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Study on the melting and solidification in a glass block containing a phase change material

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Abstract

This paper presents an experimental analysis of a phase change material (PCM) composed of by an eutectic mixture of two fatty acids. The experimental and general properties of PCM used during the tests are detailed in this paper. The purpose of the experiment is to study the phenomenon of phase change in an enclosure, focusing the research on the role of natural convection in liquid phase. The tests have been carried out for different temperatures on one side of a glass block and heat fluxes were measured. The results show that the PCM can store / release a high amount of heat, thus allowing a use of solar energy in the construction field.

1. Introduction

The storage of thermal energy is an excellent way to improve the energy efficiency of a system and obtain energy savings. There are currently three ways of storing thermal energy: chemical technology, sensible heat and latent heat [1]. This last storage technology, which is currently under high scientific interest, is based on the use of phase change materials (PCM). This technique is preferred to storing sensible heat because of its mechanism almost isothermal and providing a large storage density compared to the volume included [2].

When the temperature increases, the material passes from the solid to the liquid state by absorbing the thermal energy from the surroundings: it is the storage phenomenon. When the temperature decreases, the material changes from liquid to solid phase releasing the heat: the phenomenon of destocking. The idea of integrating these materials into the building structure is not new and dates from 1978 (Telkes [3]). The thermal inertia of a building plays an important role as a buffer between the external thermal fluctuations of outside temperature fluctuations and the indoor environment [4]. By increasing the thermal inertia due to a latent storage of solar heat entering through windows, the energy demands is reduced while maintaining thermal comfort in the building.

PCMs have been the subject of many research studies for a range of applications, giving concluding to a variety of encapsulation methods; one of the most common are micro-encapsulation, incorporation of standard paraffin in a stabilized form and encapsulation in a container or recipient. The heat transfer in this last type of container gives place to transient, non-linear phenomena, with a solid-liquid interface moving. Among the first experimental tests on the PCM we mention the research work by Zhang et al. [5] who studied the melting of paraffin n-octadecane in a rectangular enclosure heated on one wall. Another similar study is the one of Wang et al. [6] with a research for the correlation of the volume fraction of

melted and Nusselt number. Pal et al. [7] analyzed the melting of PCM-Organic triacontane (C₃₀H₆₂) in a heated chamber on one side and the front display of experimental fusion was observed.

An original idea is to fill containers of glass blocks with PCM, with transparency properties, and thus create a wall of a building facade that can let the natural light pass through while taking advantage of solar gains. The glass bricks that were once used in the development of the outer walls of buildings are now largely excluded because of insufficient heat resistance and thermal bridges ubiquitous in such walls. However, some studies show that it is possible to obtain interesting results when coupled to other products. A study in Switzerland [8] on a small cell shows that the coupling of glass block filled with PCM, an insulating polycarbonate protected by blinds can improve the comfort on the summer period and the results are promising from a point of view of thermal comfort and visual comfort. It also states that the PCM selected, whose average melting temperature is 26.1°C, is not ideal for building applications and that this value is too high. In the case of our experiment the melting temperature of the PCM has a lower value (around 21.5°C), making the PCM more appropriate for its use in buildings.

This study has as main objectives to study the melting and solidification of the PCM. The understanding of the process of phase change is crucial for achieving an accurate modeling of the system and to test other numerical systems. The PCM used in this study is a binary eutectic mixture of two fatty acids. The thermo-physical properties of the material are summarized in Table 1.

Thermo-physical proprieties	Unit	Value
Heat of fusion	J/g	152,0
Melting point	°C	21,5
Specific heat (solid state)	J/g °C	1,67
Specific Heat (liquid state)	J/g °C	2,09
Density (solid state)	g/cm ³	0,96
Density (liquid state)	g/cm ³	0,884

Table 1. Table of proprieties of the PCM used

2. Presentation of the experimental device

The experimental device consists of two metal plates exchangers that are thermostatically controlled by circulating water from two temperature-controlled bath. Both exchangers surround an enclosure of 191×191×32 mm Plexiglas filled with phase change material (see Figure 1). The plexiglass allows visualization of the phenomenon of phase change inside and at the same time it provides good structural strength of the assembly. The mounting is isolated on all sides: top, bottom and sides by extruded polystyrene Styrofoam type. The same isolation procedure has been used in other studies of PCM (eg Lamberg et al. [9]).

