CYLINDRICAL ENCAPSULATED COLD STORAGE

Juan José Milón Guzmán
Universidad Católica San Pablo, Av. Salaverry, 301, Vallecito, Cercado, Arequipa, Perú
milonjj@ucsp.edu.pe

Sergio leal Braga
Pontificia Universidade Católica do Rio de Janeiro, Rua Marquês de São Vicente, 225, Gávea, 22453-900, Rio de Janeiro, RJ, Brasil
slbraga@mec.puc-rio.br

Abstract. *An experimental apparatus was developed to investigate the thermal performance of a cold storage system utilizing water as Phase Change Material (PCM) encapsulated in cylinders. The coolant is a water-alcohol mixture (50% vol.), controlled by a constant temperature bath (CTB). Temperatures varying with time are measured inside and outside the capsule. Cylinder with internal diameter and thickness of 45 mm, 1.5 mm and length 170 mm, respectively, were made in acrylic, PVC (polyvinyl chloride), bronze and aluminium materials. Several situations were investigated for different temperatures and flow regimes. The temperature field, interface position and the heat transfer inside the cylinders were monitored.*

Keywords: *refrigeration, air conditioning, thermal storage, phase change, supercooling.*

1. Introducción

The thermal storage for air-conditioning systems is an important concept of many energy conservation programs in industrial and commercial applications. Water is widely used as the phase-change material (PCM) for thermal storage because of its advantages such as high value in latent heat, stable chemical properties, low cost and easy acquisition, no environmental pollution concern, and compatibility with the materials used in air-conditioning equipment. However, there are a few disadvantages in using water as PCM. Two of the most serious problems encountered are the supercooling phenomenon and the density inversion occurring in the water solidification during the thermal storage cooling process.

While a quantity of water is cooled in an enclosed container, freezing does not occur at its freezing point (0°C). Instead, it is normally cooled below 0°C before ice nucleation happens. Supercooled water refers to a state of metastable liquid even though the temperature of water is below its freezing temperature (Figure 1). The metastable state will end when ice nucleation occurs and the thin plate-like crystal of dendritic ice grows into the supercooled region of water. During the dendritic ice growth process, latent heat released from the dendritic ice will be consumed by supercooled water. At the end of the growth process, the temperature of water will return to its freezing point (0°C). If the metastable state exists and remains during the thermal storage process, thermal energy can only be stored in the form of sensible energy.

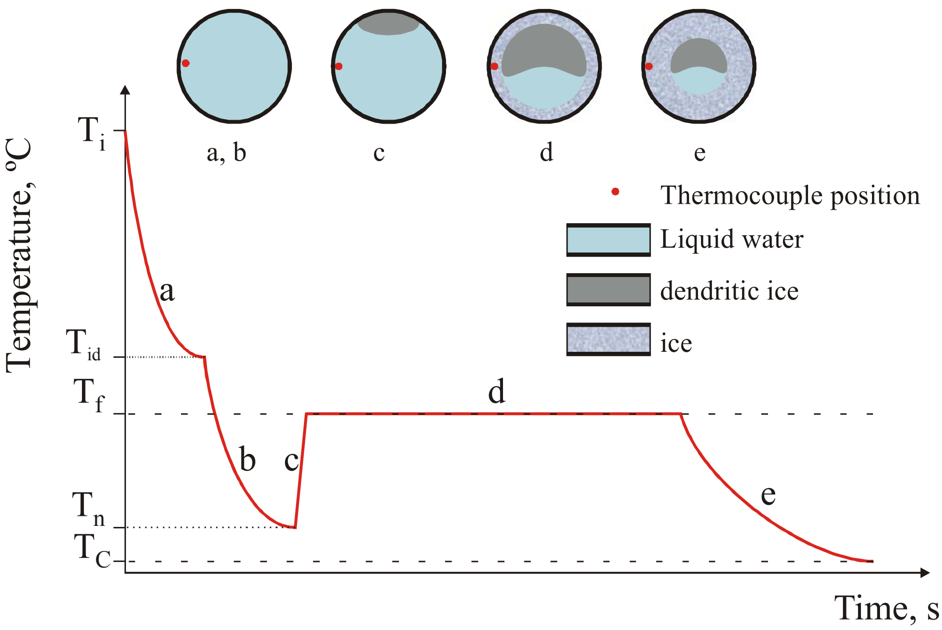

Figure 1. Process of supercooled water solidification.

