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ENERGY STORAGE USING THE PHASE CHANGE MATERIALS: APPLICATION TO THE THERMAL INSULATION

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ABSTRACT

The objective of the present study is to investigate numerically the problem of melting phase change material (PCM) containing paraffin where one of the area interfaces moves with time and wherein the result of the fusion between the coupling in the solid phase conduction and convection in the liquid phase, then processes the effect of integration of the material in the walls of the building in order to increase its thermal inertia to validate the result ,we will study the numerically transient and performance of a fixed bed filled with uniform spheres, randomly arranged and each containing a (PCM). So we use a two-dimensional theoretical model applied in two separate phases; it was used to predict the temperature distribution of the fluid and the fusible material along the bed in the energy storage method.

Keywords: Energy storage; Insulation; Phase Change Material (PCM); Simulation

1. INTRODUCTION

The development of storage systems thermal energy, which is both useful and protects the environment, has become a necessity to meet the growing energy demand. The interests of these materials has been the subject of a number of theoretical and experimental works (Zalba et al.,2003; Benmansour, 2009).

The phase change materials allow energy storage (Cho et al., 1995) in addition to insulation, For this reason, why they have so many applications in electronics (Fatih Demirbas, 2006), in the building (Ahmad et al., 2006) and in transportation (Pasupathy et al., 2008; Royon, 2011). A study has been developed (Royon et al., 2008) on Phase Change Materials (PCM), shown their importance to store a large amount of energy during the change of solid-liquid phase. The use of these materials does not contain chemical risk and has a wide range of working temperature with a low cost.

The present work is to present a numerical method of solving the problem of change of solid-liquid state in rectangular geometry where the fusion results from the coupling between the solid phase in conduction and convection in the liquid phase, and then we examine the influence of these types of materials integrated into the walls of buildings. In the third part is treated the case of heat transfer in the macro-encapsulated PCM, who owns the advantage of storing a large amount of energy that are of interest to a number of theoretical and experimental works (Sharma et al,2009).

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A numerical model was developed and validated on experimental results. Our model was developed using the COMSOL Multiphysics software.

In recent years (EL MARI, 2001; Velraj et al., 1999), efforts have been directed towards the study of the phenomenon of thermal energy storage by latent heat using (PCM). These materials have the advantage of storing large amounts of energy with a good value (mass/volume) (Xiaoming Fang et al., 2006). As part of this work we examine the case of energy storage by PCM confined in capsules. There are two types of these materials.

2. PHYSICAL MODEL AND NUMERICAL PROCEDURE

2.1. Problem of Frontier Mobile during a process of fusion of a PCM

The present work is to present a numerical method to the problem of change of solid-liquid state in rectangular geometry where the fusion results from the coupling between the solid phase in conduction and the convection in liquid phase. The mathematical modeling addresses three areas: liquid, interface and solid.

2.1.1. Modeling

The configuration adopted is a block of MCP material from a height H and a length L. The two horizontal walls are adiabatic. On the bottom wall $T_0 \langle T_m$ and on the top wall $T_p \rangle T_m$.

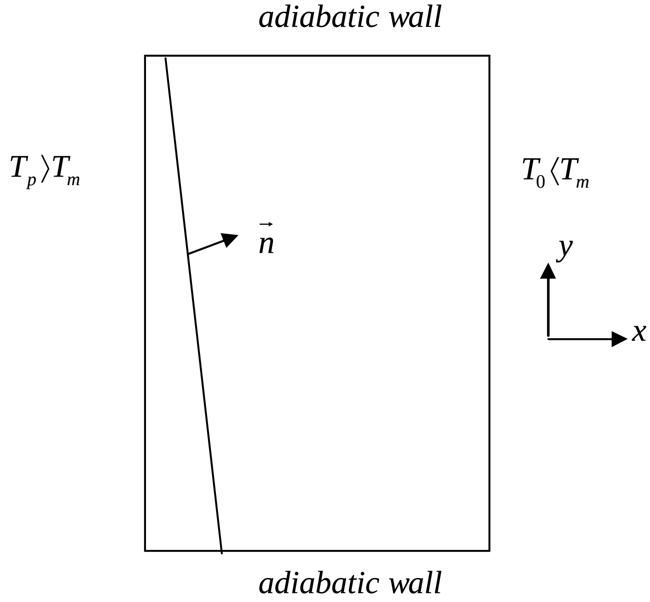


Figure 1 Geometrical configuration of PCM wall for two subdomains

2.1.2. Setting in equation

Liquid phase:

$$\frac{\partial T}{\partial t} = \alpha_s \frac{\partial^2 T}{\partial y^2} \left(T \rangle T_f \right) \tag{1}$$

$$\frac{\partial T}{\partial t} = \alpha_l \frac{\partial^2 T}{\partial y^2} \tag{2}$$

