EXPERIMENTAL INVESTIGATION OF THE TRANSIENT RESPONSE OF A LATENT HEAT STORAGE UNIT

A. Benmansour[1], M.A. Hamdan[2], A. Bengeuddache[3]
[1] Laboratoire de mécanique appliquée, Université des Sciences et de la Technologie d'Oran,
BP 1505 El-M'Naouer, Oran, Algérie Tel & Fax (213) 41 42 15 81, E- mail: b_ abdeljalil@hotmail.com
[2] Mech. Eng. Dept., Faculty of Engineering and Technology, Jordan, Amman, University.
[3] Laboratoire de Chimie des matériaux, Université d'Oran, Oran, Algérie

ABSTRACT

An experimental investigation of the transient thermal response of a packed bed of spheres containing a paraffin wax as a phase change material (PCM) is carried out in this paper. The results presented in this paper include the influence of both axial and radial temperature distribution in a randomly packed bed of uniform spheres, as well as outlet temperature fluid of both charging and recovery modes, with air as the working fluid at constant inlet temperature and variable mass flow rate.

Key Words: Thermal energy storage, latent heat, phase change material, sphere.

1. INTRODUCTION

The use of the solar energy in systems of cooling or heating as energy source alternative to the fossil energy whose reserves decreases every day is a necessity to face the increasing energy demand. But its intermittent nature poses problems of storage, since needs don't coincide in general with the availability of the resource. It is therefore necessary to develop devices of storage allowing the transfer of energy from the excess periods to the deficit periods and to adapt its production thus to its consumption.

Different types of storage units have been conceived and studied [1,2]. They all differ by the nature of the serving material of storage support and the geometry of the unit. The thermal energy is ordinarily stored under shape of appreciable heat of water. But this last requires a large volume of storage and causes in addition a problem of corrosion. The latent heat thermal energy stored in packed bed of spheres containing each a PCM can be a very interesting mean for that purpose. These materials provide a number of features, namely; the amount of energy stored in a small mass with respect to volume. In addition, their temperature remains almost constant in the PCM as pointed by Beasley and Ramanarayanan [3].

In this present work, the energy is suggested to be stored as a latent energy in a packed bed of spheres filled with paraffin wax as a PCM. Wood et al [4] and Saitoh and Hirose[5] showed that a PCM encapsulated in rigid hollow spheres has several advantages over other geometries such as cylindrical or rectangular capsules, because of the spheres increased surface area per unit volume and consequently a more effective energy utilization as reported by Wood et al [4] and Saitoh and Hirose [5]. Another reason for the selection of this configuration is that the spheres can be made self-supporting and the bed construction is simplified

2. EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic diagram of the apparatus used in this study to measure the transient temperature distribution experimentally inside a cylindrical bed which is randomly packed with spheres having uniform size and encapsulated PCM is illustrated in figure 1.

The bed container was constructed from a stainless steel cylinder of a 0.60 m overall height and a .20 m in diameter. The active test section is 0.30 m long. The packing is formed by of a 3.8 mm diameter plastic spheres filled with paraffin wax. The encapsulation of the PCM was realized by injection of molten wax into the spheres. The ratio bed-to-particle diameter is 6. Table 1 lists the characteristics of the packing container.

Airflow is produced by a centrifugal blower with variable mass flow rate. The mass flow rate of the inlet air is measured by an orifice plate flow meter. The inlet air is heated by electrical heaters and mixed so that the temperature profile of the bed is uniform. Thermocouples made of 0.20 mm diameter copper-constantan embedded in the PCM and placed at different locations in both axial and radial directions of the bed, are used to measure the temperature, as shown in figure 2

Table 1 Characteristics of bed

Bed length	0.6 m
Bed diameter	0.2 m
Packing material	PCM encapsulated plastic spheres
PCM	Paraffin wax
Particle diameter	0.038 m
Wall material	Stainless steel
Wall thickness	0.001 m

Temperature is also measured at the inlet and the outlet of the test section at both charging and recovery modes. All temperatures were measured simultaneously and stored on a personal computer for analysis with a data logger.

3. RESULTS AND DISCUSION

3.1. Charging mode

The tests were performed at a constant mass flow rate (31.5 l/s) and at inlet initial temperature of air and PCM equal to 26.4 °C and 27 °C respectively.

