Phase Change Materials

A. S. Anusha

UG Student, Dept. of Chemical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad, India,
Contact: +919603435334 e-mail: anusha_addanki@yahoo.co.in

Abstract— Phase Change Materials (PCMs) are the substances that have a high capacity to store and release a large amount of energy in the form of latent heat during change of phase. In fact, PCMs are also known as latent heat storage units. When a substance changes its phase (physical state), energy radiations are absorbed/emitted while its temperature is maintained constant. The latent heat could be put into use. In the current scenario of energy crisis, besides hunting for alternative sources of energy, it is also important to use the available energy resources efficiently. With a broad spectrum of applications in thermal energy storage, minimized fuel consumption, waste heat recovery, cooling machines and computers, space crafts' thermal systems and many more industrial requirements, PCMs pave way to efficient energy management systems. Further research and development would enhance its commercial value. This study elaborates the working principle of PCMs, their classification, parameters that should be verified while selecting a PCM and other techno-economical aspects besides highlighting the merits of their applications in various fields.

Keywords— phase change materials, change of phase, latent heat storage, efficient energy management, thermal energy storage, applications

INTRODUCTION

With the current scenario of increasing energy requirement, shortage of energy resources, there arises a need to use the existing energy resources efficiently besides searching for new sources of energy. This could be accomplished by using phase change materials (PCMs). These are the materials that are mainly used to store thermal energy during the change of phase, usually from solid phase to liquid phase.

OBJECTIVE

The primary concern behind this study is to put into use the latent heat that is absorbed or released during the change of phase of a substance. The substances with high capacity to store and release this latent heat are termed as phase change materials.

PHASE CHANGE MATERIALS

Phase Change Materials (PCMs) are the substances that have a high capacity to store and release a large amount of energy in the form of latent heat during change of phase. They are also known as latent heat storage (LHS) units. [6]

***Characteristics*:**

PCMs latent heat storage can be achieved through solid–solid, solid–liquid, solid–gas and liquid–gas phase change. However, the only phase change used for PCMs is the solid–liquid change. Liquid-gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid–gas transitions do have a higher heat of transformation than solid–liquid transitions. Solid–solid phase changes are typically very slow and have a rather low heat of transformation.

Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat. Unlike conventional SHS, however, when PCMs reach the temperature at which they change phase (their melting temperature) they absorb large amounts of heat at an almost constant temperature. The PCM continues to absorb heat without a significant rise in temperature until all the material is transformed to the liquid phase. [7] When the ambient temperature around a liquid material falls, the PCM solidifies, releasing its stored latent heat. A large number of PCMs are available in any required temperature range from −5 up to 190°C .Within the human comfort range of 20°C to 30°C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

As one of the goals of latent energy storage is to achieve a high storage density in a relatively small volume, PCMs should have a high melting enthalpy [kJ/kg] and a high density [kg/m³], i.e. a high volumetric melting enthalpy [kJ/m³]. Paraffins have an excellent stability concerning the thermal cycling, i.e. a very high number of phase changes can be performed without a change of the material's characteristics. On the other hand they are flammable and their melting enthalpy and density is relatively low compared to salt hydrates. The problem with salt hydrates is their corrosiveness and the cycling stability, which can often only be guaranteed if certain conditions are met. Another disadvantage of salt hydrates is the so called subcooling. That means that the material does not crystallize at the melting temperature but at a temperature that can be much lower. The subcooling can be reduced by adding so called nucleators into the material.

Figure 1 represents the plot of temperature versus stored heat for an ordinary substance while figure 2 shows the plot of temperature versus heat absorbed when a PCM is used. We can significantly note from these two plots how PCMs can be effective in heat energy storage and temperature control. [8]

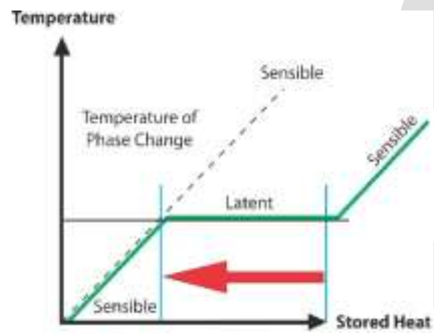

Figure 8

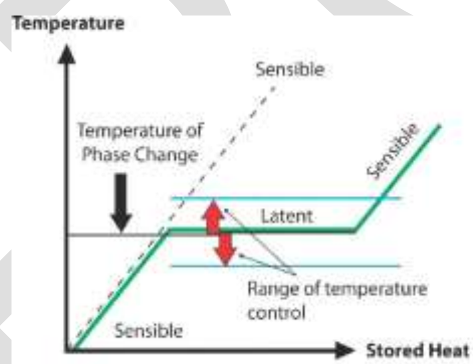

Figure 9

CLASSIFICATION

PCMs are broadly classified as follows [9]