Temperatures of inlet/outlet of heat exchangers are measured throughout the tests using thermocouples type K to ensure uniformity of temperature exchangers. The heat flux on each side of the brick is determined using two flow sensors fabricated on measure.

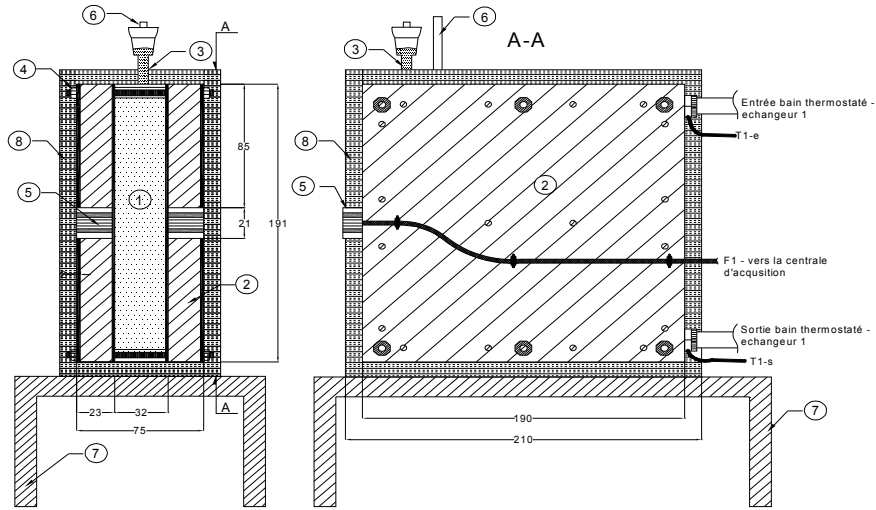


Figure 1: Experimental apparatus (1- phase change material, 2 - heat exchangers, 3- the enclosure filled with the PCM, 4-structure system, 5-flowmeter, 6 -air intake, 7-metal stand, 8- insulation

The experimental setup is designed to impose a condition of constant temperature on one hot side (rather than a constant heat flux) and a constant temperature in cold surface. Both will be brought to a temperature change over the trials to test the influence of the overheating of the liquid on one side, and under cooling with solid phase on the other side. For each test the PCM is subjected initially to a constant temperature of 20°C on both sides of the brick, which helps to fully solidify the material. Then, one side is heated with a constant temperature (40°C, 30°C and 22°C) above the melting temperature. For the analysis of solidification, one side is maintained at 22°C and the other is subjected to temperatures below the nucleation point (15°C, 10°C). The behavior of the material was also studied when it is confronted to a temperature change (type ramp in time) with a variation of 24 hours from 39°C to 12°C. The acquisition program has been developed under the LabView environment and the time interval between two measurements of heat flow is 10 seconds.

3. Results

The fusion of PCM in the rectangular enclosure of brick Plexiglas is modified by the phenomenon of natural convection in liquid phase. The heat transfer within the material, which has a direct influence on the quality of destocking and storage of energy, is a coupling of natural convection and the increase the rate of phase change. The natural convection accelerates the liquefied state, causing a greater ratio of liquefied in the upper part of the enclosure. In the early phases of the liquefied state, the velocity of the PCM under liquid state is low, but increases gradually as the heating is higher and the convection is dominant until the velocity begins to be reduced due to a higher temperature uniform in the liquid [7].

