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PHASE CHANGE MATERIAL AS THERMAL ENERGY STORAGE MEDIUM AND APPLICATIONS

Engineering

KEYWORDS: Latent Heat, Phase Change Material, Sensible Heat, Solar Dryer, Thermal Energy Storage

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ABSTRACT

Solar energy is a renewable energy source that can generate electricity, provide hot water, heat and cool buildings and provide lighting. In response to the dependence on fossil fuels, environmental impacts, maximization of green energy resources and increasing electrical energy costs, thermal energy storage technologies has been developed. The use of 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. Phase change material (PCM) is a substance with a high heat of fusion which, on melting and solidifying at a certain temperature is capable of storing and releasing large amount of energy. Phase change materials (PCMs) are one of the latent heat materials having low temperature range and high energy density of melting – solidification compared to the sensible heat storage. There are large numbers of phase change materials (PCMs) that melt and solidify at a wide range of temperature making them attractive in a number of applications.

1. INTRODUCTION

Energy storage is a key issue to be stressed to allow renewable sources, to match energy supply with demand. There are numerous energy storage technologies which are capable of storing energy in various forms including chemical, electrical, mechanical and other novel approaches. 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 conservation of energy. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCM). Phase change materials exhibits thermodynamic properties of storing large amount of latent heat during its phase change. They absorb and emit heat while maintaining constant temperature. Within the human comfort range of 200C to 300C, latent thermal storage materials are very effective and store 5 to 14 times more heat per heat per unit volume than sensible storage materials such as water, masonry and rock. Thermal energy can be stored in well-insulated fluids or solids. It can be stored as latent heat by virtue of latent heat of change of medium. The temperature of the medium remains more or less constant since it undergoes a phase transformation. Thermal storage capacity per unit volume and per unit mass of PCMs as compared to other storage techniques is very high. Thermal gradients during charging and discharging are small and simultaneous charging and discharging is possible with appropriate selection of heat exchanger.

High cost of fossil fuels, gradual depletion of its reserve and environmental impacts of their use have put severe constraints on their consumption and have increased the emphasis on using alternative renewable energy such as solar energy which is environmental friendly and has less environmental impact. Energy storage is therefore, essential to any system that depends largely on solar energy. Solar radiations cannot be stored directly but need to convert first into energy and then thermal solar energy can be stored by various methods such as thermal, electrical, chemical and mechanical.

2. THERMAL ENERGY STORAGE

There are various techniques of storing energy such as thermal, mechanical, electrical and chemical. Thermal energy can be stored in well insulated fluid or solid as a change in internal energy of a material as sensible heat, latent heat and thermo-chemical. The selection of the type of thermal energy storage depends on various factors such as the storage period, range of temperature, space, economic viability and operating conditions. An overview of various techniques of storage of solar thermal energy is shown in figure 1[3].

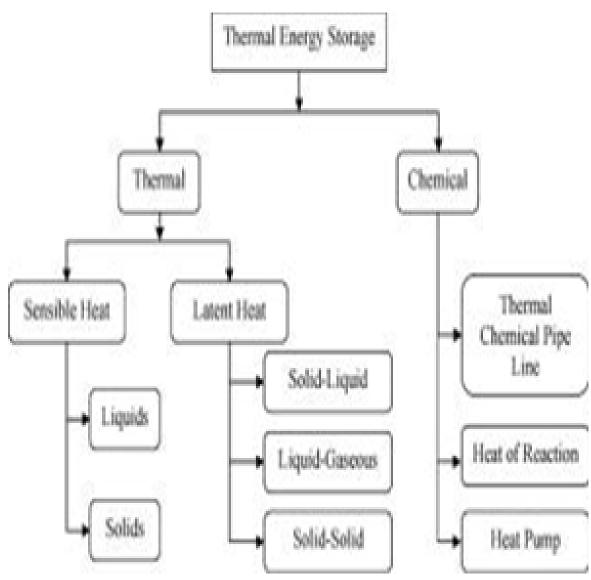

Figure 1: Different Types of Thermal Storage of Solar Energy

2.1 Sensible Heat Storage

In sensible heat storage (SHS) system, thermal energy is stored by raising the temperature of a solid or liquid by using its heat capacity. In this system heat capacity and the change in temperature of the material is utilized for charging and discharging. The amount of heat stored depends on the specific heat of the medium, the change in temperature and the amount of storage material.