Solid phase:

$$\frac{\partial T}{\partial t} = \alpha_s \frac{\partial^2 T}{\partial x^2} \left(T \langle T_f \right) \tag{3}$$

$$\frac{\partial T}{\partial t} = \alpha_s \frac{\partial^2 T}{\partial y^2} \tag{4}$$

α is the thermal diffusivity which writing according on the conductivity of the material $\alpha = \frac{k}{\rho C_p}$. Indices *s* and *l* represent solid and liquid phases respectively.

Solid - liquid interface

$$T_s = T_f \tag{5}$$

$$\rho_s L \frac{\partial X}{\partial t} = k_f \vec{\nabla} T_f - k_s \vec{\nabla} T_s \tag{6}$$

where T_s and T_f described respectively the temperatures at the interface of the two media solid and liquid, the X describe the position of the interface and L the latent heat.

2.1.3. Boundary condition

The horizontal walls ($y = 0$, $y= L$) are adiabatic:

$$\frac{\partial T_f}{\partial y} = 0 \quad \text{and} \quad \frac{\partial T_s}{\partial y} = 0 \tag{7}$$

The side walls

$$\begin{cases} T_f = T_p \rangle T_m & \ldots\ x=0 \quad (8) \\ T_s = T_0 \langle T_m & \ldots\ x=L \quad (9) \end{cases}$$

At the interface: - in the fluid phase: $T_f = T_m$

- in the solid phase: $T_s = T_m$

2.2. Integration of MCP in the walls of buildings

2.2.1. Geometric configuration

In this section we will examine the interest the utility of PCM in the field of thermal insulation. So we consider a wall consisting of three layers: the middle layer is a material phase change covered by both sides with a layer of brick. The latter is subject to a condition of high temperature. So to describe this problem we consider the following configuration:

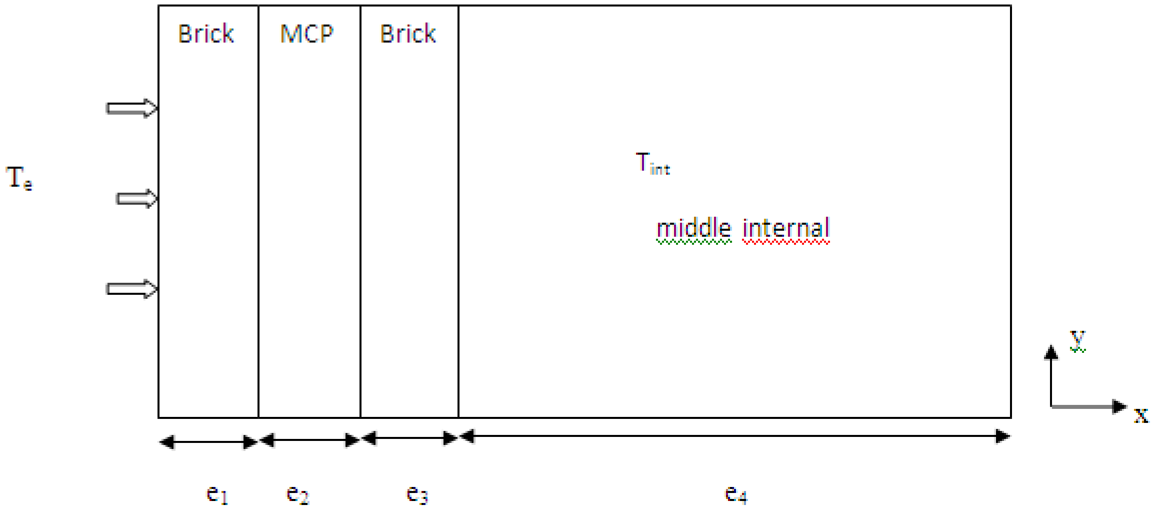


Figure 2 Geometric configuration for Integration of (PCM) the walls of buildings

2.2.2. Setting equation
The heat balance equations are as follows:

$$\alpha_i \frac{\partial^2 T_i}{\partial x^2} = \frac{\partial T_i}{\partial t} \quad l_{i-1} \le x \le l_i \quad i=1,\,2,\,3,\,4 \tag{10}$$

or

$$\alpha_i = \frac{k_i}{\rho_i C_i} \quad l_0 = 0 \;,\; l_i = l_{i-1} + e \tag{11}$$