No important degradation of paraffin wax is observed after a large number of test cycles because the melting point temperature stayed constant.

Figure 3 illustrates the temperature evolution of the air and PCM inside the bed at the same depth. One notes that the curve profiles are different. This difference is very pronounced (3°) when the PCM is in the liquid phase. This difference is probably due to the time lag between the two curves, as a result of the sphere thermal inertia surrounding the thermocouple. More over the calculation of the required time necessary to reach the ambient fluid temperature is 29 s. which is not negligible. This could be another explication of the temperature difference between air and sphere filled with PCM.

Figures 4 and 5 illustrate the PCM temperature evolution with respect the time for three axial positions and three radial positions respectively. The results show that the bed temperature is almost uniform because the maximum difference does not exceed 2,5 °C, and the PCM temperature increases with time until it reaches a steady state condition.

Figure 6 represents the PCM temperature variation with respect of the bed depth for different time intervals. These curves show one again that the PCM is uniformly heated.

3.2. Recovery mode

Figure 7 and 8 represent the temperature evolution with respect the time for three axial positions and three radial positions respectively. The results show that during the discharging mode; as indicated in these figures, and once the heaters were switched off, the entering cooled air causes a drop in temperature to a value that is larger than the ambient temperature by a certain amount. Also the PCM temperature decreases more rapidly when the PCM is in the liquid phase. This can be explained by the fact that the air mass flow rate is very important compared with the PCM volume, in one hand, and the necessary time of heat regeneration is very large in the transient phase of the PCM and when it is at the solid state in the other hand

4. CONCLUSION

An experimental investigation of the transient thermal response of a packed bed of spheres filled with a paraffin wax as a phase change material is presented in this paper.

According to the results given in the present work, the following conclusions can be drawn:

1 - The paraffin wax as PCM is suitable for latent heat storage because no important degradation is observed after a large number of test cycles.

2 - There is no significant effect of the bed ratio (length / diameter) for a packed bed with constant volume storage of PCM.

3 - The ratio air mass flow rate over storage volume is an important design parameter for the latent thermal energy storage in a packed bed containing a PCM.

REFERENCES

[1] J.A. Duffie and W.A. Beckmann, *Solar Engineering of Thermal Processes*, John Welly and Son. New York, (1980)

[2] D.E. Beasley and Clark, *Transient Response of Packed Bed for Thermal Energy Storage*, International Journal of Heat and Mass Transfer, 27 (1984), pp 1659 – 1669

[3] D.E. Beasley and C. Ramanarayan, *Thermal Response of Packed Bed of* Spheres *Containing a Phase Change Material*, International Journal of Energy Research, 13 (1989), pp 253 – 265

[4] R.J. Wood, S.D. Gladwell, P.W. O'Callaghan and S.D. Probert, *Low Temperature Thermal Energy Storage Using Packed Beds Encapsulated Phase Change Materials,* International Conference on Energy Storage, April 29 – May 198,1Brighton, UK, pp 145 – 158.

[5]. T. Saitoh and K. Hirose, *High Performance Phase Change Thermal Energy Storage,* Chem. Eng. Commun, 41 (1986),pp 39 – 58

