

Review on Phase Changing Materials as Thermal Energy Storage System in Buildings

R. Kathiravan¹, Dr. A. Muthadhi²

¹Research scholar, ²Assistant Professor, Pondicherry Engineering College, Pudhucherry, India

Abstract - Use of building materials incorporating active thermal components such as Phase Changing Materials (PCM) cause significant energy savings. Thermal energy storage (TES) systems using phase change material (PCM) have been recognized as one of the most advanced energy technologies in enhancing the energy efficiency and sustainability of buildings. Phase change materials are capable of storing and releasing energy in the form of heat in determined temperature ranges, produce a comfort thermal condition inside the building and reduce its energetic demand. Unlike conventional storage materials, PCM absorbs and release heat at a nearly constant temperature. It stores 5–14 times more heat per unit volume than sensible storage materials. In this paper, recent development of PCMs with concrete, their incorporation and the influence of PCMs on the properties of concrete at the different stages are reviewed.

Keywords – Energy efficiency, Phase changing material, Thermal energy storage (TCS), Microencapsulation

I. INTRODUCTION

Due to the rapid economic development, utilization of natural resources has been tremendously increased. However the resources are limited and liable due to global warming, climatic changes and emissions of greenhouse gases [1]. Energy storage is an important factor, especially renewable sources, to compensate energy supply with demand [2]. Various storage technologies are emerging in the form of thermal energy, kinetic energy, chemical solution etc., for energy storage in buildings. Thermal energy storage (TES) system is one of the most efficient methods to store adequate thermal energy in the building and contribute to environmental friendly energy use [3].

Phase change materials (PCM) have received considerable attention for use in latent heat thermal energy storage (TES) systems. Phase changing materials are the substance that absorb or release large amount of heat as it undergo phase transformation and exhibit high energy storage capacity [4]. When the temperature rises above a certain point, the chemical bonds in the material will start to break up and the material will absorb the heat in an endothermic process where it changes state from solid to liquid. As the temperature drops, the material will give off energy and return to a solid state.

The energy used to alter the phase of the material, given that the phase change temperature is around the desired comfort room temperature, will lead to a more stable and comfortable indoor climate, as well as cut peak cooling and heating loads. Many varieties of PCMs are known to melt with a heat of fusion in any required range. However, the implementation of latent heat storage 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. [5]

II. PHASE CHANGING MATERIALS

A. Classification of phase changing materials

Phase change materials can be divided into different subcategories based on their chemical composition. Three major groups are: (i) organic compounds, (ii) inorganic compounds and (iii) inorganic eutectics or eutectic mixtures. The organic compounds are divided as paraffins and non-paraffins. Each group has its typical range of melting temperature and its range of melting enthalpy is given in Figure.1 and the classifications of PCMs are shown in Table.1 [6].

B. Organic phase changing materials

Organic PCMs are described as paraffin and non-paraffin materials. E.g. Fatty acids, alcohols and glycols. Organic materials have stable phase change temperature (without phase segregation), consequent degradation of latent heat fusion, self- nucleation (no super cooling) and usually non-corrosiveness. [7]

Paraffins are straight-chain or branched saturated organic compounds with the composition C_nH_{2n+2} . Paraffin can be obtained from crude oil, coal and other organic materials like wood, lignite, bituminous shale, fish tallow, etc. With increasing average molecular weight, the melting point of paraffin rises. [8]. Commercial paraffin waxes are cheap with moderate thermal storage densities (200 kJ/kg or 150 MJ/m³) and a wide range of melting temperatures. It under go negligible sub-cooling and are chemically inert and stable with no phase segregation. However, it has low thermal conductivity, which limits their applications.

Metallic fillers, metal matrix structures, finned tubes and aluminum shavings were used to improve their thermal conductivity [9]. Pure paraffin waxes are very expensive, and therefore, only technical grade paraffin was used.