2.2.3. The boundary condition

$$T=T_e \;,\; x=0 \tag{12}$$

$$\lambda_i \frac{\partial T_i}{\partial x} = \lambda_{i+1} \frac{\partial T_{i+1}}{\partial x} \quad , \; x = l_i \;,\; i = 1,2,3 \tag{13}$$

$$\frac{\partial T_4}{\partial x} = 0 \quad , \; x = l_4 \tag{14}$$

3. RESULTS AND VALIDATION

3.1. Heat transfer within the PCM

The numerical results are given for a rectangular enclosure containing a PCM brought to the melting temperature T_m= 310 K.

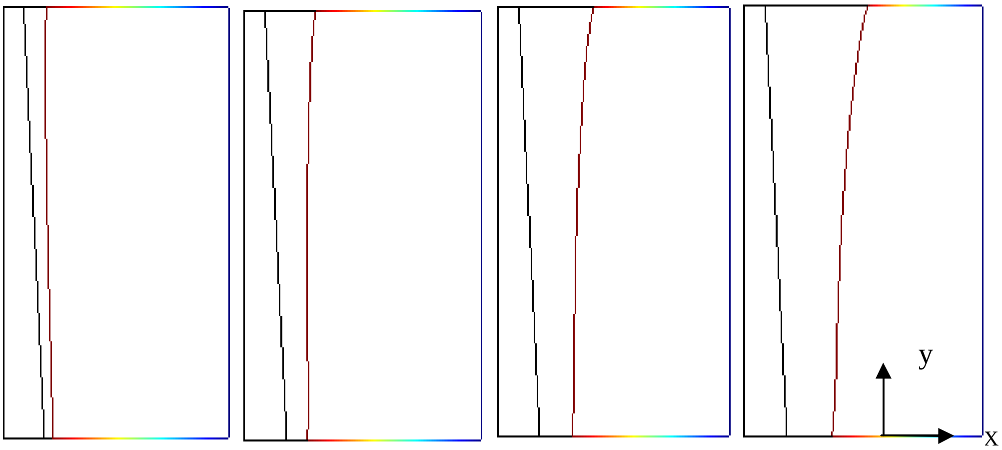


Figure 3 Evolution of the meltingfront

Figure 3 shows the evolution of the melting front in time *t*. When the merger begins, when melting begins, the driver manages dimensional system heat exchange liquid phase. We note that during the conduction regime the heat flow is uniform and the melting front is right and parallel to the wall. The temperature gradient in the solid matrix becomes important since its thickness decrease over time due to the evolution of the melting front.

In Figure 4, the temperature profile in the solid matrix is linear which indicates stationary of the interface.

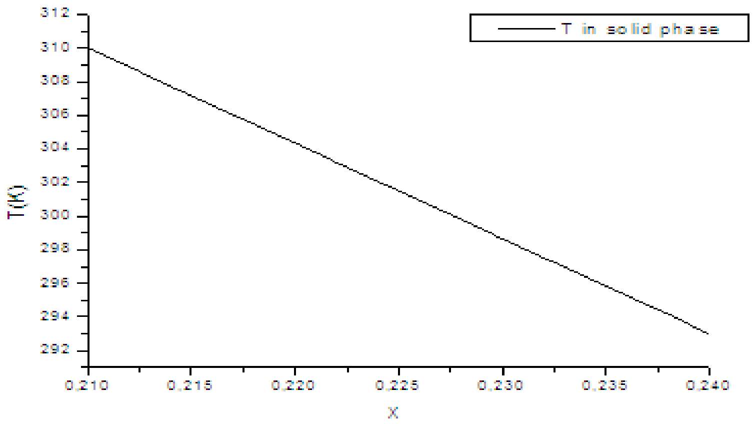


Figure 4 Evolution of the temperature in the solid region

In this section we study the effect of form factor ($A=H/L$) on the progress of the melting front and the evolution of temperature in the solid phase, maintaining the same boundary conditions, the same height (H=0.7) and varying only the width of the material (L).

The evolutions of the temperature in the solid phase for four different values of the aspect ratio are reported in Figure 5.

In this case, increasing the aspect ratio favors a more rapid melting. This is what explains the decrease in the aspect ratio ($A=H/L$).