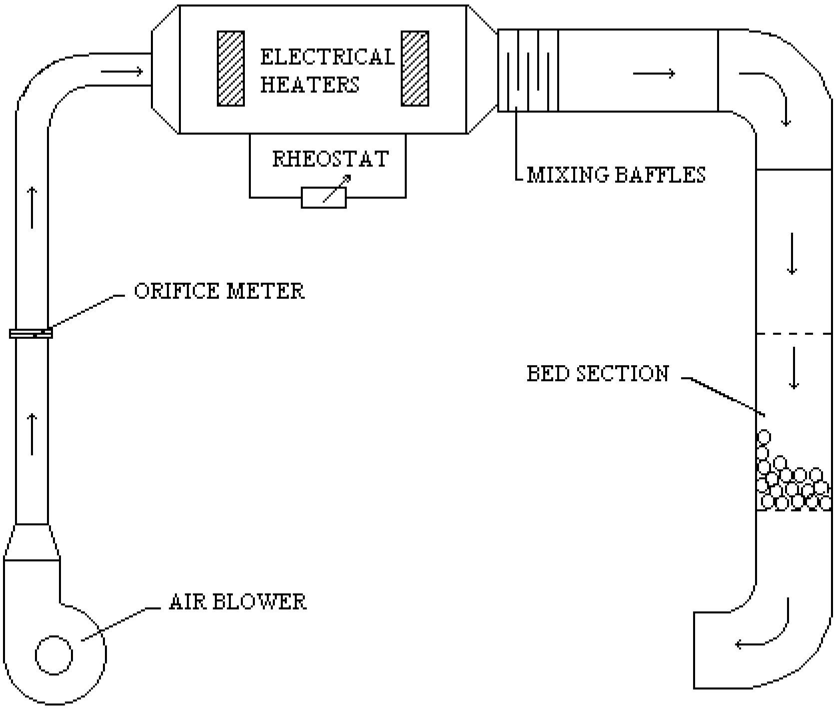

Figure1. Schematic diagram of apparatus

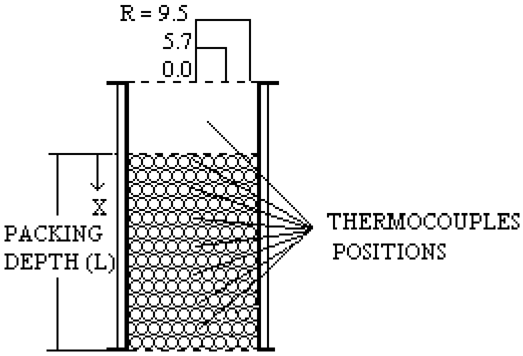

Figure 2. Bed section and thermocouples positions

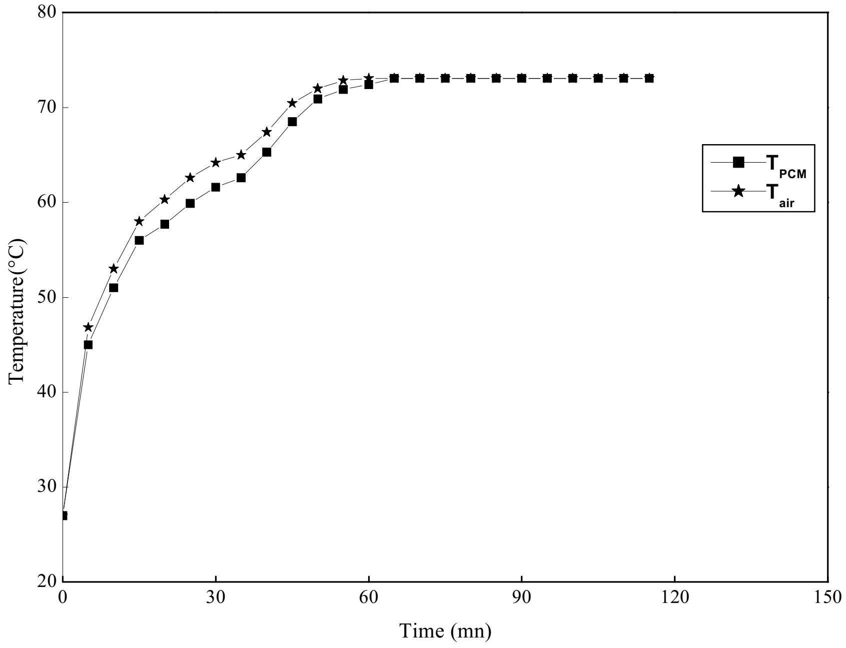

Figure 3 Temperature evolution of air and PCM inside the bed at the same depth

