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Review On Phase Change Material As Thermal Energy Storage Medium: Materials, Application

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ABSTRACT

Solar energy is a renewable energy source that can generate electricity, provide hot water, heat and cool a house and provide lighting for buildings. In response to increasing electrical energy costs, thermal storage technology has recently been developed. This paper presents an introduction to previous works on thermal energy storage using PCM and their applications. The choice of the substances used largely depends upon the temperature level of the application. Phase change material (PCM) are one of the latent heat materials having low temperature range and high energy density of melting– solidification compared to the sensible heat storage. Latent heat thermal energy storage (LHTES) with phase change materials (PCMs) deserves attention as it provides high energy density and small temperature change interval upon melting/solidifying. 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. Latent heat thermal energy storage (LHTES) offers a huge opportunity to reduce fuel dependency and environmental impact created by fossil fuel consumption.

Keywords* - *Phase Change Material (PCM), renewable energy, Thermal Energy storage, Latent heat thermal energy storage (LHTES), high energy density.

I. INTRODUCTION

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 research and development stage.

II. THERMAL ENERGY STORAGE

Thermal energy storage can be stored as a change in internal energy of a material as sensible heat and latent heat

2.1 ` SENSIBLE HEAT STORAGE

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

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

$$Q = \int_{T_1}^{T_2} m * C_p * dT = m * C_p * (T_2 - T_1)$$

Q is the amount of thermal energy stored or released in form of sensible heat (kJ), $\mathbf{T_1}$ is the initial temperature (ºC), $\mathbf{T_2}$ is the final temperature (ºC), **m** is the mass of material used to store thermal energy (kg), and $\mathbf{C_p}$ is the specific heat of the material used to store thermal energy (kJ/kgºC).

Water is known as one of the best materials that can be used to store thermal energy in form of sensible heat because water is abundant, cheap, has a high specific heat, and has a high density. In addition; heat exchanger is avoided if water is used as the heat transfer fluid in the solar thermal system. Until now, commercial applications use water for thermal energy storage in liquid based systems. Table 1 shows Selected Materials use for Sensible Heat Storage are [1]

Table 1 MATERIAL FOR SENSIBLE HEAT STORAGE

Phase	Medium	Temp Rang [°C]	Density Kg/m³	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	7-97	1000	4180
	Engine Oil	Up to 157	888	1880
	Ethanol	Up to 77	790	2400
	CalorieaHT43	12-260	867	2200
	Butanol	Up to 118	809	2400
	Other Organic	Up to 420	800	2300

2.2 LATENT HEAT STORAGE

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. Two types of latent heat are known, latent heat of fusion and latent heat of vaporization. Latent heat of fusion is the amount of heat absorbed or released when the material changes from the solid phase to the liquid phase or vice versa, while latent heat of vaporization is the amount of thermal energy absorbed or released when the material changes from the liquid phase to the vapour phase or vice versa. Indeed, latent heat of vaporization is not paid attention for latent thermal energy storage applications because of the large change in the volume accompanied by this type of phase change.

The amount of thermal energy stored in form of latent heat in a material is calculated by

$$Q = m * LH$$

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).

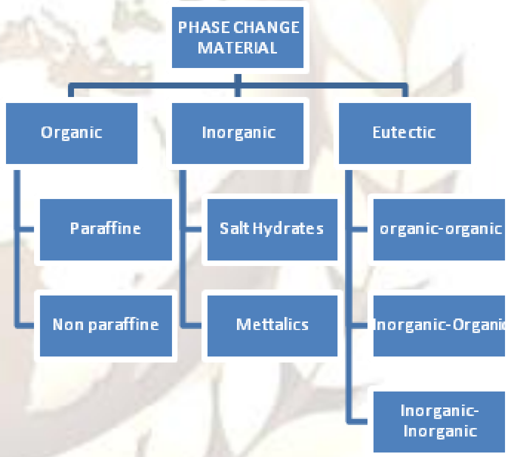
It is clear from above Eq. that the amount of thermal energy stored as latent heat depends on the mass and the value of the latent heat of the used material. Materials used to store thermal energy in form of latent heat are called phase change materials.

III. COMPARISON BETWEEN SENSIBLE AND LATENT THERMAL ENERGY STORAGE

Latent heat storage is particularly attractive since it provides 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. They store 5–14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. But latent thermal energy storage still facing many problems concerning the materials used to perform the storage process such as high cost, low thermal conductivity and stability of thermo physical properties after many cycling.