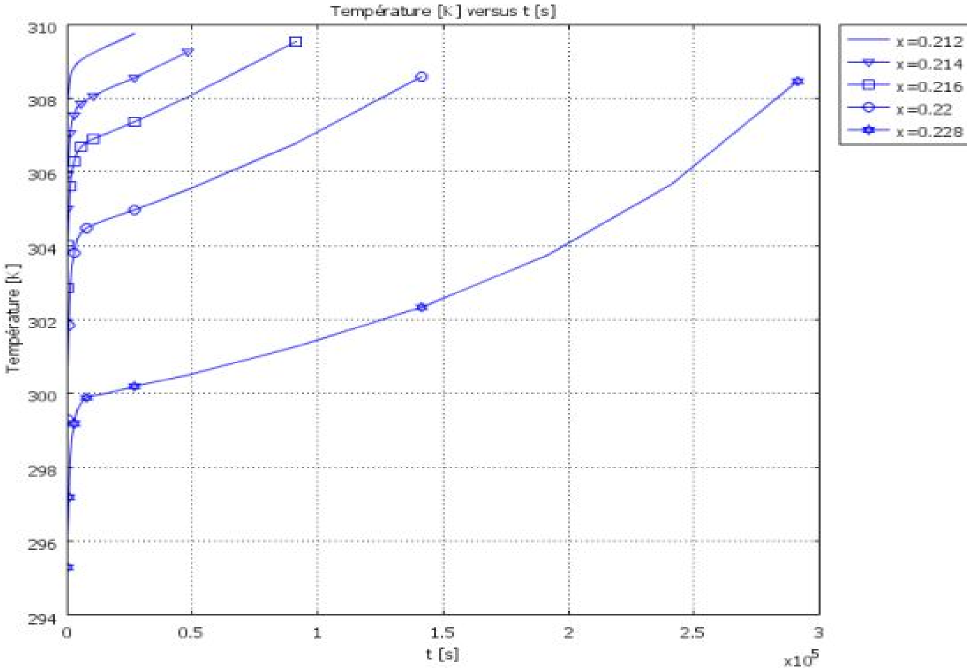


Figure 5 Progress of the melting front in the solid phase over time

3.2. Heat transfer in a wall containing PCM

We represent in Figure 6 evolution of the temperature profile along the horizontal axis of our field. These results show the usefulness of the materials (PCM) to provide thermal comfort in buildings. It is found that heat applied to the exterior of the building has been absorbed by the material to keep the ambient temperature inside the building. The thermal insulation of a building is to minimize heat exchange between inside and outside to achieve the goal of energy saving. Integrating phase change materials (PCM) into building walls is a potential method of reducing energy consumption in buildings.

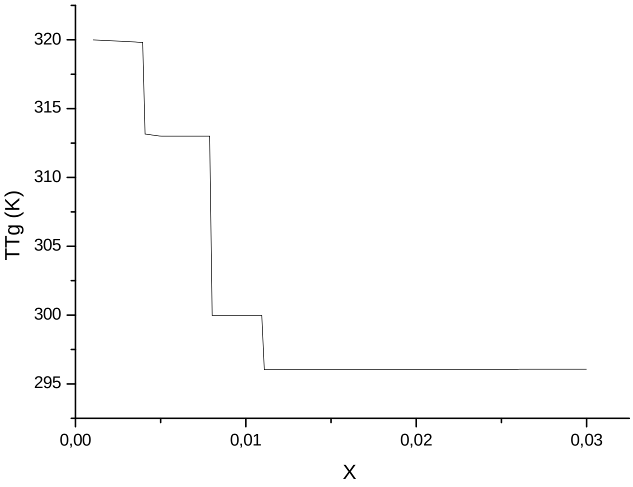


Figure 6 Evolution of temperature along the *x* axis plane *y* = 1m

The importance of the use of these materials is defined by their ability to absorb energy by the phenomenon of phase change. In our case we study the case of fusion (solid-liquid).

3.3. Validation Study of heat transfer in macro-encapsulated PCM

In this part is to study numerically the performance of a packed bed thermal energy storage system, which is randomly packed with spheres having uniform sizes and encapsulated the phase change material (PCM), traversed by a flow of air.

Our numerical model was developed and validated based on experimental data (Sharma, A.et al, 2009). Our modeling of the experiment is done using the simulation software based on finite element method, Comsol 3.4-Multiphase.

The proposed system is a vertically oriented cylinder containing spherical particles filled by PCM and traversed by a stream of air. Modeling based on equations of energy in the fluid phase and the PCM.