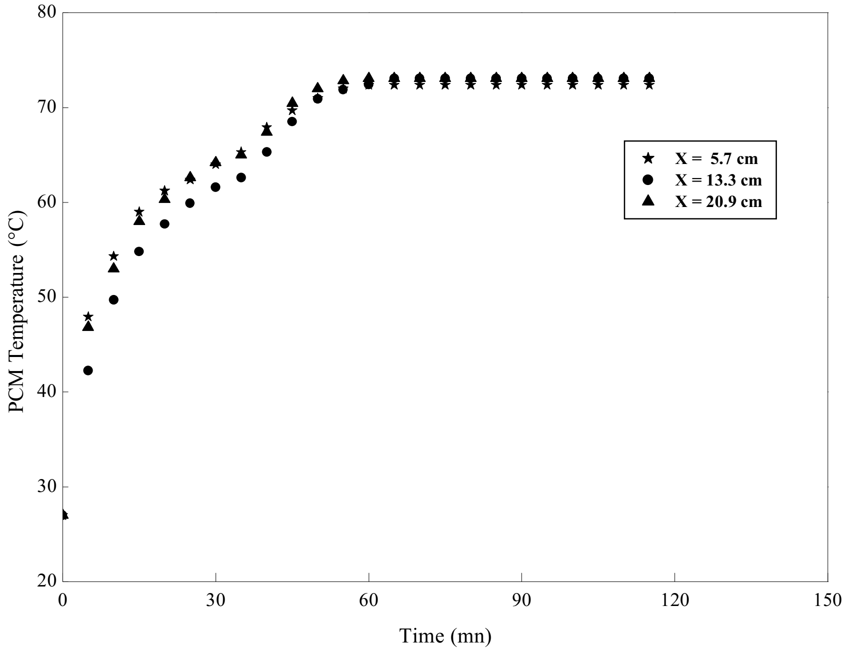

Figure 4. PCM temperature for three axial positions, charging mode

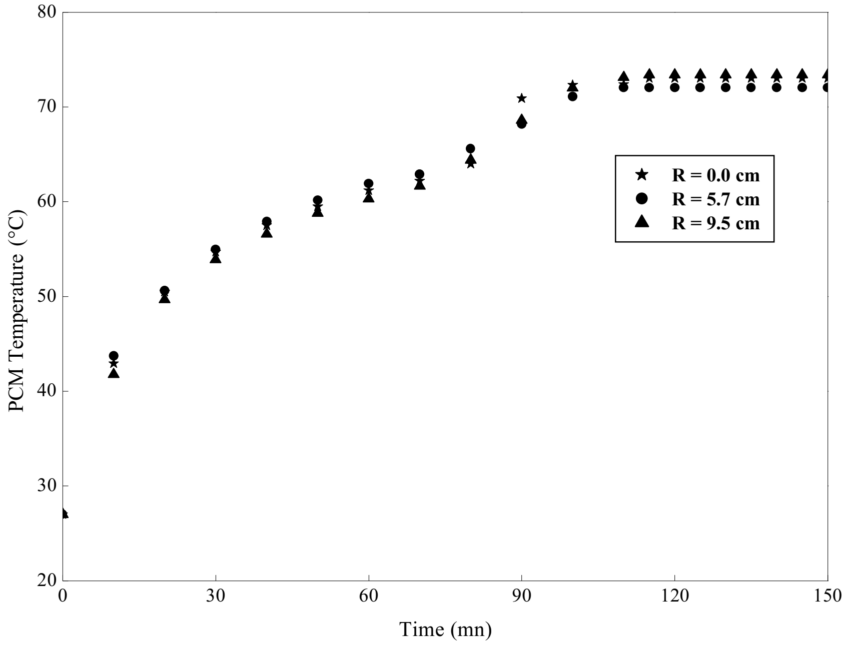

Figure 5. PCM temperature for three radial positions, charging mode

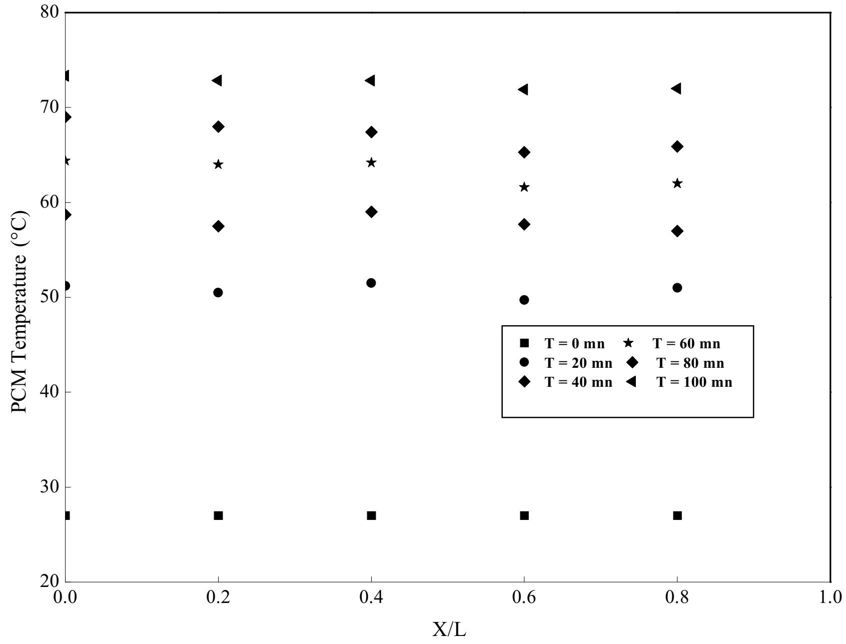

