Chapter

# Introductory Chapter: Nano-Enhanced Phase-Change Material

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## 1. Phase-change materials

The consumption of any kind of energy has a significant role in protecting energy in the economic development of any country. Today, request in the sector has led to beautiful and large buildings around the world. It is noteworthy that buildings will spend about 30% of the worldwide energy produced. More energy demand for developing economies is projected; the lack of awareness about the pricing of fossil fuels and the increasing information about environmental problems has donated to the serious consideration of different renewable energies. Among different types of energy, heat transfer is universally observed in nature as geothermal energy and energy radiation in nature. This energy is a side effect of a large amount of energy production units and energy conversion products and systems. Energy storage may be maintained to maintain energy before energy use, or it can be used as a way to maintain calm in buildings, saving energy in different sectors of the society. An energy storage system should have certain features that include proper energy storage material with a specific melting temperature at the optimum range, decent heat transfer well, and pleasant enclosure compatible with the most important energy storage methods. Today, to reduce fossil fuel consumption in buildings, thermal energy storage systems should be employed to augment the efficiently. **Figure 1** shows examples for the industrial and internal application of thermal energy storage systems (see [1, 2]). One of the advantages of utilizing thermal storage is that it can be consistent with supply [3].

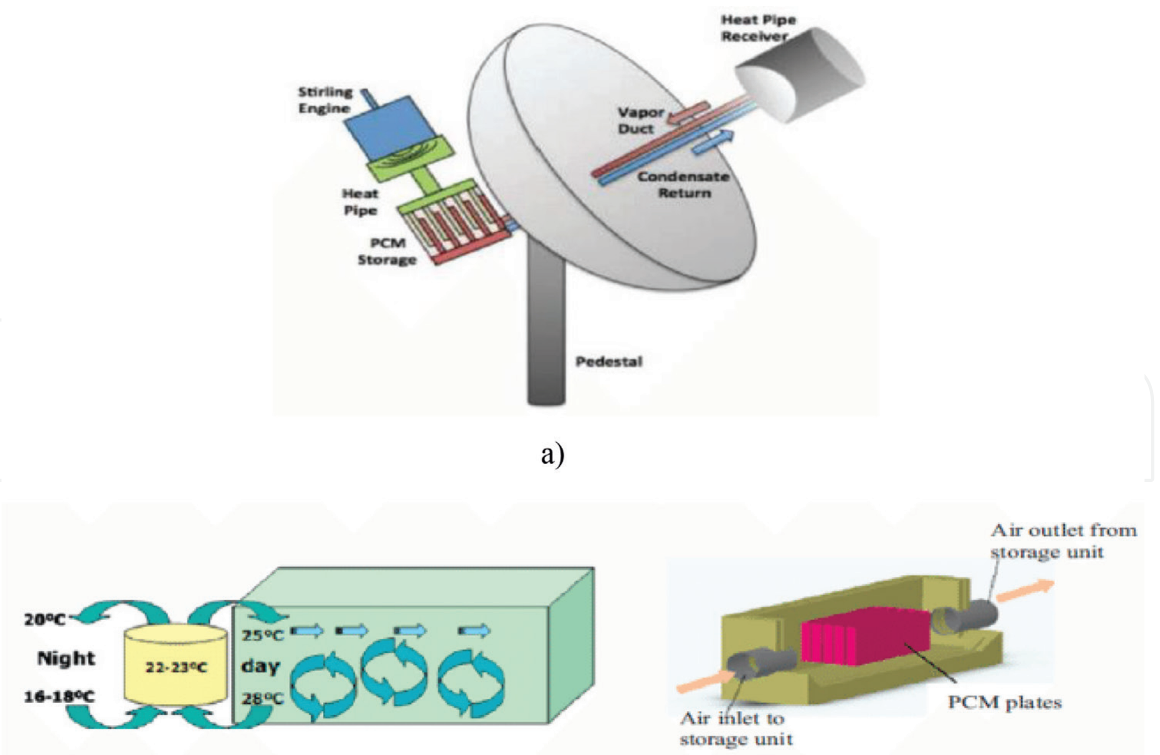
## 2. Techniques for energy storage

### 2.1 Latent heat

Release or absorption of energy by changing the phase as gas to liquid or liquid to solid can be considered as the main reason for such way.

### 2.2 Sensible heat

Energy is saved by increasing material temperature. Efficiency of thermal storage relies on temperature difference, specific heat, and amount of material. The best material in this view is water due to its low cost and great heat capacity.




b)

**Figure 1.**
*NEPCM for energy storage units [1, 2]. a)Latent energy storage for dish striling power generation b)PCM in free cooling systems.*

## 2.3 Electrical energy

The electric energy has been stored through the battery. Battery is charged directly to a direct current source and converted to the electrical energy when discharged. Storing of electrical energy is produced by photovoltaic cells with the use of battery during the power loss.

## 2.4 Mechanical energy

This system includes the storage of gravitational energy, pumped water power storage, and the storage of compressed air energy.