There are several studies about solidification of water. Chen et al. (1998), studied the numerical and experimental method to analyzer the influence of nucleation agents in the water solidification process inside cylindrical copper capsules of different sizes and Chen and Lee (1999), auditioning result whit different material of capsules. Yoon et al. (2001) studied experimentally the freezing phenomenon of saturated water within the supercooled region in a horizontal circular cylinder using the holographic real time interferometry technique. Milón and Braga (2003) studied the phenomenon of supercooling in spherical capsules of different diameters.

2. Experimental model

The experimental model, shown schematically in Figure 1, consists in a test section (a), an observing system (b), a cooling system, which includes a CTB (Constant Temperature Bath) (c), and a measurement and data acquisition system (d).

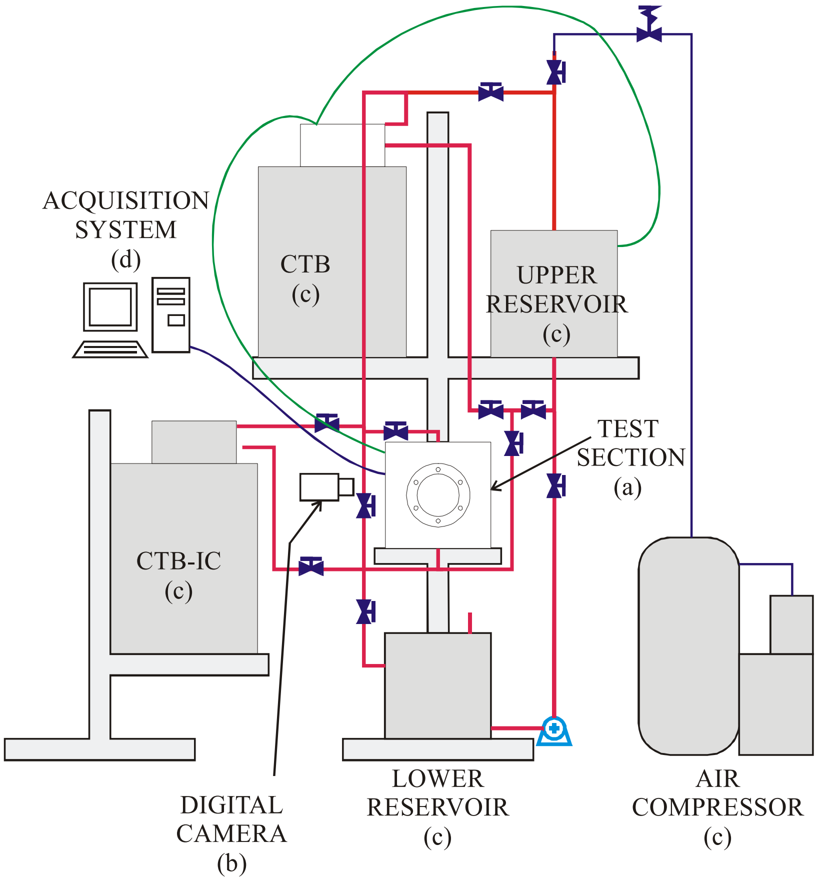

Figure. 2. Experimental Model.

2.1. Test section

The walls are made of 10 mm thick acrylic plate externally covered with 25 mm thick insulation. A cross section is shown in the Figure 3. The diffuser function is to homogenize the coolant temperature (T_C) in the test section. The temperature control is carried out by a constant temperature bath which receives the signals from a temperature sensor RTD type PT-100. K type thermocouples were used for the circulating fluid temperatures registration. An overflow tank, working at atmospheric pressure, was installed to compensate the volume variation during the phase change process. In the same figure, the cylindrical capsule, filled with the PCM (distilled pure water), can be observed. To define the volume of the PCM, a sliding disk (movable in the axial direction) is used. K type thermocouples of 0,076 mm diameter, covered with Teflon, are also indicated in Figure 4.