3.3.1. Geometric configuration and boundary condition

The storage bed is represented by the following scheme:

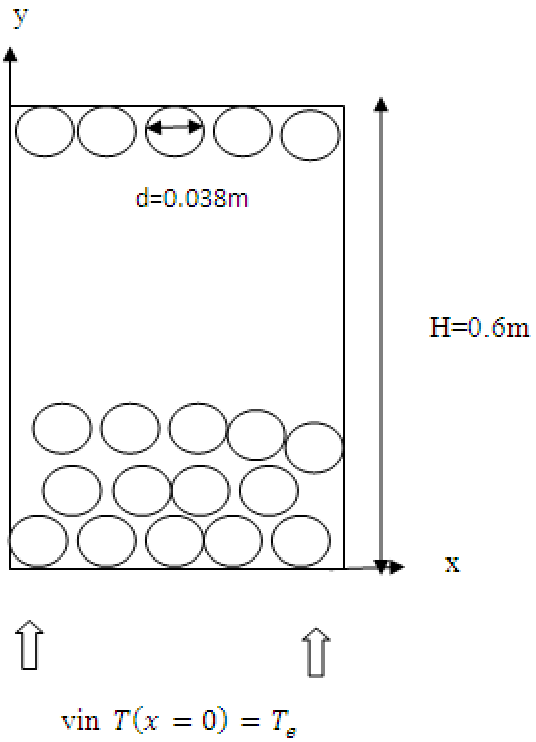


Figure 7 Diagram of the storage bed

The numerical study has been made in the case of a cylindrical bed of 0.6m high and 0.2m in diameter filled with plastic spheres of equal diameter of 0.038m each containing paraffin wax (melting range 58°C –60°C) and through which air heated and maintained at a constant inlet temperature higher than the melting temperature of the material chosen.

Figure 8 illustrates the comparison mode load (storage), predicted values of the temperature of the fluid and the PCM and those measured experimentally (Sharma, A.et al, 2009). The comparison shows a good agreement between calculated and experimental results.

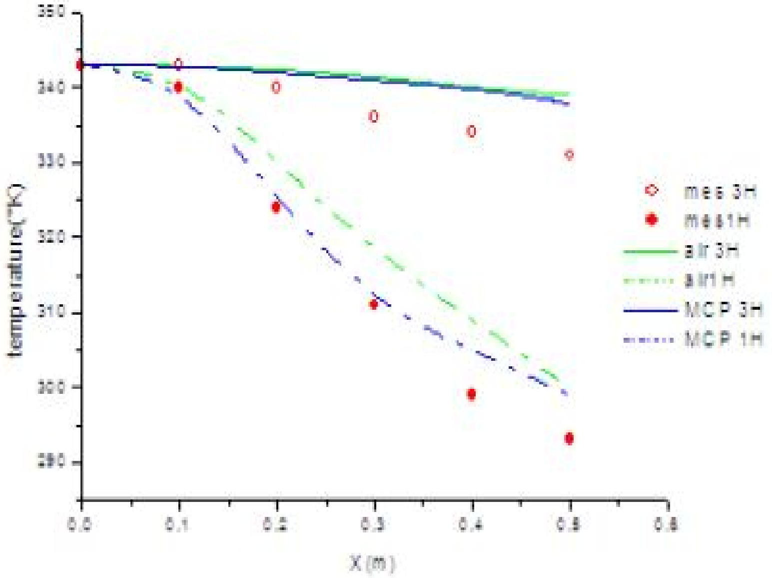
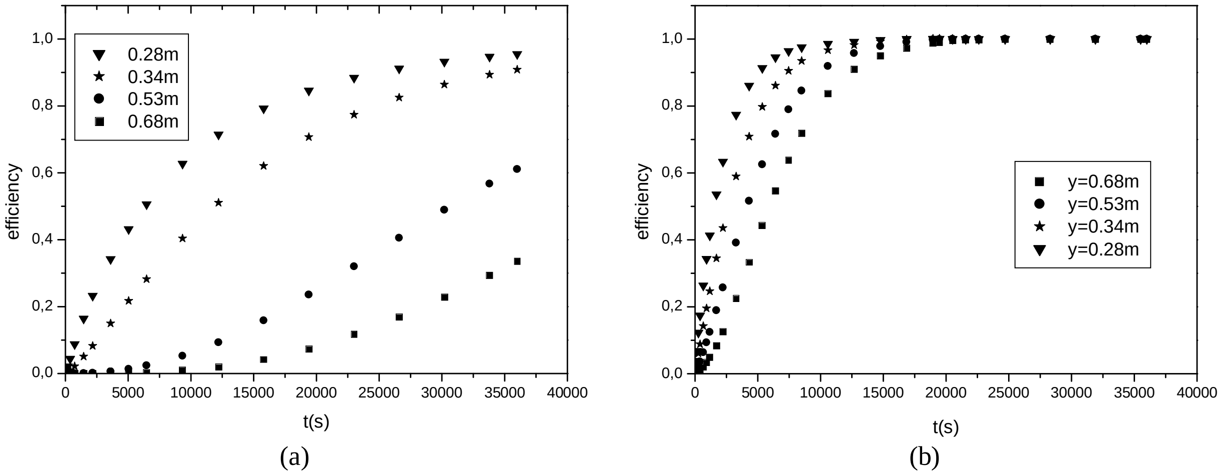