The amount of thermal energy stored in the form of sensible heat can be calculated by

$$Q = \int_{T_1}^{T_2} mC_p dT = mC_p(T_2 - T_1) \qquad \text{(i)}$$

Water is known as one of the best materials that can be used to store thermal energy in the form of sensible heat because water is abundant, cheap, has high specific heat and high density. Moreover, heat exchanger is avoided if water is used as the heat transfer fluid in the solar thermal system. Table 1 [4] shows the sensible heat storage capacity of some selected materials.

Table 1: List of Materials for Sensible Heat Storage

Phase	Medium	Temperature Range (^{0}C)	Density kg/m^3	Specific Heat J/kg-K
Solid	Rock	7-27	2560	879
	Brick	17-37	1600	840
	Concrete	7-27	2100	880
	Sand	7-27	1550	800
	Soil	7-27	2040	1840
Liquid	Water	7-27	1000	4180
	Engine Oil	Up to 157	888	1880
	Ethanol	Up to 77	790	2400
	Butanol	Up to 118	809	2400
	Other Organic	Up to 120	800	2300

2.2 Latent Heat Storage

Latent heat of storage is based on the absorption/ desorption of energy when a storage material undergoes a phase change from solid to liquid, liquid to gas or vice-versa. Latent heat storage is attractive since it provides a high energy storage density at a constant temperature or over a limited range of temperature variation, which is represented graphically in figure 2.

The storage capacity of the LHS system with a phase change material (PCM) medium [5] is given by

$$Q = \int_{T_i}^{T_m} mC_{sp}\,dT + m\,a_m\Delta h_m + \int_{T_m}^{T_f} mC_{lp}\,dT \qquad \text{(ii)}$$

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

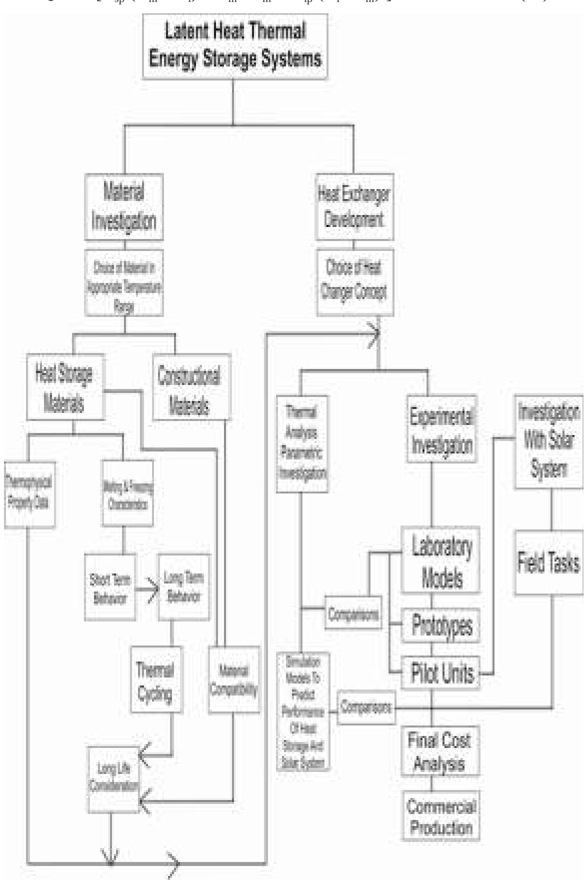

Figure 2: Flow Chart of Different Stages Involved in the Development of Latent Heat Storage System

So, PCMs research is studied in two ways, (a) material oriented research and (b) system oriented research. Schematically, different stages involved in the development of latent heat storage system are represented in figure 3 [3].

4 CLASSIFICATION OF PCMS

A comprehensive list of PCM materials is available in various papers. To summarize these PCMs can be categorized into three types (i) Organic (ii) Inorganic (iii) Eutectic [4],[6].