## 2.5 Thermochemical energy storage

Absorption and discharge of energy through the failure and deformation of the molecular bond during the chemical reaction can be considered as the basis of this method. The mass of material, the type of reaction, and the amount of change affect the stored heat directly. The phase variation can take the form of solid-gas, liquid-gas, solid-solid, and solid-liquid. In change of solid, the heat is saved in a change from one type of crystal to another. These changes generally have low-energy content and a small change in volume relative to the change of solid to liquid. Heat transfer takes place when the phase changes. Liquid phase and solid phase converge up and down by absorbing and releasing heat at temperatures that release or absorb heat at the uniform temperatures. These materials store energy (5–14 times) relative to tangible energy storage. Phase-to-phase materials are more than loneliness for the transfer of heat, but to use this material, there is a need for a heat exchanger between the PCM and source. This is because of the low diffusion factor of PCM.

### 2.6 Heat storage

Heat storage is a variation of internal energy of the material which can be sensible, latent, and thermochemical forms.

## 3. PCM

### 3.1 Categories

Phase materials are organic or mineral compounds can save and absorb high heat energy within them. The storage of heat energy in these materials occurs within phase-change mechanism. In distinctive sources, different categories for PCM were performed, but as the common area of these divisions, mainly phase-change materials fall into two nonorganic categories. The most common organic material of this material is paraffin wax and the most common nonorganic sample of hydrate salt. It is worth noting that there are significant differences between the characteristics of organic phase transition material and nonorganic PCMs. Three important categories must be categorized into hydrate salts, organic matter, and eutectics. Organic materials are also composed of high-carbon and hydrogen chains whose phase-change temperatures are above 0°C (see **Figure 2**). Comparison of the cases is listed in **Table 1**. In the following section, varied chemistry categories of phase-change materials, disadvantages, and advantages are discussed. The criteria for choosing a suitable phase-change material for different uses are discussed below. Then, to define PCMs, plus some examples of applications of these materials, techniques for increasing the efficiency of these materials in energy storage systems have been investigated. Finally, with a review of past work in this area, a summary of the whole chapter is presented.

#### *3.1.1 Inorganic materials*

The inorganic PCMs are generally categorized into two groups of metals and hydrated salts. These phase-change materials are denser and more energy-efficient than organic phase-change materials. In terms of price, organic phase-change materials are extensively cheaper. In addition to the benefits mentioned above, inorganic phase-change materials are widely corrosive. Generally, the problem is overcooling, which means they are hardly crystalline when they reach the freezing point.

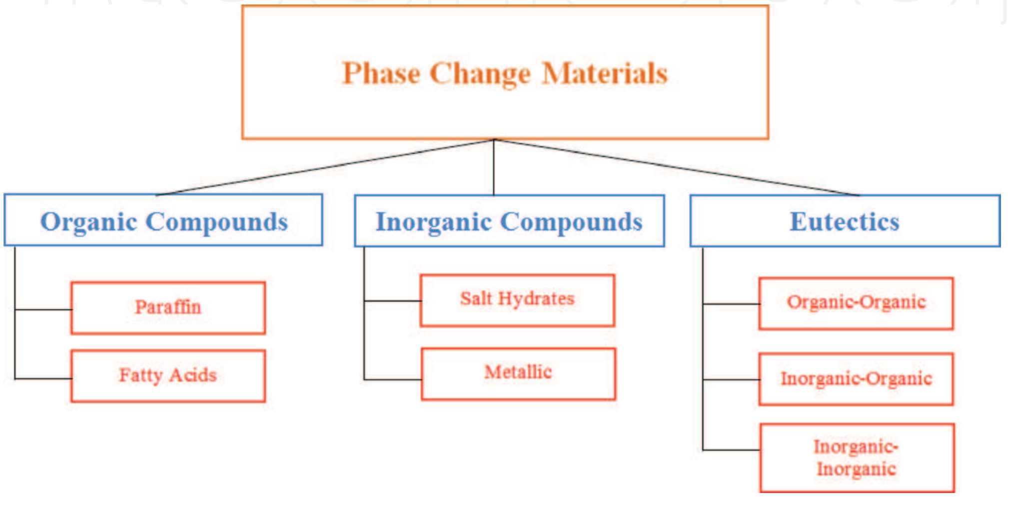



**Figure 2.**
*Different kinds of PCM.*

| Disadvantages | Benefits | Classification |
|---|---|---|
| Corrosion<br>Supercoiling | Availability in low cost<br>Low volume change<br>High thermal conductivity<br>High heat of fusion | Inorganic PCMs |
| Flammability<br>Low thermal conductivity<br>Relative large volume change | Good compatibility<br>Recyclable with other materials<br>No supercoiling<br>High heat of fusion<br>Availability in a large temperature range | Organic PCMs |
| Lack of test data | High volumetric thermal storage density<br>Sharp melting temperature | Eutectics |

**Table 1.**
*Various types of PCMs.*

#### *3.1.2 Organic materials*

The organic PCMs should be separated from the group of paraffin and non-paraffins, such as fatty acids, esters, glycolic acids, and alcohols.