IV. CLASSIFICATION OF LATENT HEAT STORAGE MATERIALS

Latent heat storage materials also called phase change materials (PCMs). Lists of most possible materials that may be used for latent heat storage are available in papers by Abhat [2], Lorsh et al. [3], Lane et al. [4], and Humpries and Griggs [5].



4.1 ORGANIC

Organic materials are classified as paraffin and non paraffin.

4.1.1 Paraffins

It consists of a mixture of straight chain alkanes CH3–(CH2)–CH3. The crystallization of the (CH3)- chain release a large amount of latent heat increase with chain length.

Advantage:- Paraffin is safe, reliable, predictable, less expensive and non-corrosive, chemically inert and stable below 500 8C, show little volume changes on melting and have low vapor pressure in the melt form.

Disadvantages: - low thermal conductivity, no compatible with the plastic container and moderately flammable.

4.2.2 Non-Paraffins

The non-paraffin organic are the most numerous of the phase change materials with highly varied properties. Each of these materials will have its own properties unlike the paraffin's, which have very similar properties. This is the largest category of candidate's materials for phase change storage. Abhat et al. and Buddhi and Sawhney have conducted an extensive survey of organic materials and identified a number of esters, fatty acids, alcohol's and glycol's suitable for energy storage. These organic materials are further subgroups as fatty acids andother non-paraffin organic. These materials are flammable and should not be exposed to excessively high temperature, flames or oxidizing agents.

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

Major drawback:-Their cost, which are 2–2.5 times greater than that of technical grade paraffin's. They are also mild corrosive.

Table 2 PROPERTIES OF SOME PARAFFIN'S

Paraffin	*Freezing point/range (^{O}C)*	*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**

4.2 INORGANIC

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

Properties:-High latent heat of fusion per unit volume, relatively high thermal conductivity (almost double of the paraffin's), and small volume changes on melting. They are not very corrosive, compatible with plastics and only slightly toxic.

Major problem: - as PCMs is the most of them, which are judged suitable for use in thermal storage, melts incongruently. As n moles of water of hydration are not sufficient to dissolves one mole of salt, the resulting solution is supersaturated at the melting temperature. The solid salt, due to its higher density, settles down at the bottom of the container and is unavailable for recombination with water during the reverse process of freezing. This result in an irreversible melting–freezing of the salt hydrate goes on decreasing with each charge–discharge cycle. Another important problem common to salt hydrates is that of supercooling.

Table 3 PROPERTIES OF SOME NON-PARAFFIN

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 Naphthalene	**56.7**	**103**
Bee wax	**61.8**	**177**
Glyolic acid	**63.0**	**109**
Acrylic acid	**68.0**	**115**
Phenylacetic acid	**76.7**	**102**
Methyl Brombrenzoate	**81**	**126**
Catechol	**104.3**	**207**
Acetanilide 222	**118.9**	**222**

4.3 EUTECTIC

The eutectic is a minimum-melting composition of two or more components, each of which melts and freezes congruently forming a mixture of the component crystals during solidification [8]. A large number of eutectics of inorganic and organic compounds have been reported [7]-[8]. Eutectics are generally better than straight inorganic PCMs with respect to segregation [9].

Table 4 PHASE CHANGE TEMPERATURE AND HEAT OF FUSION OF TYPICAL COMMERCIAL PCMS

PCM Name	**Type of Product**	**Melting Temp. (°C)**	**Heat of Fusion (kJ/kg)**	**Source**
Astorstat HA17	(Paraffins and Waxes)	21.7-22.8	-	Astor Wax by Honey Well (PCM Thermal Solution)
Astorstat HA18		27.2 - 28.3	-	
RT26	Paraffin	24 - 26	232	Rubitherm GmbH
RT27		28	206	
Climsel C23	Salt Hydrate	23	148	Climator
Climsel C24		24	108	
STL27	Salt Hydrate	27	213	Mitsubishi Chemicals
S27	Salt Hydrate	27	207	Cristopia
TH29	Salt Hydrate	29	188	TEAP
-	Mixture of Two Salt Hydrate	22-25	-	ZAE Bayern
E23	Plus ICE (Mixture of Non-Toxic Eutectic Solution)	23	155	Environ-mental process system (EPS)