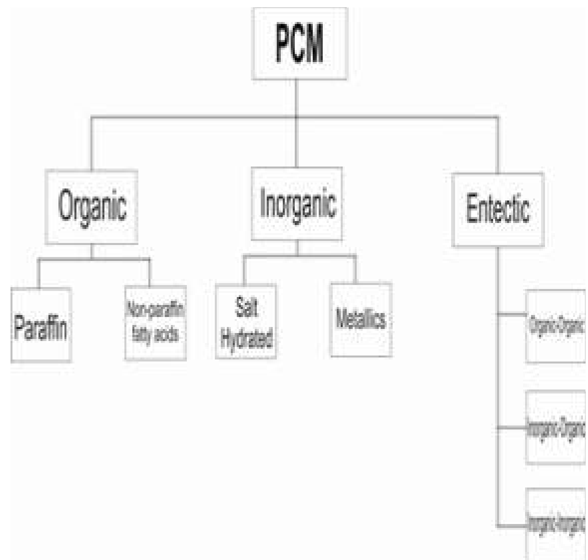

FIGURE 3: Classification of PCMs

4.1 Organic

Organic materials are classified as paraffin and non-paraffin

4.1.1 Paraffin: The main interest with organic materials is that they involve long term cyclic chemical and thermal stability. Paraffin consists of mixture of straight chain of alkenes CH_3-(CH_2)-CH_3. The crystallization of the (CH_3)- chain release a large amount of latent heat. The latent heat of fusion of paraffin varies from nearly 170KJ/kg to 270 kJ/kg between 5^{0}C to 80^{0}C which makes them suitable for many solar applications.

Table 2: Properties of Some Paraffin's [6]

Paraffin	Freezing point/range (^{0}C)	Heat of fusion (kJ/kg)
6106	44	189
P116	45-48	210
5853	48-50	189
6035	558-60	189
6403	62-64	189
6499	66-68	189

Advantages:

It is safe, reliable, predictable, less expensive, non-corrosive, and chemically inert and show little volume changes on melting and have low vapor pressure.

Disadvantages:

Low thermal conductivity, Incompatible with the plastic container and moderately flammable.

4.1.2 Non-paraffin:- Then non-paraffin organic materials are most common of the PCM's with highly varied properties. This is the largest category of candidate's materials for phase change storage. Number of easters, fatty acids, alcohols and glycols have been identified suitable for energy storage. These materials are flammable and should not be exposed to high temperature flames and oxidizing agents.

Features:
High heat of fusion, inflammability, low thermal conductivity, low flash points, varying level of toxicity and instability at high temperature.

Major drawbacks:
High cost, which is 2 to 2.5 times more than that of the paraffin. They are mild corrosive.

Table 3: Properties of Some Non-Paraffin [6]

Materials	Melting Point(°C)	Latent Heat (kJ/kg)
Formic acid	7.8	247
Glycerin	17.9	198.7
Methyl Palmitate	29	205
Camphenilone	39	205
Docasyl Bromide	40	201
Caprylone	40	259
Phenol	41	120
Cyanamide	44	209
Hydrocinnamicacid	48	118
Camphene	50	238
Nitro Napthalene	56.7	103
Bee wax	61.8	177
Glyolic acid	63	109
Acrylic acid	68	115
Phenylacetic acid	76.7	102
Methyl Brombrenzoate	81	126
Catechol	104.3	207
Acetanilide 222	118.9	222

4.2 Inorganic
Inorganic compounds include salt hydrate, salts, metals and alloys.

Properties:
High latent heat of fusion, high thermal conductivity (double of the paraffin), small volume changes on melting, compatible with plastic, very corrosive and little toxic.

Major drawbacks:
The solid salt due to its high density settle down at the bottom of the container and is unavailable for recombination with water during the reverse process of freezing and results in an irreversible melting-freezing of the salt hydrate and go on decreasing with each charge and discharge cycle.

4.3 utectic
It is a minimum-melting of two or more components, each of which melts and freezes congruently forming a mixture of the component crystals during solidification. A large number of eutectics of inorganic and organic compounds have been investigated. Eutectics are generally better than straight organic PCM's with respect to segregation. Another common problem of salt hydrate is super cooling.

