidify, reducing their capacity to store latent heat. These problems are overcome by packaging PCM in containers and by adding thickening agents.

To solve some of the problems inherent I inorganic PCMs, an interest has turned towards a new class of materials: low volatility, anhydrous organic substances such as paraffin's, fatty acids and polyethylene glycol. Those materials were more costly than common salt hydrates and they have somewhat lower heat storage capacity per unit volume. It has now been realized that some of these materials have good physical and chemical stability, good thermal behavior and adjustable transition zone. When salt hydrates are used as PCM they have a tendency to super cool and do not melt congruently so that segregation results. Even though advances were made, some hurdles remained towards the development of reliable and practical storage systems utilizing salt hydrates and similar inorganic substances.
Hydrated salts are attractive materials for use in thermal energy storage due to high volumetric storage density, relatively high thermal conductivity and moderate costs compared to paraffin waxes. Glauber salt (Na_2SO_4. H_2O) which contains 44% Na_2SO_4 and 56%H_2O has been studied in 1952 [6,2], and it has melting temperature of 32.4ºC, latent heat of 254Kj/Kg. The selection of such material as PCM for a specific application should be based on thermodynamic properties, kinetic properties and chemical properties. For low temperature applications ranging from 0°C to 99°C, Salt Hydrates would be the best option owing to their availability in a less temperature range with a reasonable specific heat capacity of 133.4(cal/deg.mol), thermal conductivity of 0.987 W/m-K, density of 1552 kg/m3 in the solid phases respectively and phase transfer temperature ranging from 35°C - 39°C.

3.3 EXPERIMENTAL PROCEDURE:

A comparison has been made between different sized latent heat storage vessels and sensible heat storage in a water tank with different degree of stratification. The storage vessel consists of a number of closed cylindrical pipes filled with the phase change medium (paraffin)(Fig. 5). These pipes were surrounded by heat transfer fluid. Bajnoczy et al. studied the two-grade heat storage system (60–308C and 30–208C) based on calcium chloride hexahydrate and calcium chloride tetrahydrate. Authors also studied the storage capacity changes during the cycles and possible use of a solar energy storage system for domestic water-heating system. Kamiz Kayguz et al. Has conducted an experimental and theoretical study to determine the performance of phase change energy storage materials for solar water-heating systems. $CaCl_2$□$6H_2O$ was used as phase change material. Author also compared the performance of PCM, water and rock based storage system. Whenever solar energy is available, it is collected and transferred to the energy storage tank that is filled by 150 kg encapsulated phase change material (PCM). It consisted of a vessel packed in the horizontal direction with cylindrical tubes.

The energy storage material ($CaCl_2$□$6H_2O$) is inside the tubes (the tube container made of PVC plastic) and heats transfer fluid (water) flow parallel to them. Rabin et al. also studied a solar collector with storage for water heating having salt hydrate as a phase change material. The results of parametric studies on the effect of the transition temperature and of the thickness layer of the salt-hydrate PCM on the thermal performance of the charging process are also presented. Sharma et al. designed, developed and performance evaluate of a latent heat storage unit for evening and morning hot water requirements, using a box type solar collector. Paraffin wax (m.p. 548C) was used as a latent heat storage material and found that the performance of the latent heat storage unit in the system was very good to get the hot water in the desirable temperature range.

Mettawee and Assassa investigated a the thermal performance of a compact phase change material (PCM) solar collector based on latent heat storage. In this collector, the absorber plate–container unit performs the function of both absorbing the solar energy and storing PCM. The solar energy was stored in paraffin wax, which was used as a PCM, and was discharged to cold water flowing in pipes located inside the wax. The collector's effective area was assumed to be 1 m2 and its total volume was divided into five sectors. The experimental apparatus was designed to simulate one of the collector's sectors, with an apparatus-absorber effective area of 0.2 m2.

Outdoor experiments were carried out to demonstrate the applicability of using a compact solar collector for heating. The time-wise temperatures of the PCM were recorded during the processes of charging and discharging. The solar intensity was recorded during the charging process. Experiments were conducted for different water flow rates of 8.3–21.7 kg/h. The effect of the water flow rate on the useful heat gain was studied. The heat transfer coefficients were calculated for the charging process. The propagation of the melting and freezing front was also studied during the charging and discharging processes. The experimental results showed that in the charging process, the average heat transfer coefficient increases sharply with increasing the molten layer thickness, as the natural convection grows strong. In the discharge process, the useful heat gain was found to increase as the water mass flow rate increases

The PCM module geometry adopted was to use several cylinders at the top of the water tank. Several experiments with two, four and six PCM modules were carried out in the real installation. A granular PCM–graphite compound of about 90 vol.% of sodium acetate trihydrate and 10 vol.% graphite was chosen as the PCM for the experiments presented here.

Author concluded that the inclusion of a PCM module in water tanks for domestic hot-water supply is a very promising technology. It would allow to have hot water for longer periods of time even without exterior energy supply, or to use smaller tanks for the same purpose. Suat et al. presented a conventional open-loop passive solar water-heating system combined with sodium thiosulfate pentahydrate-phase change material (PCM) were experimentally investigated during November and then enhancement of solar thermal energy storage performance of the system by comparing with those of conventional system including no PCM was observed.