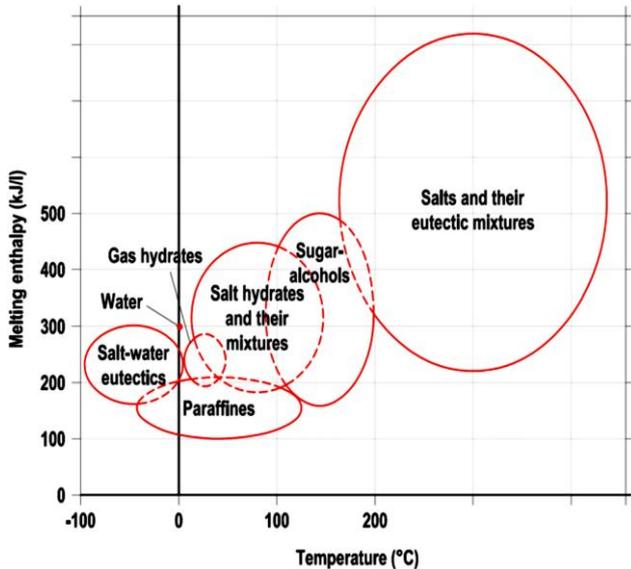


Fig1. Melting enthalpy and melting temperature for different groups of phase change materials

Non-paraffin PCMs include organic materials such as fatty acids, esters, alcohols and glycols. Non Paraffin have high heat of fusion values comparable to that of paraffin. It shows reproducible melting and freezing behavior and freeze with no supercooling. Some of the features of these organic materials are as follows: (i) high heat of fusion, (ii) inflammability, (iii) low thermal conductivity, (iv) low flash points, (v) varying level of toxicity, and (vi) instability at high temperatures.

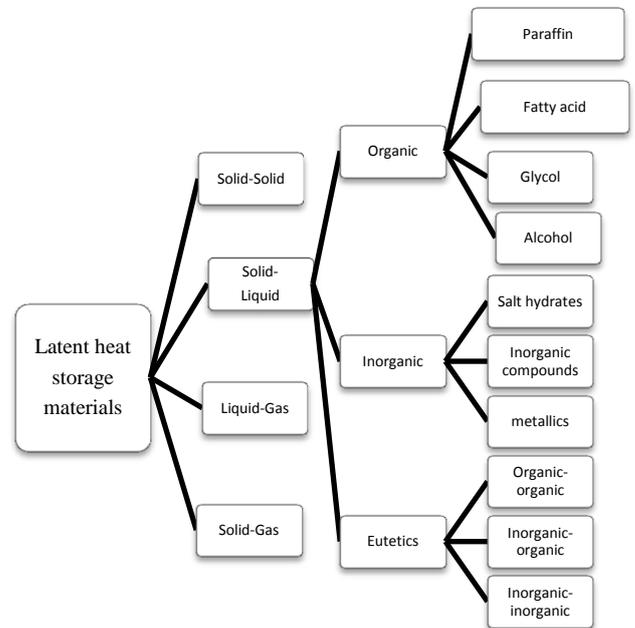
Non-paraffin PCMs have excellent melting and freezing properties and can be adapted for thermal storage. Its cost is three times higher than organic paraffins) [10].

C. Inorganic phase changing materials

Inorganic PCMs have higher heat of fusion than most organic PCMs, good thermal conductivity, affordable and are non-flammable [3]. Hydrated salts are typical inorganic PCM used, and have a high thermal storage density (about 240 kJ/kg) and has higher thermal conductivity than paraffin waxes, 0.5 W/(mK) [7]. These materials have some useful characteristics:

- (i) It changes its state within useful temperature ranges;
- (ii) It has relatively high latent heat per unit volume;
- (iii) It does not have flammable hazard;
- (iv) It is relatively inexpensive.

Table 1
Classification of PCM



But, these materials are corrosive and require special containment as well as space for the containers. The extra cost of these facilities offsets the cost advantage of the PCMs themselves [2, 3]. However, the major reasons for inorganic PCMs, not suitable for use in building materials are their tendencies to supercool and to melt incongruently

D. Eutectic phase changing materials

Eutectics PCMs are a mixture of multiple solids that are proportioned in such a way to produce very melting point. The main advantage of eutectics is that their melting points can be adjusted by combining different weight percentages of components. Eutectics do also possess high thermal conductivity and density and do not experience any segregation and super cooling. However, the latent and specific heat capacities are much smaller than salt hydrates and paraffin.[7,8]

E. Selection process for PCMs

Appropriate PCMs were selected by evaluating a set of criteria in which the following characteristics were examined [11]. The following properties are

➤ Thermo physical properties

- i. High latent heat of fusion per unit volume so that smaller size of container can be used
- ii. PCM should melt completely (i.e. congruent melting) during its phase so that the solid and liquid phases are homogenous.

- iii. PCM should be in the desired operating temperature range for thermal comfort in buildings.
- iv. It should be thermally reliable (i.e. cycling stability) so that it can be used in long run.
- v. Favorable phase equilibrium and no segregation.

