

An Introduction to Phase Change Materials as Heat Storage Mediums

Thomas Hasenöhr

Dept. of Energy Sciences, Faculty of Engineering,
Lund University, Box 118, 22100 Lund, Sweden

Abstract

Phase change materials (PCMs) have a high heat storage density. This article briefly discusses the physical reason for this property and some important applications of PCMs. Moreover, the major advantages and drawbacks of salt hydrates and paraffins used as PCMs and some solutions to cope with the low thermal diffusivity of paraffins are presented.

Nomenclature

C_p	Specific heat [J/(kg K)]
h	Enthalpy [J/kg]
Δh_m	Latent heat [J/kg]
m	Mass [kg]
Q	Heat [J]
T	Temperature [K]
T_i	Initial temperature [K]
T_f	Final temperature [K]
T_m	Melting temperature [K]

when there is enough wind, and solar collectors can only produce heat when the sun is shining. Often, availability and demand do not occur simultaneously. Sometimes more energy might be produced than demanded and vice versa. Energy storing however is an approach to overcome this problem. Energy is produced when the conditions allow for it, and excessive energy can be stored and used as soon as demand is higher than production.

Introduction

At present, renewable energies and increased energy efficiency play an important role in energy politics. They are both an important approach to reduce the climate change and, especially for countries without or with minor fossil energy resources, a chance to achieve more independence from fossil fuels.

The availability of some kinds of renewable energy is uncontinuous. Wind power stations for instance can only produce power

As to heat energy storing, a new class of materials has been introduced and developed during the last decades: Phase change materials (PCMs). The present article gives a brief introduction to the PCM technology. After presenting the concept of PCMs, some advantages, disadvantages and problems in connection with the utilization of PCMs will be discussed. Finally a few approaches to cope with the problem of the low thermal diffusivity of paraffin, an important PCM, will be presented.

PCM characteristics

The most essential difference between PCMs and conventional heat storing mediums like water or rock is that the melting point of PCMs is within the working temperature range. Basically, even water is a PCM and probably it was the first material to be used as a such, for example in connection with food cooling with ice. However, as the melting point of water is 0°C , it can not be used as a PCM for heat storage applications where the working temperature range usually is well above 0°C . Anyway, it is a good and everyday example to show how much heat can be absorbed in a phase change: Smelting ice to water requires approximately the same amount of energy as heating water from 0 to 80°C [3].

A certain amount of heat, the so-called latent heat (h_m), is absorbed or released when a material melts or solidifies, respectively. This gives materials an extra heat storing capacity if their melting point is located within the relevant temperature range. The melting and solidification process happens at a virtually constant temperature, see Figure 1.

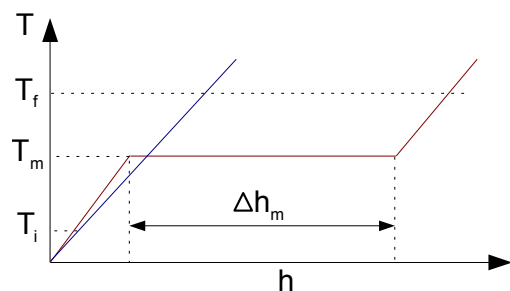


Figure 1: **T-h-diagram.** Schematic temperature-enthalpy-curves with (red line) and without (blue line) phase change.

The heat stored in a sensible (i.e. without phase change) heat store process is

$$Q = \int_{T_i}^{T_f} mC_p dT \quad (1)$$

and the heat stored in a PCM heated from a temperature T_i below the melting point T_m to a temperature T_f above T_m is

$$Q = \int_{T_i}^{T_m} mC_p dT + m\Delta h_m + \int_{T_m}^{T_f} mC_p dT \quad (2)$$

where the term $m\Delta h_m$ is the latent heat. This additional term increases the energy stored when heating the material from T_i to T_f considerably. Depending on the medium and the temperature range, in a latent heat storing process can be stored between 5 - 14 times as much energy per volume as in a sensible heat storing process [1].

There are different kinds of phase change. Solid-solid phase changes have comparably low latent heat and the volume change is low. The latent heat in solid-liquid phase changes is quite high, but the volume changes with up to 10 percent approximately. Solid-gas and liquid-gas phase changes have the highest latent heat, but they are also connected with vast volume changes [1]. As a compromise, solid-liquid PCMs are used in many technical applications. Their latent heat increases the energy storage density considerably while the moderate volume change can be handled quite easily.

PCM Applications

There is a variety of applications for PCMs. One major sector is in buildings: PCMs can be embedded in wall- and ceilingboards, trombe walls and under-floor heating systems to increase heat storage capacity and thus support temperature regulation, resulting in a lowered need for additional heating and cooling. Another important sector may be (solar) water heating systems, as well as air-based heating systems and air-conditioning systems, where PCMs serve as an efficient heat or cool storage, respectively.

As an example, PCM applications can considerably reduce the energy consumption of greenhouses, where usually much energy is consumed due to heating. Yet another application are transport containers which have to provide a constant temperature, for instance for medicine or blood preservations. Lastly, PCMs are even used in functional wear [1], [3].

Salt Hydrates vs. Paraffins

The most important groups of PCM with a solid-liquid phase change are salt hydrates and paraffins. Scientists disagree meanwhile on which group is most promising. For instance, Sharma et al. [1] state that salt hydrates are the most important PCM group while Kim and Drzal [2] think that paraffins are most promising.