Heat storage performances of the same solar water-heating system combined with the other salt hydrates-PCMs such as zinc nitrate hexahydrate, disodium hydrogen phosphate dodecahydrate, calcium chloride hexahydrate and sodium sulfate decahydrate (Glauber's salt) were examined theoretically by using meteorological data and thermophysical properties of PCMs with some assumptions. It was obtained that the storage time of hot water, the produced hot water mass and total heat accumulated in the solar water heating system having the heat storage tank combined with PCM were approximately 2.59–3.45 times of that in the conventional solar water-heating system. It was also found that the hydrated salts of the highest solar thermal energy storage performance in PCMs used in theoretical investigation were disodium hydrogen phosphate dodecahydrate and sodium sulfate decahydrate

3.4.Buildings

PCMs have been considered for thermal storage in buildings since before 1980. With the advent of PCM implemented in Trombe wall, wallboards, shutters, under-floor heating systems and ceiling boards can be use as a part of the building for heating and cooling applications. In the literature, development and testing were conducted for prototypes of PCM wallboard and PCM concrete systems to enhance the thermal energy storage (TES) capacity of standard gypsum wallboard and concrete blocks, with particular interest in peak load shifting and solar energy utilization.

The application of PCMs in building can have two different goals. First, using natural heat that is solar energy for heating or night cold for cooling. Second, using manmade heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time and also with respect to power. Basically three different ways to use PCMs for heating and cooling of buildings are:
(i) PCMs in commercial and public building walls,
(ii) PCMs in other building components other than walls, and
(iii) PCMs in heat and cold storage units.

Different applications for latent heat thermal energy storage (LHTES) in buildings are given below.

3.5.PCM Trombe wall

Several authors have proposed the inclusion of phase change materials in walls partitions ceilings and floors to serve as temperature regulators. The phase change materials have been used to replace masonry in a Trombe wall. Experimental and theoretical tests have been conducted to investigate the reliability of PCMs as a Trombe wall.

For a given amount of heat storage, the phase change units require less space than water walls or mass Trombe walls and are much lighter in weight. These are, therefore, much convenient to make use of in retrofit applications of buildings. Commonly used PCMs are salt hydrates and hydrocarbons. Metallic additives were used for increasing the overall conductivity and efficiency.

In order to provide a better picture of how PCM latent heat storage can help to improve thermal performance of an ordinary Trombe wall for passive solar heating. The analysis evaluated transient temperature of an ordinary concrete Trombe wall having thicknesses of 30 cm (12 in.) and 10 cm (4 in.). The resulting data were compared with those of the same wall design configuration but having 20% by weight of a paraffin type PCM homogeneously mixed with the concrete wall material. Castellon et al. studied a Trombe wall was recently added to the south facade to investigate if the effect of the PCM can be used all year long in Mediterranean weathers to reduce both cooling and heating demands.

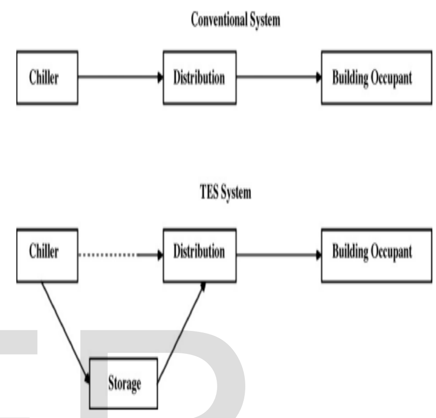
3.6.PCM wallboards

The wallboards are cheap and widely used in a variety of applications, making them very suitable for PCM encapsulation. However, the principles of latent heat storage can be applied to any appropriate building materials. Processes where by this PCM could be incorporated into plasterboard either by post manufacturing imbibing of liquid PCM into the pore space of the plasterboard or by addition in the wet stage of plasterboard manufacture were successfully demonstrated.

The idea of improving the thermal comfort of lightweight buildings by integrating PCMs into the building structure has been investigated in various research projects over several decades given by Kedl and Stovall and Salyer and Sircar, Shapiro et al. Shapiro , Feldman et al., Hawes et al, Neeper Stovall and Tomlinson , Drake , Peippo et al. , Feustel and co-workers , Athienitis et al. , Kissock et al. , Kalousek and Hirs . Most of these attempts applied macro-capsules or direct immersion processes, which both turned out to present several drawbacks. Due to these problems, none of these PCM products was successful in the wider market. The new option to microencapsulate PCMs, a key technology which overcomes many of these problems, may make PCM products accessible for the building industry. Schossig et al.

4. Design of heat exchanger for thermal energy storage

Generally the phase change material have low thermal conductivity and expand on melting therefore, the design of a suitable heat exchanger is an important component of a latent heat storage system. Various kind of heat exchanger were tried by a number of researchers and are a given under. Buddhi designed and fabricated a PCM based shell and tube type heat exchanger without fins for low temperature industrial waste heat recovery. To improve the effective thermal conductivity of the system, the radial distance among the tubes was kept 3–4 cm. He studied the thermal performance of this heat exchanger for charging and discharging process of PCM for different mass flow rates and temperature of the inlet water. Commercial grade stearic acid has been used as a phase change material and filled up to about 90% of the volume. Due to poor thermal conductivity of PCM, the value of overall heat transfer coefficients was founded low. Schematic diagram of a shell and finned tube type heat exchanger with heat storage and two stage feed water tank



Major system cooling components.

5. CONCLUSION

This project 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. This project presents the current research in this particular field, with the main focus being on the assessment of the thermal properties of various PCMs. That project also presents the paraffin melt fraction studies of the few identified PCMs used in various applications for storage systems with different heat exchanger container materials.

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