Organic PCMs

Organic PCM are naturally existing petroleum bi-products that have their unique phase-change temperature. These include paraffins and fatty acids. Paraffin (C_nH_{2n+2}) and fatty acids ($CH_3(CH_2)_{2n}COOH$) They are chemically and thermally stable. They have little or no subcooling. They are not corrosive in nature and can be applied comfortably. Yet, they pose certain challenges too. They are flammable in nature. Hence domestically PCMs must be protected with a layer that protects from fire accidents. Organic PCMs have lower melting enthalpy and also have a low density.
Examples of organic PCMs include lauric acid, paraffin wax.

Inorganic PCMs

Inorganic PCMs are engineered hydrated salt solution made from natural salts with water. The chemical composition of salts is varied in the mixture to achieve required phase-change temperature. Special nucleating agents are added to the mixture to minimize phase-change salt separation and to minimize super cooling, that are otherwise characteristic of hydrated salt PCM. They include Salt hydrates (M_nH_2O).They have high density ad have a high melting enthalpy. Hence they have a broad spectrum of applications. Subcooling of inorganic PCMs poses a challenge to their applications. It means that as the substance melts, subsequently another part of the substance solidifies and makes the effect unevenly spread. Besides, they have poor stability. They are corrosive in nature. Hence, corrosion resistant coatings must be given before they are applied.

Examples of inorganic PCMs are calcium-chloride hexahydrate, sodium acetate trihydrate.

Eutectic mixture

A eutectic system is a mixture of chemical compounds or elements that have a single chemical composition that solidifies at a lower temperature than any other composition made up of the same ingredients. This composition is known as the eutectic composition and the temperature at which it solidifies is known as the eutectic temperature. Eutectics may be a combination of Organic-organic, organic-inorganic, inorganic-inorganic compounds.

Example of a eutectic mixture is Water and Ethylene Glycol. Combination of a hydrated salt and water can also form an effective eutectic system.

THERMOPHYSICAL PROPERTIES OF SELECTED PCMS[1]

Material	Type	Melting point (^oC)	Heat of fusion (kJ/kg)	Cost (US$)
Lauric acid	Organic	44.2	211.6	1.6
Sodium sulfate ($Na_2SO_4 \cdot 10H_2O$)	Inorganic	32.4	252	0.05
Trimethylo-ethane	Organic	29.8	218.0	
Water	Inorganic	0	333.6	0.003

Table 1

Thermal composites

Thermal-composites is a term given to combinations of phase change materials (PCMs) and other (usually solid) structures. A simple example is a copper-mesh immersed in a paraffin-wax. The copper-mesh within parraffin-wax can be considered a composite material, dubbed a thermal-composite. Such hybrid materials are created to achieve specific overall or bulk properties. [11]

In this case the basic idea is to increase thermal conductivity by adding a highly conducting solid (such as the copper-mesh) into the relatively low conducting PCM thus increasing overall or bulk (thermal) conductivity. If the PCM is required to flow, the solid must be porous, such as a mesh. [12]

A thermal composite is not so clearly defined, but could similarly refer to a matrix (solid) and the PCM which is of course usually liquid and/or solid depending on conditions.

SELECTION CRITERIA

A material should satisfy the following criteria for being chosen as a PCM:

- ***Thermodynamic properties***

International Journal of Engineering Research and General Science Volume 4, Issue 2, March-April, 2016
ISSN 2091-2730

The phase change material should possess the Melting temperature in the desired operating temperature range. It should possess High latent heat of fusion per unit volume and high specific heat, high density and high thermal conductivity. [3] It should undergo a congruent melting small volume changes on phase transformation and small vapour pressure at operating temperatures to reduce the containment problem.

- ***Kinetic properties***

A PCM should have High nucleation rate to avoid supercooling of the liquid phase. [5] It should possess High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system.