Figure 6. PCM temperature, Charging mode

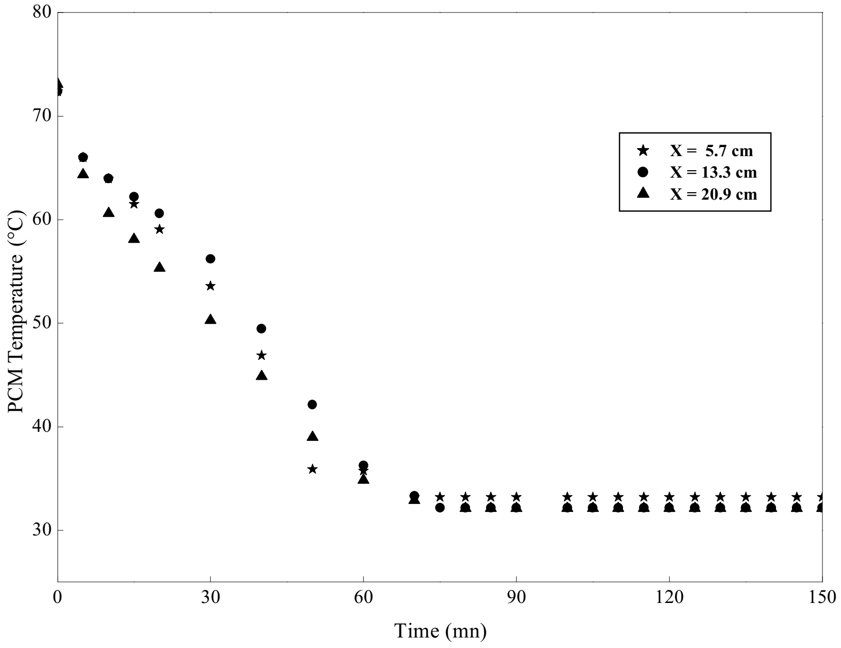

Figure 7. PCM temperature for three axial positions, Recovery mode

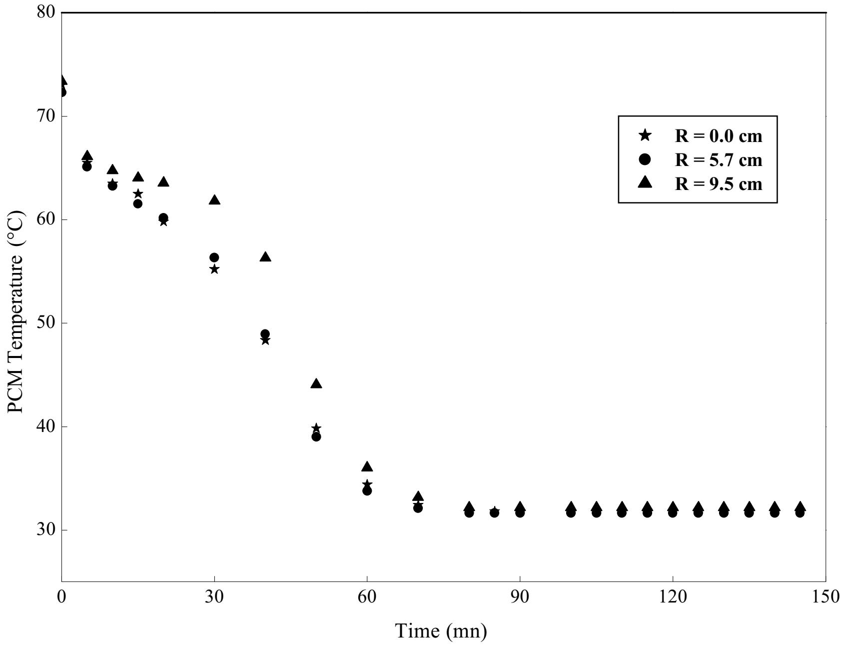

Figure 8. PCM temperature for three radial positions, Recovery mode