Generally, salt hydrates have a higher fusion energy than paraffins. Yet, their major problem is a phenomenon called incongruent melting, which reduces the reversibility of the phase change process and thus the heat storage capacity of the salt hydrate. The problem of incongruent melting can be resolved with a number of chemical and physical/mechanical solutions, depending on the application.

In paraffins, incongruent melting does not occur. Yet, paraffins have a major drawback compared to salt hydrates: Low thermal conductivity. The thermal conductivity of a generic paraffin used as PCM is slightly above 0.20 W/mK [2] and thus circa a factor two lower than the thermal conductivity of most salt hydrates [1].

Other than for water or other liquids used as a heat storage medium, solid-liquid PCMs generally cannot even be used as a heat transfer medium. Therefore, in many heat storage applications water is used to transport the heat from the heat source, for instance a solar collector, to the storage unit, which contains PCM. As the molten PCM would mix with the water and then be spread over the entire circulation system, it has to be separated from the water. Therefore containers are

used whose material must be chemically stable both in contact with water and the PCM and should facilitate the heat transport between water and PCM. Figure 2 depicts a PCM element with aluminium casing.

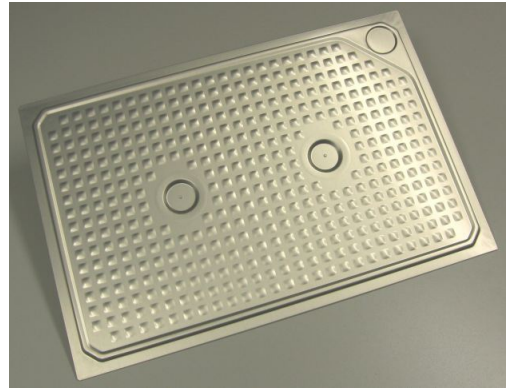


Figure 2: **PCM element with aluminium casing** (source: *Rubitherm Technologies GmbH* www.rubitherm.de).

Performance Enhancement of Paraffin PCMs

Let us have a closer look on the main difficulty connected with paraffins used as PCM, their low thermal diffusivity. The time a PCM needs to melt and solidify essentially limits the performance of a latent heat storage unit. Because of the low thermal diffusivity of paraffin, the heat transport within the PCM is slow and thus the speed of the melting process is limited. Hence the heat storing process takes comparably much time. The same is true for the solidification process, limiting the heat release rate.

Considerable effort has been spent on investigating and solving this problem. Basically there are two approaches to increase the performance on paraffin-based PCM heat storage units: Adjusting the geometric design of the heat storage tank and creating new paraffin compounds with an increased thermal diffusivity. In the following, a few possible approaches that have been investigated in order to improve paraffin-based PCM performance are given.

The most analysed PCM heat storage design is the shell and tube configuration [4]. Figure 3 shows a part of a shell and tube PCM heat storage unit used in combination with a solar collector. Esen et al. [6] have simulated the melting process of several PCMs used to store energy from a domestic solar collector, varying the design parameters of the shell and tube container. They state that the melting time is shortest if the PCM is located in the shell and the heat transport fluid flows in the tubes. Moreover, they give recommendations for appropriate design parameters for a given melting time, inlet temperature and mass flow rate of the heat transfer medium and the PCM volume for some PCMs.



Figure 3: **Shell and tube configuration.** *The PCM is located in the cylindrical capsules (source: German Aerospace Center (DLR) (<http://spie.org/x8476.xml?pf=true&ArticleID=x8476>)).*

Aghbalou et al. [4] conducted an investigation to achieve exergetic optimization of a solar collector run with a PCM heat storage. In this case, the storage tank is rectangular and contains a number of PCM-slabs that are arranged parallel to the flow direction of the water used as heat transfer medium. Depending on PCM melting temperature, recommendations for the optimal length and

maximum thickness of the slabs is given.

As mentioned above, another approach to increase the performance of paraffin in heat storing applications is to enhance heat conductivity. Mettawee and Assassa [7] embedded aluminium powder in paraffin. The aluminium powder had a particle size of $80 \mu\text{m}$ and a mass fraction of 0.5 %. As a consequence, the charging time was reduced by approximately 60 %.

A composite PCM of paraffin and xGNP, a special sort of graphite nanoparticles, was tested by Kim and Drzal [2]. The thermal conductivity increased linearly with the xGNP weight fraction within the tested range from 0 to 7 %. Embedding 7 % of xGNP increased the thermal conductivity of the paraffin from 0.26 to 0.8 W/mK. In spite of this considerable mass fraction, neither the thermal stability nor the latent heat capacity of the material was affected.

Both adopting the design of the heat storage tank and modifying the thermo-physical properties of paraffin are valuable approaches to enhance the performance of paraffin PCMs. Meanwhile, the best results will be achieved by combining both approaches.

Conclusion

Phase change materials have two favourable properties. They have a very high heat storage density and they store and release a considerable amount of heat at a constant temperature. This makes PCMs in many applications an interesting alternative to other heat storage mediums. But in spite of achieved improvements there is still potential and need for further performance enhancement, especially in the temperature range between 5-25, which is crucial for building-related applications [3]. The need to save energy is ever-increasing and PCMs might be an important future material class when engineers design energy-efficient applications.

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