V. REQUIRED PROPERTIES OF PCM

Amongst above thermal heat storage techniques, latent heat thermal energy storage is particularly attractive due to its ability to provide high-energy storage density and its characteristics to store heat at constant temperature corresponding to the phase transition temperature of phase change material (PCM). Selection of PCM is based on the application but the PCM to be use should possess Thermo physical, kinetics and chemical properties which are as follows

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

Physical properties:-
(i) Favourable phase equilibrium.
(ii) High density.
(iii) Small volume change.
(iv) Low vapour pressure

Kinetic properties:-
(i) No super cooling.
(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

VI. COMPARES BETWEEN ORGANIC, INORGANIC AND EUTECTIC

Table 5 SALT HYDRATE AND WAX PARAFFIN COMPARISON

	Organic	Inorganic	Eutectic
Advantages	Low Cost (120Euro/kWh) Self nucleating, Chemically inert and stable, No phase segregation, Recyclable, Available in large temperature range	Moderate cost (130 Euro/kWh), High volumetric storage density, (180-300 MJ/m³), Higher thermal conductivity (0.6W/m°C), Non flammable, Low volume change	Sharp melting point, Low volumetric storage density
Disadvantages	Flammable, Low thermal conductivity (0.2W/m°C), Low volumetric storage density (90-200 MJ/m³)	Subcooling, Phase segregation, Corrosion of containment material	Limited available material property data

VII. APPLICATIONS OF LATENT HEAT STORAGE PCM

7.1 SOLAR WATER HEATER:-

Solar water heater is getting popularity with increasing costs of energy since they are relatively inexpensive, simple to fabricate and install, and easy to maintain. To increase the capacity of systems without ultimately requiring huge volumes or high temperatures, these systems were designed with PCMs either located on the bottom, top, or vertical walls. The PCMs were especially interesting when it came to deliver hot water the morning after solar collection [10]. In this study [10], the author used 17,5kg of paraffin wax (m.p. 54°C) in one heat exchanger and water in the other to enable the comparison.

7.2 SOLAR AIR HEATER

The problem of solar air heating with systems involving PCMs has been studied for more than 30 years as evidenced by the pioneering work of Morrison, Abdel Khalick, and Jurinak [14]. The main conclusion of their studies was that the PCM should be selected on the basis of the melting point rather than its latent heat and also that systems based on sodium sulphate decahydrate as storage medium needs about one fourth the storage volume of a pebble bed and one half 5 that 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. [13] indicate that 47% normal-and-peak-hour energy savings, and 12% overall energy consumption reduction were observed.

7.3 FLOOR AND CEILING

Farid and Kong [11] constructed slabs containing encapsulated PCMs in spherical nodules. The plastic spheres contained about 10% empty space to accommodate volume expansion. Athienithis and Chen [12] 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.

7.4 OFF-PEAK STORAGE:

Latent heat storage systems were proposed to utilize off-peak electricity. Using this electricity, PCMs are either melted or frizzed to store it in the form of latent heat thermal energy and the heat/coolness is then available when needed. These systems are generally embedded with active systems to reduce the peak load and thus eventually reducing the electricity generation costs by keeping the demand nearly uniform

7.5 Indoor Walls

The wallboards are suitable for PCM encapsulation. For instance, paraffin wax, fatty acids, or liquid butyl stearate impregnated walls can be built by immersion. One of the interests is the shifting of heating and cooling loads to off-peak times of electric utility, the other is to reduce peak power demand and down size the cooling and heating systems. Although much work has been done on impregnation techniques, analytical studies, and optimal melting temperatures, much has to be done to include such advanced wallboards in actual buildings. Although gypsum wallboards are naturally considered as they are cheap and widely used, 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.

7.6 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. The format of the conference papers cannot allow a survey of the key references on this subject. These will be discussed at the conference.

VIII. Conclusion

(1) To provide an overview of phase change materials use in the context of power demand reduction.

(2) To open new possibilities for eventual collaboration with the IEEE members.

(3) To be able to promote synergetic solutions and processes in the domain of energy management.

(4) In the present paper, a detailed study on PCM incorporation in building material, PCMs integration with building architecture for space heating, space cooling and in combination of heating and cooling has been carried out.

(5) The optimization of these parameters is fundamental to demonstrate the possibilities of success of the PCMS in building materials. Therefore, the information like operational range and limitations evolved in a project with PCM's as heat transport medium and elaborate calculation for analysis supported by a simulation programme would definitely be a remarkable and reckonable guidance for deciding and designing PCMs in building application.

(6) 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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