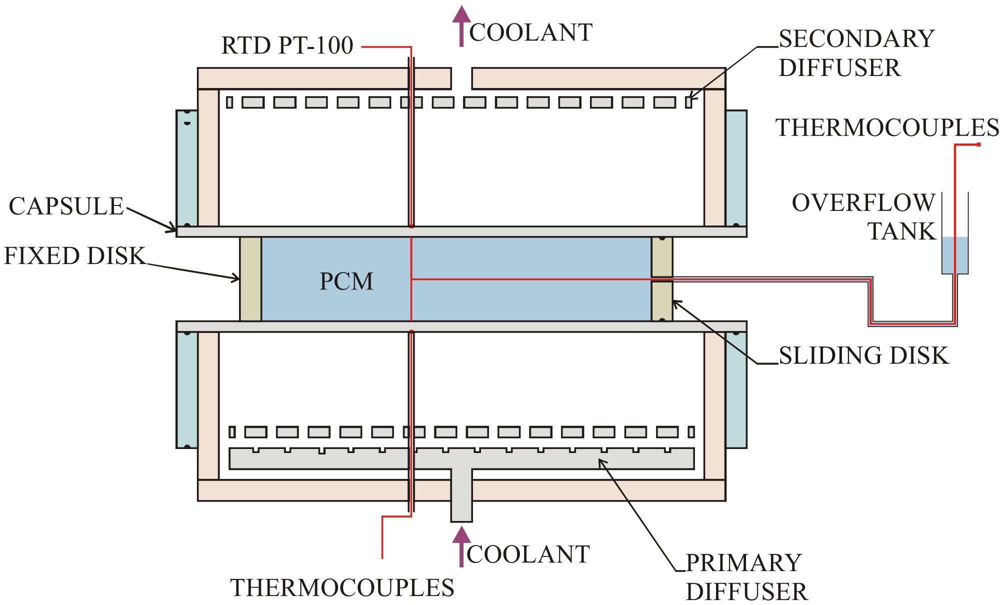

Figure 3. Test section details.

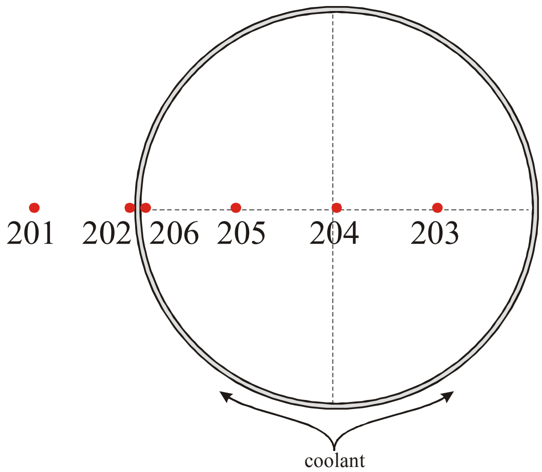

Figure 4. thermocouples positions.

2.2. Cooling system

The cooling system is schematically showed in Figure 1. It is composed by two constant temperature baths (CTB), two reservoirs (upper and lower) and the coolant. The initial temperature for the tests is set at one CTB-IC while the other CTB is set at the test temperature. The temperature control system Proportional Integral Derivative (PID) maintains the temperature into a range of ±0.05 °C with a refrigeration power of 800 W at 0 ºC and 1000 W of electric power heater. The coolant is an alcohol-water solution (50% in volume).

2.3. Measuring and data logging system

The measurements and storage of data are made by the data acquisition system and a personal computer (PC). The acquisition equipment, which communicates with the PC by the RS232 communication port, receives, processes and transmits the temperature signals to PC, for storage and posterior analysis.

3. Experimental procedure

Stage I: The initial water temperature inside the capsule (25.0 ºC) is imposed using the constant temperature bath for the initial condition (CTB-IC). The other CTB
controls the coolant temperature in the upper reservoir.

Stage II: The coolant of the upper reservoir pass through the tests section imposing the test temperature, absorbing the initial thermal loads and passing later to the lower reservoir.

Stage III: The coolant of the CTB is addressed toward the test section until the conclusion of the test.

Stage IV: After each test, a pump impels the coolant toward the upper reservoir for a new test.

This procedure is carried out to maintain constant the test temperature along each test. The duration of each test varies from 30 to 60 minutes, depending of the test conditions. The data is acquired once a second.

3.1. Uncertainties of measurements

Uncertainties are presented in Table 1.

Table 1: Uncertainties of measurements

Parameter	**Uncertainty**
Temperature	0.1 ºC
Time	0.01 s
Length	0.01 mm

4. Results and discussion

In Fig. 5, it can be observe some of the characteristic curves of the solidification process of the water in different materials from cylindrical capsules. It is shown the temperature variation of the different positions from the thermocouples inside of the capsule. In the cases of acrylic and PVC, the characteristic curve with more of 50% of occurrence probability it showed that the nucleation does not happen and the PCM stays in a metaestable liquid state, these experiences were stopped after 5 hours. In the cases of bronze and aluminum presented supercooling with nucleation, apparently the parameter that influenced more in this process is the thermal conductivity of the material.