➤ *Chemical Properties*

- i. Corrosion resistant to construction and encapsulated materials
- ii. High freeze or melt stability
- iii. Chemical stability
- iv. Non-toxic, non-flammable and non-explosive so as to assure safety
- v. No degradation after large number of thermal (freeze/melt) cycles so as to assure long operation life
- vi. Chemically compatible with construction and encapsulated materials

➤ *Kinetic properties*

- i. High rate of nucleation so as to avoid super cooling of the PCM in liquid phase.
- ii. High rate of crystal growth so that heat recovery from the storage system is optimum.

Table 2
List of PCM commercially available in market

Organic	Paraffins	Inorganic
Polyglycol	Paraffin C14	H ₂ O
Polyglycol E 600	Paraffin C15–C16	LiClO ₃ ·3H ₂ O
Polyglycol E 6000	Paraffin C16–C18	Mn(NO ₃) ₂ ·6H ₂ O
Dodecanol	Paraffin C13–C24	LiNO ₃ ·3H ₂ O
Biphenyl	Paraffin C ₁₈	Na ₂ CO ₃ ·10H ₂ O
Propianide	Paraffin C ₂₃ –C ₅₀	Na ₂ S ₂ O ₃ ·5H ₂ O
Dimethyl-sulfoxide	Paraffin C ₂₀ –C ₃₃	Ba(OH) ₂ ·8H ₂ O
Laurinic acid		MgCl ₂ ·6H ₂ O
Lakisol		KNO ₃
Palmitic acid		KOH
Stearic acid		MgCl ₂
HDPE		CaBr ₂ ·6H ₂ O
Miristic acid		NaNO ₃

III. PCM INCORPORATION INTO CEMENTITIOUS SYSTEM

PCM was incorporated into cementitious systems by a variety of means: (i) immersion of cured concrete into a melted liquid PCM, (ii) impregnation via saturation or vacuum saturation with porous aggregates [10], (iii) direct mixing of either encapsulated PCM or bulk PCM into concrete during mixing.

A. Immersion method

Soaking of the porous concrete products in a melted PCM (named immersion PCM-concrete) is called as immersion technique which was first introduced by Hawes. It is the immersion of porous concrete products in a container already filled with the liquid PCM. The effectiveness of emersion process mainly depends on absorption capacity of the concrete, temperature and types of PCM being employed [12].

B. Impregnation method

Impregnation consists of three basic process

- a. Evacuation of air and water from the porous or light weight aggregates with the help of vacuum pump.
- b. Soaking of porous aggregates in the liquid PCM under vacuum ends second step.
- c. Pre-soaked PCM porous aggregate functioning as a 'carrier for the PCM' is mixed into the concrete

C. Direct mixing method

Direct incorporation it is the simplest method in which liquid or powderedPCMs are directly added to building materials such as gypsum, concrete or plaster during production [6]. PCM must be first encapsulated within a chemically and physically stable shell before directly mixing it with concrete. Encapsulation can be done by interfacial polymerization, emulsion polymerization, in situ polymerization as well as spray drying. For direct mixing, the shell hardness of the PCM microcapsules should be sustainable and indestructible to avoid any damage during the concrete mixing.

IV. ENCAPSULATION OF PHASE CHANGING MATERIALS

The process of encapsulation increases the heat transfer area and also helpful in forming a barrier and protecting the PCM from the outside environment and controlling the volume changes of the PCM [12] This process comprises the involvement of PCM within a capsule of various materials, forms and sizes prior to incorporation so that it may be introduced to the mix in a convenient manner. There are two principal means of encapsulation.

A. Macro encapsulation

This procedure comprises the inclusion of PCM in some form of package such as tubes, pouches and panels. These containers can serve directly as heat exchangers or they can be incorporated in a building product.

B. Micro encapsulation

This is a process comprising of PCM as a core material enclosed in polymer or inorganic shell to maintain the shape and prevent PCM from leakage during the phase change process. [7] This can be achieved by emulsification followed by membrane formation around each micro droplet by interfacial polymerization. [8]

The coated particles can then be incorporated in any matrix which is compatible with the encapsulating film [7,8]. It follows that the film must be compatible with both the PCM and the matrix.