- ***Chemical properties***

A PCM should possess the following chemical properties [6]:

- Chemical stability
- Complete reversible freeze/melt cycle
- No degradation after a large number of freeze/melt cycle
- Non-corrosiveness, non-toxic, non-flammable and non-explosive materials

- ***Economic properties***

The material being put into use as a PCM must be easily available at a low cost.

WORKING OF A PCM

Let us consider a solid PCM exposed to an environment of varying temperatures. When the temperature rises, the PCM melts and absorbs heat. When the temperature drops, the PCM solidifies, and heat is emitted. During the phase change, the temperature remains constant. Phase change materials (PCMs) therefore take their name from their mechanism of action. Owing to their unique microencapsulation technology, PCMs can be integrated invisibly into the most diverse of construction materials, thus lending them their impressive properties.

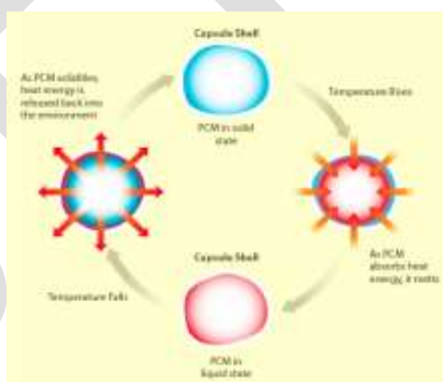

Figure 3

METHODS OF APPLICATION OF PCMs

i. Macro encapsulation

The PCM is encapsulated in e.g. cylindrical or spherical modules which are integrated into the storage tank. In order to ensure a good heat exchange between the surrounding heat transfer medium (water or a mixture of water and glycol in most of the cases) and the PCM, the modules should have a high ratio between surface area and volume, i.e. a high heat transfer area per volume unit. This implies that the modules should in principle be as small as possible, which is of course a matter of cost. The advantages of this kind of integration are the possibility of a relatively simple integration of PCMs into an existing storage tank and the possibility to use PCMs with different melting points in one tank. [10]

ii. Microencapsulation

Paraffins can also be micro-encapsulated with diameters of just a few µm as shown in the figure 3. Due to the small diameter the ratio of surface area to volume is very high and the low thermal conductivity is not a problem. It provides improved heat transfer between the PCM and surroundings because of increased surface area. If these microcapsules are dispersed in a fluid (mostly water), they form a pumpable slurry, that can be used as an energy transport- and storage medium, as a so-called PCM slurry. A microencapsulation of salt hydrates is not possible. Microencapsulation adds cost because it involves several chemical synthesis steps.

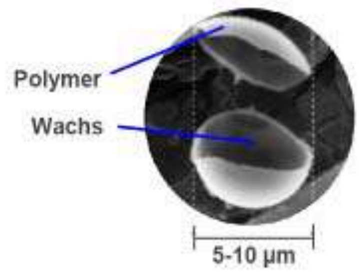

Figure 4

APPLICATIONS OF PCMs

Applications of phase change materials include, but are not limited to [2]:

- Thermal energy storage
- Conditioning of buildings, such as 'ice-storage
- Cooling of heat and electrical engines
- Cooling: food, beverages, coffee, wine, milk products, green houses
- Medical applications: transportation of blood, operating tables, hot-cold therapies
- Waste heat recovery
- Off-peak power utilization: Heating hot water and Cooling
- Heat pump systems
- Passive storage in bioclimatic building/ architecture (HDPE, paraffin)
- Smoothing exothermic temperature peaks in chemical reactions
- Solar power plants
- Spacecraft thermal systems
- Thermal comfort in vehicles
- Thermal protection of electronic devices
- Thermal protection of food: transport, hotel trade, ice-cream, etc.
- Textiles used in clothing
- Computer cooling
- Turbine Inlet Chilling with thermal energy storage
- Telecom shelters in tropical regions. They protect the high-value equipment in the shelter by keeping the indoor air temperature below the maximum permissible by absorbing heat generated by power-hungry equipment such as a Base Station Subsystem. In case of a power failure to conventional cooling systems, PCMs minimize use of diesel generators, and this can translate into enormous savings across thousands of telecom sites in tropics.

MAJOR CHALLENGES TO PCMs

There are various challenges to PCMs which are illustrated below [4].