Figure 8 Comparison between vertical temperature fields measured and calculated values by our model

3.3.2. Storage efficiency of the bed



(a) (b)

Figure 9 Variation of the efficiency of bed during storage at different positions and different values of *y*, (a) vin=0.002m/s and, (b) vin=0.02m/s

The efficiency of the bed is defined by the following expression: $\frac{T_2 - T_{am}}{T_e - T_{am}}$

T_e with the temperature in the PCM.

We have shown in Figures 9(a) and 9(b), the effectiveness of the bed during the storage period for differing positions along the bed and for two different air flows. It may be noted that during the same time period and for the same positions of *H*, efficiency increases with *v* (air flow), so we see that more hot air is introduced, more heat is store

The process of storing higher the melting temperature of the PCM. The fluid flow between the nodules increases their melting temperature. We note that that in our model the flow between the nodules is considered forced. Yet as the fluid velocity is low there is surely movement of natural convection superimposed. Natural convection expected in this flow will come from the difference between the temperature of the capsule wall and the fluid.

Figure 10 shows us the role of PCM to store heat changes, achieve insulation and thermal comfort inside buildings because of their role to store heat by the phenomenon of phase change.

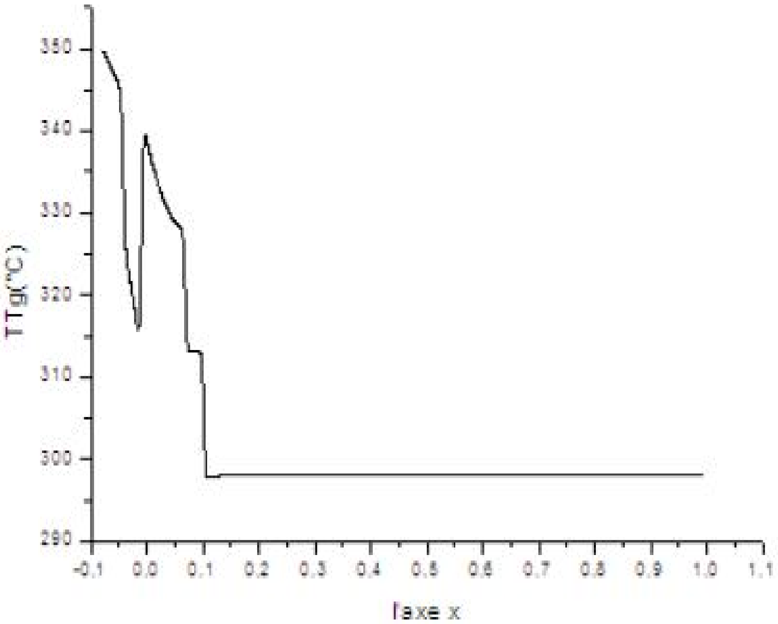


Figure 10 Evolution of temperature along the axis *x* of system

4. CONCLUSION

This work aims to establish a numerical model that has allowed us to overcome the problem of melting in rectangular pregnant fitted with heat sources in the presence of natural convection, and to locate, over time, the melting front, and evaluated the thermal transfer mode that manages the process melting. The results are satisfactory and allow comparing different PCM.

In second party has a material consisting of paraffin waxes for applications to improve the thermal inertia in buildings. Results confirm that the presence of this material can play a significant role in the summer comfort by stabilizing the temperature of the medium in which it is inserted. This type of PCM results in a good solution, because of the reduction of heat transfer in the building industry.

5. ACKNOWLEDGEMENT

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