C. Nano encapsulation

In some fields especially in latent functionally thermal fluids, microencapsulated PCMs had not well done under repeated cycling, because the large particles of the microencapsulated PCM not only increased the fluid's viscosity, but also were often crushed during pumping. Therefore, it is necessary to develop nano-encapsulated PCMs with smaller particle size as compared with microencapsulated PCMs.

Microencapsulated PCMs are formed from PCM as core and a material as shell to retain the shape and prevent PCM leakage during the phase change process [10]. The PCM microcapsules or nano capsules have some advantages, such as increasing the heat transfer area and controlling the volume changes of storage material during the period of phase change [11, 12]. Most attention in preparing micro and nano capsules was on using organic materials as shell, but the use of inorganic shell materials has gained growing interest recently

V. PROPERTIES OF CONCRETE USING PCM

A. Fresh Properties of concrete

Fresh properties of self-compacting concrete were examined (SCC) by testing the slump flow, V-funnel time and J-ring properties. The results show that it is possible to produce good self-compacting properties using PCM microcapsules. The slump flow PCM-SCC mixtures were similar to plain SCC mix by adjusting the water content and the dosage of super plasticizer. It shows slightly higher viscosity, when PCM dosage is about 5 to 8 % which was attributed to the higher water content, but the particle size of PCM microcapsules used could affect the workability of the concrete mixture [13].

B. Heat of Hydration

The use of PCM resulted in a reduction of heat in the hydration process and the reduction was more pronounced when the PCM was directly added to the mixture.[14]

When PCM melted at a designed temperature, the retarder was released into the cement matrix and it controlled the rate of heat release by cement hydration. Using paraffin wax PCM in the cement mortar caused an one-hour delay in reaching the peak temperature which indicate the retardation of cement hydration. PCM had a significant effect in retarding (delay in reaching peak temperature) and suppressing (reduction in peak temperatures) the hydration of the cement matrix. [15]

C. Mechanical properties

The compressive strength PCM-concrete dramatically reduced with the inclusion of PCM. But in immersion technique, it has been found that there is no significant difference in the strength between the control and immersion PCM-concrete. It is possibility to achieve a compressive strength of over 25 MPa and a tensile splitting strength of over 6MPa (after 28 days) for some structural application purposes. However, in the case of direct mixing, inclusion of PCM microcapsules in SCC significantly reduces the compressive strength [16].

The compressive strength of PCM in Self Compacting Concrete decreases by 13% for each additional percentage of PCM added by total concrete weight. The two mechanisms responsible for this decrease in strength are (i) significant disparity between the intrinsic strength of the microcapsules and other concrete constituents such as cement paste, and (ii) damage of PCM resulting in paraffin wax leaking from the broken microcapsules and mixing with other concrete constituents.

D. Thermal properties

The heat storage capacity of concrete is significantly increased when PCM is applied. The thermal properties of PCM are important factors for practical use, how the energy can be released by a solidifying PCM and how quickly a PCM can be 'refilled' by absorbing energy from the ambient environment or direct solar radiation [11]. The thermal characteristics of the PCM concrete specimens were determined by differential scanning calorimetry. To overcome practical problems of solid liquid phase transitions, PCMs have to be microencapsulated and turned into solid formulations for applications in various thermal management applications. To remain functional over numerous phase transition cycles, microencapsulated PCMs have to remain encapsulated within the impermeable microcapsule walls for the whole product life. PCM microcapsules need to be highly resistant to mechanical and thermal properties.

VI. APPLICATIONS OF PCMS

A. PCM enhanced concrete

PCM enhanced concrete (thermo-concrete) is another possibility for applying PCMs in building constructions.

To produce low cost storage materials with structural and thermostatic properties, thermo-concrete is an appropriate PCM with a concrete matrix [10].

B. Building applications

To improve the performances of technical installations such as hot water heat stores, pipe insulation and cool thermal energy storage and latent heat thermal storage systems, PCMs can be incorporated. In addition, the improvement of double facades with PCMs has been achieved for better control of the cavity temperature [9].

C. Noise absorption or insulation

Microcapsules containing a magnetic fluid were used to absorb or insulate noise. Examples included noise-absorbing thermally expanding microcapsules, made of a thermoplastic resin, which contained a hydrophobic organic solvent with 5-200 nm magnetic particles, and a hydrophobic liquid foaming agent. The noise-absorbing microcapsules were incorporated into paints, and mixed in or adhesively attached to construction materials

VII. SUMMARY

Organic and inorganic compounds are the two most common groups of PCMs. Most organic PCMs are non-corrosive and chemically stable, exhibit little or no sub-cooling, are compatible with most building materials and have a high latent heat per unit weight and low vapor pressure. Their disadvantages are low thermal conductivity, high changes in volume on phase change and flammability. Inorganic compounds have a high latent heat per unit volume and high thermal conductivity and are non-flammable and low in cost in comparison to organic compounds. However, they are corrosive to most metals and suffer from decomposition and sub-cooling.