In Fig. 6, it is shown the advance of the solidification front according to the temperature of the TF, this for each material of the capsule. According to the statistical parameters it was observed that, for the case of PVC and acrylic only presented nucleation for temperatures of -8 and -10 ºC, being the acrylic the one which presents a smaller time of solidification. In the cases of bronze and aluminum, for the four temperatures, always nucleation happened. It is possible to stand out that in the cases of bronze with $T_C =$ -8 and -10, supercooling does not appear.

In Fig. 7, a report of the time of the solidification appears according to the temperature of the fluid of transference for the different materials from the capsules. In the case of acrylic and PVC, with temperatures greater to -8 ºC, does not appear nucleation (it remains in liquid state), for the case of the bronze, this parameter is for smaller temperatures of -4ºC, and in the case of aluminum, is of -6 ºC. This gives us a reference of which temperature is necessary to impose to the TF to obtain an effective solidification of the PCM within the capsule.

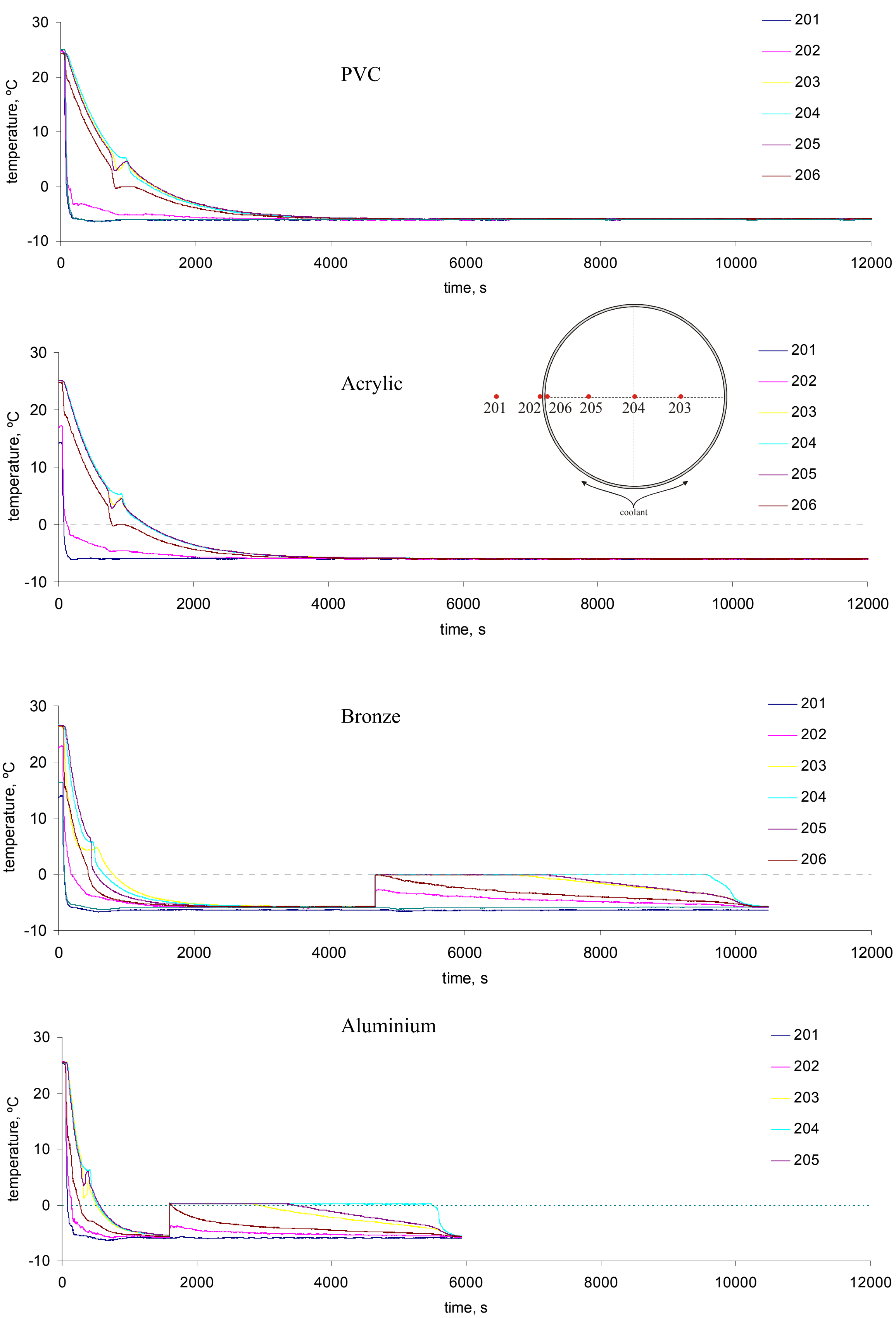

Figure 5. Characteristic curves of cooled water encapsulated, T_{TF} = -6 ºC

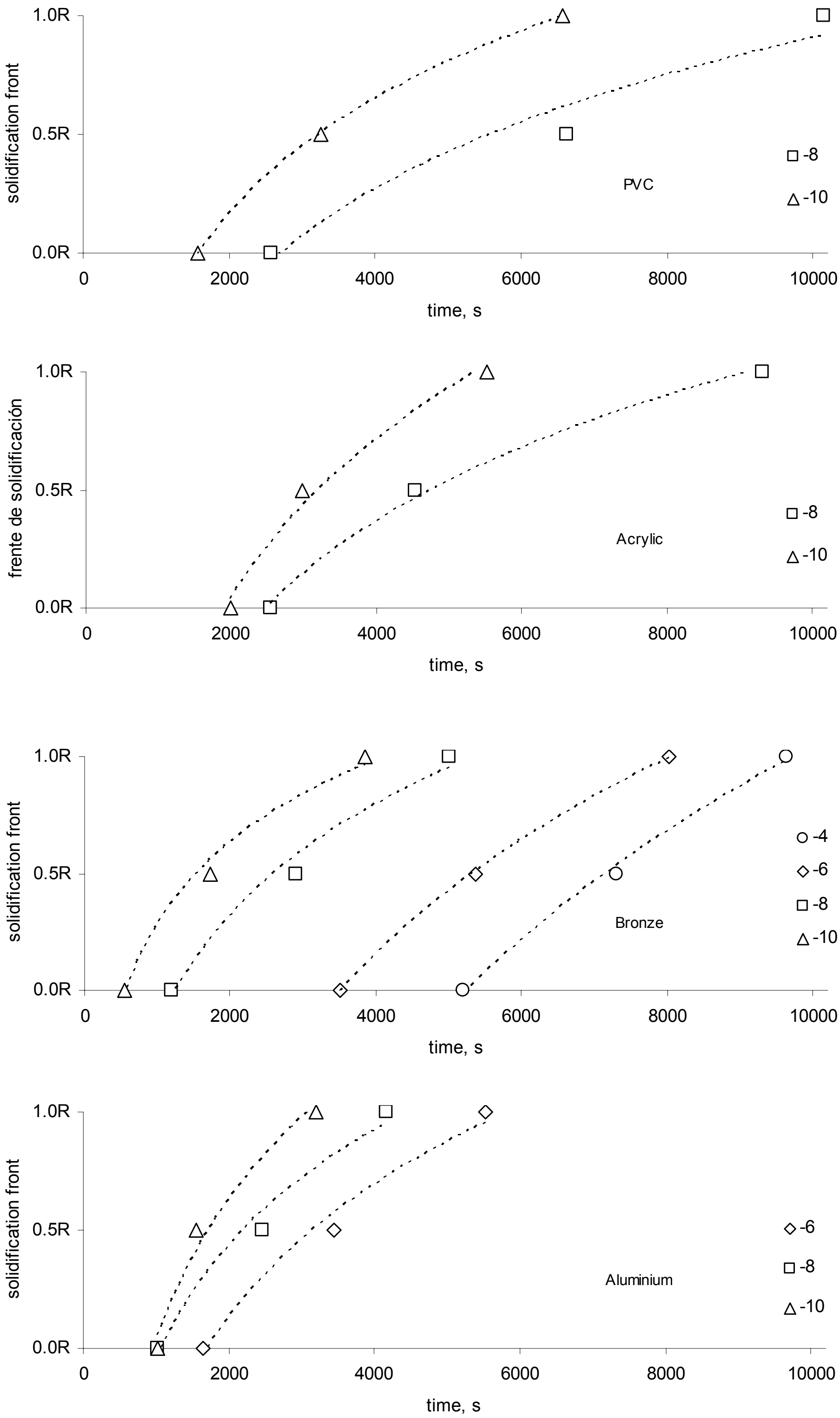

Figure 6. Variation of the solidification front for different capsules

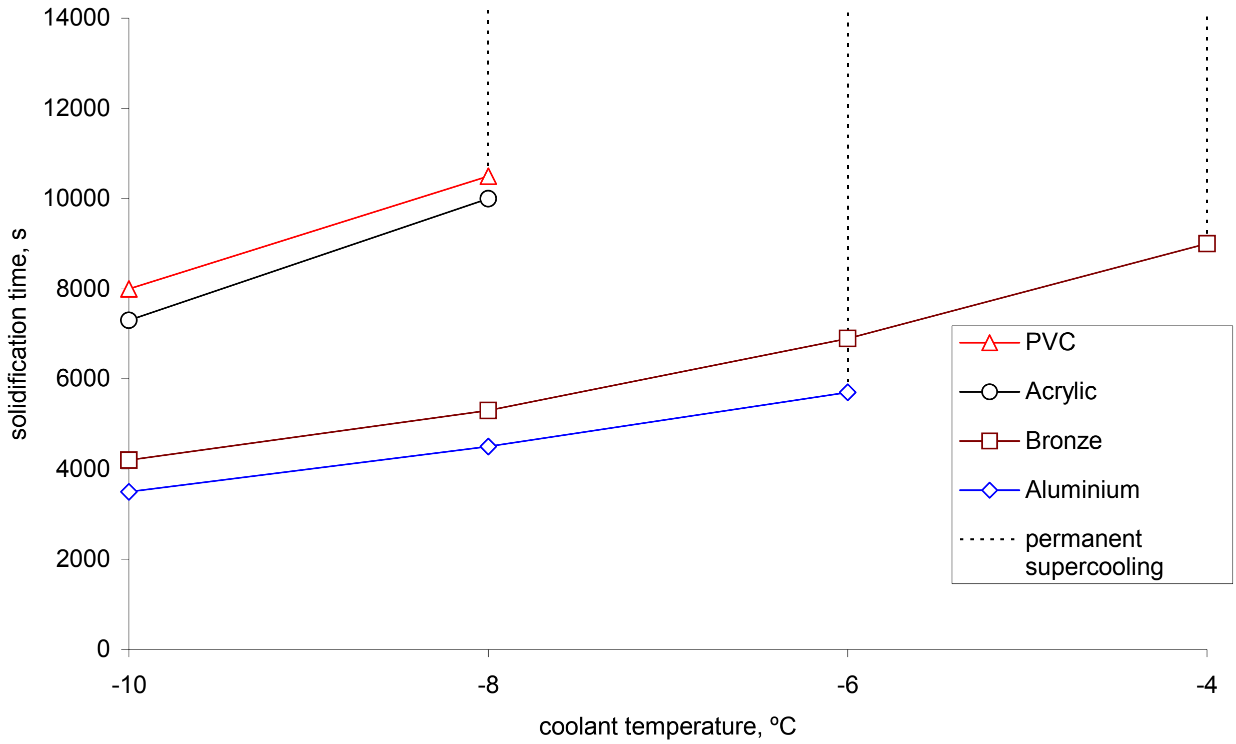

Figure 7. Solidification time for different coolant temperature.

5. Conclusions

According to the done test, the acrylic capsules and PVC with temperatures over to -8 ºC, does not appear nucleation (it remains in metastable liquid state), for the case of the bronze, this happen for temperatures over to -4ºC and in the case of aluminum is -6 ºC. This gives us a reference of which temperature is necessary to impose to the T_C to obtain an effective solidification of the PCM inside of the capsule.

An indicative parameter of the time of solidification could be the material of the capsule because the results present an inverse relation with this parameter (to greater thermal conductivity, smaller time of solidification).

6. Acknowledgements

This paper was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq of Brazil.

The authors also wish to thank the Agreement Pontificia Universidade Católica do Rio de Janeiro and Universidad Católica San Pablo for motivating this research work.

7. References

Chen, S. L. and Lee, T. Z.,1998, “A study of Supercooling Phenomenon and Frezing Probability of Water Inside Horizontal Cylinders”, International Journal of Heat and Mass Transfer, Volume 41, Issues 4-5, 3, Pages 769-783.

Yoon, J. I., Moon, C. G., Kim, E., Son, Y., S.J., Kim, D. and Kato T, 2001, “Experimental Study on Freezing of Water with Supercooled Region in a Horizontal Cylinder”, Applied Thermal Engineering 21, 657-668.

Milón, J.J., Braga, S.L., 2004, “Spherical Encapsulated Cold Storage”, 4th European Thermal Science Conference.

8. Responsibility notice

The authors are the only responsible for the printed material included in this paper.