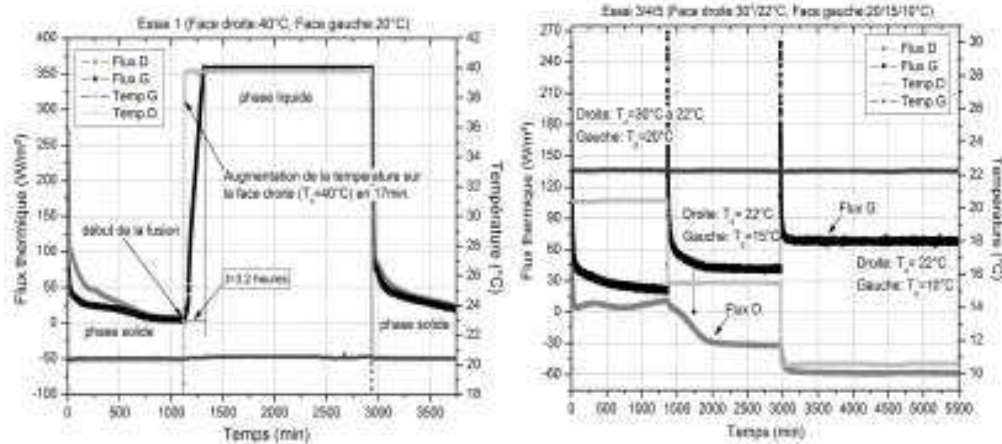


Figure 2: Evolution of heat flux on both sides of the brick for different tests (constant temperature on the two sides)

During the tests, the temperature difference between the inlet/outlet of water in the exchangers was less than 1°C. Initially, the material is in solid phase at a uniform temperature slightly below the melting temperature, in our case 20°C. At $t = 0$, an uniform heating temperature T_1 (40°C, 30°C and 22°C) is imposed on the right side, while the opposite face is kept at 20°C (see Figure 2). The phase change is made gradually from the hot wall to the cold wall, following 4 distinct regimes illustrated in the figure. Initially, the heat transfer occurs only by conduction and the liquid/solid interface remains parallel to the walls, the spread of melting following a similar pattern to the problem of Stefan.

While the difference between the front and the wall is still very low, the phenomenon of natural convection generated by temperature differences in the liquid phase takes over the conduction in the upper part of the enclosure: the liquefied state will progress more quickly. It then enters in a mixed conduction and convection combination. In the case of Trial 1 (see Figure 2) the phase change will last 3.2 hours until the material completely changes its state of solid to liquid when a temperature difference $\Delta T = 20^\circ\text{C}$. During this period the accumulation of energy is realized in the PCM and a volume expansion is detected. This heat accumulated is approximately of 111.25 kJ/m².

Two thermal boundary layers are formed, one in the hot wall and the other colder at the interface. The non-uniform distribution of heat flow under the influence of convection will curve gradually the interface along its entire height, while the boundary layers grow up and move away to separate. This is the convection regime, which became largely predominant to conduction, in which there is a strong gradient in the boundary layers around a central liquefied stationary core and linearly stratified.

The convective phase continues until the arrival of the front on the cold wall. The scheme called "solid compact" begins, which has studied only by a very limited researchers (especially in Jany and Bejan offer an analysis theory of scales [10], Benard et al. interested briefly [11]).

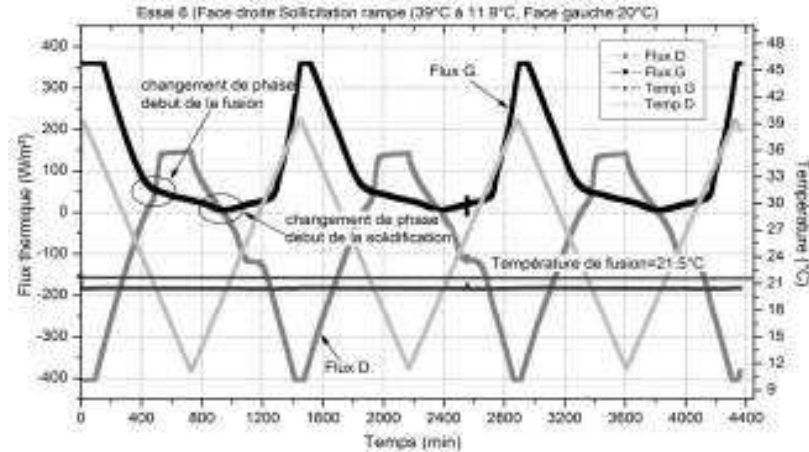


Figure 3: Evolution of heat flux on both sides of the brick to a solicitation type level on the right side of the brick

For a solicitation type ramp (see Figure 3) the PCM changes its physical state several times over a period of 24 hours, but it never arrives to a fully liquid state or homogeneous solid throughout the volume.

4. Conclusions

A brick filled with transparent phase change material eutectic mixture was studied in an experimental setup that was designed to analyze the behavior of this material to various fluctuations in temperature on one side of the brick, but also on a 24 hours variation. The results showed that the PCM can store and destock a significant amount of energy and its use of such concept in the construction sector is foreseen. In addition, its melting temperature of 21.5°C is ideal for building applications [12].

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