- ***Incongruent melting of salt hydrates*.**

  Many minerals do not melt uniformly. Instead they decompose as they melt.
  The figure 4 shows the melting pattern of water-NaCl system.

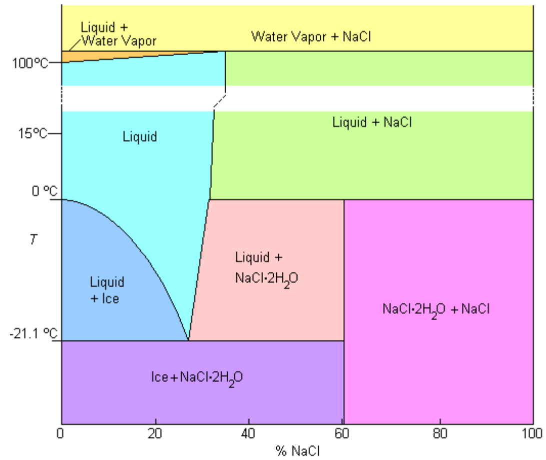

Figure 5

- ***Corrosion***

  Salt hydrates are corrosive in nature due to the presence of alkaline elements such as sodium, calcium, potassium, etc.

Figure 6

- ***Flammability***

  Organic PCMs which comprise of paraffins and fatty acids are highly flammable in nature. Application of these substances must be done with utmost care.

Figure 7

- ***Expensive microencapsulation***

Microencapsulation provides improved heat transfer between the PCM and its surroundings because of increased surface area but adds cost because it involves several chemical synthesis steps. The final PCM cost varies greatly depending on the approach adopted to encapsulate the PCM.

CONCLUSION

Phase change materials provide an effective and efficient way to save energy and use the available energy efficiently. Easy availability of these materials makes their application comfortable. Depending on the field of application, a suitable PCM must be selected. Further research against unfavorable chemical properties and cost reduction would enhance their commercial value in the global market.

REFERENCES:

[1] Belén Zalbaa, José Ma Marína, Luisa F. Cabezab, Harald Mehlingc, "Review on thermal energy storage with phase change: materials, heat transfer analysis and applications" Applied Thermal Engineering, Volume 23, Issue 3, February 2003, Pages 251–283

[2] Sharma, Atul; Tyagi, V.V.; Chen, C.R.; Buddhi, D. (2009). "Review on thermal energy storage with phase change materials and applications". Renewable and Sustainable Energy, Pages: 318–345,

[3] Hawes DW, Banu D, Feldman D, 'Latent heat storage in concrete II, Solar Energy Materials', 1990, 21, p.61–80.

[4] Pasupathy, A; Velraj, R; Seeniraj, R (2008). "Phase change material-based building architecture for thermal management in residential and commercial establishments". Pages: 39–64.

[5] Yinping, Zhang; Yi, Jiang; Yi, Jiang (1999). "A simple method, the -history method, of determining the heat of fusion, specific heat and thermal conductivity of phase-change materials". Measurement Science and Technology 10 (3): 201–205. Bibcode:1999MeScT..10..201Y

[6] Tamme, Rainer (February 20, 2003). "Phase Change - Storage Systems" (PDF)

[7] Omer, A (2008). "Renewable building energy systems and passive human comfort solutions". Renewable and Sustainable Energy Reviews 12 (6): 1562–1587.

[8] Bony, J., Ibanez, M., Puschnig, P., Citherlet, S., Cabeza, L., Heinz, A., (2005), Three different approaches to simulate PCM bulk elements in a solar storage tank, Phase Change Material and Slurry: Scientific Conference and Business orum, 5.-17. Juni 2005, Yverdon les Bains, Schweiz, S. 99 - 107

[9] Cabeza, L., (2005), Storage Techniques with Phase Change Materials, Thermal energy storage for solar and low energy buildings, State of the art by the IEA Solar Heating and Cooling Task 32, June 2005, Seite 77-105

[10] A. Heinz, W. Streicher, "Application Of Phase Change Materials And Pcm-Slurries For Thermal Energy Storage", https://intraweb.stockton.edu/eyos/energy_studies/content/docs/FINAL_PAPERS/8B-4.pdf.

[11] schoeller®-PCM - Schoeller Textiles

[12] PCM technology - DuPont™ Energain