The application of PCM's in concrete cause reduction in the workability as well as the strength properties of the concrete. Thermal behavior of the PCM has shown significant increase in the thermal storage of the building and gives comfort condition to the building. However, the thermal and the mechanical strength of encapsulated PCM should strongly be influenced by the morphology of their particles.

PCM, which can be applied are vast ranging from heat and coolness storage in buildings to thermal storage in concrete and protective clothing. A PCM with an easily adjustable melting point would be a necessity as the melting point is the most important criterion for selecting a PCM for passive solar applications. Many more applications are yet to be discovered.

REFERENCES

- [1] Ravikumar M, Srinivasan PSS, "Analysis of heat transfer across building roof with phase change material", Journal of Computational Information Systems, Vol.4, pp.1497-1505, 2012
- [2] Tung-Chai Ling, Chi-Sun Poon, "Use of phase change materials for thermal energy storage in concrete: An overview", Construction and Building Materials, Vol.46, pp.55-62, 2013
- [3] Mario A Medina, Kyoung Ok Lee, Xing Jin, Xiaoqin Sun, "On the use of phase change materials in building walls for heat transfer control and enhanced thermal performance", APEC Conference on Low-carbon Towns and Physical Energy Storage, Changsha, China 25-26 May, 2013
- [4] Hawes D.W., Banu D, Feldman D, "Sol. Energy Mater". 19 (1989) 335
- [5] Feldman D, Khan M.A, Banu D, "Energy storage composite with an organic PCM", Solar Energy Materials 18 (1989) 333-341.
- [6] Hawes D W, Feldman D, "Absorption of phase change materials in concrete", Solar Energy Material and Solar Cells, Vol. 27, p. 91,101, 1992.
- [7] Zhao, C. Y. and Zhang, G. H. (2011), "Review on microencapsulated phase change materials (MEPCMs): Fabrication, characterization and applications". Renewable and Sustainable Energy Reviews, Vol. 15, No. 8, pp. 3813-3832.
- [8] Castellon, C., Medrano, M., Roca, J., Nogues, M., Cabeza, L. F., & Castell, A. "Use of Microencapsulated Phase Change Materials in Building Applications". ASHRAE. Project ENE2005-08256-C02-01/ALT, 2007.
- [9] M.Ravikumar, Dr. PSS. Srinivasan, "Phase change material as a thermal energy Storage material for cooling of building", Journal of Theoretical and Applied Information Technology, 2008, vol. 4, pp. 503-511.
- [10] Mohammed M. Farid, Amar M. Khudhair, Siddique Ali K. Razack, Said Al-Hallaj, "A review on phase change energy storage: materials and applications", Energy Conversion and Management, 2004, 45, pp.1597-1615.
- [11] Ruben Baetens, Bjørn Petter Jelle, Arild Gustavsen, "Phase change materials for building applications: A state-of-the-art review, Energy and Buildings", Vol.42, pp.1361-1368, 2010
- [12] Pendyala, Swetha, "Macroencapsulation of Phase Change Materials for Thermal Energy Storage" (2012). Graduate Thesis and Dissertations
- [13] Pawan R. Ingole, Tushar R Mohod, Sagar S Gaddamwar, "Use of Phase Change Materials in Construction of Buildings: A Review" International Journal of Engineering Research and General Science Volume 2, Issue 4, June-July, 2014
- [14] Belen Zalba, Jose M Marin, Luisa F. Cabeza, Harald Mehling, "Review on thermal energy storage with phase change: materials, heat transfer analysis and applications", Applied Thermal Engineering 23 (2003) 251-283.
- [15] Atul Sharma, Tyagi V.V., Chen C.R., Buddhi, "Review on thermal energy storage with phase change materials and applications" Renewable and Sustainable Energy Reviews 13 (2009) 318-345.
- [16] J.A. Molefia, A.S. Luyta, I. Krupa, "Thermal and mechanical properties of Phase change conductive polymer Composite materials."