5 APPLICATIONS OF LATENT HEAT STORAGE PCMS
A large number of solid liquid PCMs have been investigated for heating, cooling and drying applications. Recently, the incorporation of heat storage system in solar dryer has grown interest to the researchers. In this paper, an attempt has been taken to summarize the investigation of the solar drying system with PCM's. This review will help to find the design and development of suitable heat storage unit for solar dryers.

5.1 Solar Air Heater
Solar air heating incorporating PCM's has been studied for the last three decades as evidenced by the pioneering work of Morrison, Abdil, Khalick and Jurinah. They concluded that the selection of PCM's should be on the basis of melting point rather than its latent heat and also that system containing sodium sulphate decahydrate as storage medium needs about one forth as storage volume of a pebble bed and one half that of water tank. Recent research has found yield improved thermal comfort in winter by involving hybrid systems and shape stabilized phase change material. Zhou et al observed 47% normal and peak hour energy savings and 12% overall energy consumption reduction [7].

5.2 Solar Water Heater
With the increasing costs of energy and simple fabrication and installation, easy maintenance and relatively inexpensive nature of solar water heater, it is getting popularity. Without increasing the volume and temperature, the capacity of the system has increased by using PCMs located either on the bottom, top or vertical walls. PCMs were found interesting once it helped to deliver hot water in the morning after solar collection. Morisson et al. used 17.5 kg paraffin wax (M.P.-540C) in one heat exchanger and water in the other to enable the comparison [8][12].

5.3 Solar dryer
Different techniques have been explored by developing drying models for accelerating the solar drying of agricultural products by considering the possible use of thermal storage materials. Tiwari et al. experimentally evaluated a crop dryer cum water heater and crop dryer rock bed storage. On the basis of analytical results, it was observed that the drying time is significantly reduced on using the water and the rock bed as storage media. The system can be used to provide hot water in case the drying system is not in operation. The water heater below the air heater systems will act as a storage material for drying the crop during off-sunshine hour. Chouhan et al. studied the comparative performance of coriander dryer coupled to solar air heater and solar air heater-cum rock bed storage. They concluded that the average moisture content of the grains in the grain bed can be reduced from 28.2% (db) to 11.4%(db) in 27 cumulative sunshine hours (3 sunshine days) by using the solar air heater only, whereas by using the solar air heater during sunshine hours and the rock bed energy storage during off-sunshine hours the same amount of moisture can be evaporated in 31 cumulative hours (18 sunshine and 13 off-sunshine hours).

5.4 Buildings
PCMs have been considered for thermal storage in buildings since before 1980. The wallboards are suitable for PCM encapsulation. Paraffin wax, fatty acids, or liquid butyl stearate impregnated walls can be built by immersion. It helps in reducing the peak power demand and downsizing the cooling and heating systems. Building blocks and other building materials impregnated with PCM can be used in constructing a building. This could result in a structure with large thermal inertia without the usual large masses associated with it. [5][17]

5.5 Green Houses
PCMs can be used in green houses for storing the solar energy for curing and drying process and plant production. During the sunshine hours excess energy is captured and stored, and utilized during the off-sunshine hours and thereby maintaining constant temperature. [6]

6. CONCLUSION
The paper is focused on the thermal energy storage technology integrating with PCMs for different applications. These technologies are

in general very beneficial for the energy conservation and in particular for human beings. PCMs act as a house of thermal energy and deliver it as and when needed due to its high latent heat of fusion and hence, help in saving energy. Wide applications of PCMs in various areas optimal use of PCMs have not been exploited but improvements in thermal heat storage of PCMs make them implementable on wide range. Organic compounds specially paraffin waxes most suitable for latent heat storage due to their compatibility with human comfort temperature of about 24 0C and is affordable.

The optimization of these parameters is fundamental to demonstrate the possibilities of success of PCMs for various applications. In the near future, more advanced PCMs will be incorporated in global energy management solutions as the low cost, environment friendly and easily available energy sources will be permitted.

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