#### *3.1.3 Disadvantages and advantage of organic and nonorganic material*

The advantages of organic material include the presence in the temperature range, freezing of overcooling, ability to melt compatible with common materials, non-separable and recyclable, and great fusion heat. The limitations of this organic material include low storage capacity, low thermal conductivity, and thermal flammability. The advantages of nonorganic materials include considerable latent heat and low cost. The limitations of nonorganic material include a large change in volume, overheating, separation, and corrosion.

#### *3.1.4 Phase-change material selection and selection criteria*

To select the phase-change material, there exist some parameters that should be studied, namely, thermodynamic characteristics, kinematic properties, chemical properties, and economic features.

##### *3.1.4.1 Thermodynamic characteristics*

The melting temperature must react in the wanted temperature range and low vapor pressure at the reaction temperature to decrease the issue of inhibiting melting.

##### *3.1.4.2 Kinematic properties*

The high reaction rate is important for avoiding the superconducting fluid phase and high growth rates; therefore, system can restore heat from storage units.

##### *3.1.4.3 Economic features*

It is economically low-cost and also available.

#### *3.1.4.4 Chemical properties*

The chemical and full cycle and non-degradation after the successive cycles are important issues.

### *3.1.5 Application of phase-change material*

The materials of phase changes have found many applications due to the changing temperature. Materials that melt below 15°C can be used to cool and ventilate room air are used. Materials that melt above 90°C are used to reduce temperatures where temperatures can rise suddenly and prevent fire. The PCM, whose melting temperature is between these two values, is used to store solar energy. PCMs for cold and heating temperatures in smaller proportions have building applications. In addition to the melting point of PCM, in the design of each heat storage unit that operates on the basis of PCM, the following notes must be considered: the material of the desired PCM with the wanted melting temperature and a PCM storage chamber that is talented of absorbing the volume changes of these materials within phase change. It should be noted that in order to get better efficiency, the melting temperature should be within the working temperature range, in addition to its thermal insulation, the phase-change properties can also be used. However, there are plenty of ways to use these materials in design of buildings. But one of the most significant points in the use of such materials, like other static systems, is the issue of calculating economic justification and the time of returning capital after the time of operation. In some cases, the use of PCM can decrease the thermal flux of the entrances to the building by up to 38%. Furthermore, the augment in the number of holes in the PCM in the recipe makes a reduction of 11% in heat flux. However, since the use of these materials in raw form can be disadvantageous due to the type PCM, and also due to the possibility of fluid PCMs, it can be necessary to enclose in the liquid phase. In order to provide both micro- and macrocomponents, phase changes are embedded in the enclosures and are thus encapsulated. In this way, the major difference between microcapsules and microcapsules is in the size of the casings or capsules. In the microcapsule method, the materials are embedded in spheres of 1–30 microns in diameter. In microcapsule method, materials in larger compartments are embedded in envelopes or containers of different sizes. The bulk of these compartments are made of plastic packs, as well as high-density polyethylene panels. Both microcapsules and microscopes have advantages and disadvantages. Encapsulation of materials is carried out using various materials. Encapsulation using plastics and metals is expensive but safe. In the construction industry, both methods can be used, but according to the place of use and also in combination with other building materials, the application of each method creates significant differences among the results and thermal treatment of the building. In the application of microcapsules of phase-change materials as fine-grained concrete, attention to the lack of functional interactions between these materials is important for the initial performance of fine-grained concrete. In this way, micro-capsulation of the material by saturation of the phase change in the fresh concrete is very effective in the thermal behavior of the materials.

#### *3.1.5.1 PCM for heat storage*

Newly, several researchers focus on improving the efficiency of building energy in order to enhance the performance of buildings [4]. Among different technologies, PCM has a major contribution to the development of high-efficiency buildings [5].

PCMs are materials that are talented of high absorption, release, and storage of energy at a relatively stable temperature. Thermal energy can be saved by saving energy or sensible energy with thermal changes in material content. This energy is available when the process is reversed. A number of papers have been reviewed [6] on PCMs that have been investigated for heat transfer, transportation, and various issues related to the system. Due to high-density changes, phase-change materials that require supports are not preferred over the high-energy process. Thus, for thermal applications, the latent fusion of PCMs is used. For a specific program, melting point and latent heat are important criteria to be chosen. Many of the phases modifying substances are considered, such as paraffin, water, and salt hydrates. Some properties, including diffusivity and thermal conductivity, are very important [7]. To improve the storage of thermal energy, the first review of nanomaterials in phase-modified materials is given by Elgafy and Lafdi [8]. Some effective applications of phase-change materials have been presented by Salyer et al. [9] and Demirbas [10], which can be referred to solar power plants for saving daytime energy and reuse it the next day, medical treatment, pharmaceuticals, pharmaceuticals, transportation, photovoltaic cells, thermal management systems, and electronic systems to prevent very high temperatures. One of the main uses of this material in the building is energy conservation.

## 4. Nanotechnology

### 4.1 Use of nanotechnology in heat storage unit

Development of nanotechnology has led to the emergence of a bunch of high-performance nano-structured materials. These materials are capable of absorbing thermal energy and high release and become for industrial applications. NEPCM has been used for various applications [11–36].

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