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The Effect of Inclination on the Passive cooling of the solar PV panel by using Phase change Material

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Abstract-A two-dimensional (2D) numerical model was used to simulate the use of a phase change material and inner fins incorporated to a PV panel, in order to control the temperature rise of the PV cells at various inclination angles from 0 º to 90º with respect to vertical at increments of 15°. The PCM (RT25) is placed in a cavity directly in contact with the PV panel. This cavity enclosed on both sides by aluminum layers, and contains extended surfaces (fins).This PV-PCM system is studied numerically using finite volume method.

The predicted temperatures have been compared with experimental and numerical data of the literature and a good agreement was obtained for both the isothermal contours and time evolution of the temperature.

The bulk of the PCM melting within the system is dominated by natural convection for angle inclination lower than 45º. In other hand, for the inclinations higher than 45º the heat transfer in conduction mode increases until at 90º, where natural convection disappears completely and the conduction manifests alone. The obtained results reveals that the temperature of the PV panel increases with the increase of the inclination and that small inclinations (lower than 45 º) allow for a better cooling of this panel.

Keywords Phase Change Material, heat storage, PV cooling, Effect of inclination.

1. Introduction

Nowadays, the efficiency of the conversion of solar light into electricity for the PV panels is still one of top priorities for many academic and industrial research groups. The solar tracking is one of the proposed solutions for improving the efficiency of PV conversion [1]. Thus, in order to get the maximum energy efficiency, the PV panel changes continuously its position by an adequate angle of inclination as shown in figure 1.a.

The photovoltaic (PV) panel absorbs only about 16% of the incident solar energy that is converted into electricity; the other part of insolation absorbed is transformed into heat [2]. The photovoltaic cell efficiency drops with the increase of temperature[3]. This can reduce the efficiency of 0.5% per °C. Since, for example, silicon solar cells are characterized at 1000W/m^2 and 25ºC as ideal temperature for the cell, keeping the PV panel temperature at 25ºC can retain the efficiency of the panel. In addition, cells will exhibit long-term degradation if the temperature become excessive[4].

This problem can be avoided by maintaining the PV panel at adequate temperature. However, the use of cooling can lead to a significant increase in conversion efficiency of the PV cells. Recently, the phase change materials (PCM) was developed and employed to regulate the rise in PV temperature. These materials absorb energy as latent heat at constant temperature. For the PV of operating temperature 25 °C, we use the phase change materials with the temperature of solid-liquid phase transition at or close to 25°C.

Huang et al., [5] have modeled numerically the PCM integrated with PV by using the finite volume method, and they have predicted the time evolution of the temperature of the system. Later, Huang et al. [6] have experimentally evaluated the PV/PCM system with different configurations, where the metallic fins were inserted inside the PV/PCM rectangular cavity to enhance heat transfer. Recently, the experimental results of Ahmad [7] show that PCM are an effective solution for PV cooling and keeping higher power outputs in arid zones.

As the increase of the thermal conductivity of the PCM could augment the heat transfer rate, different methods have been developed to increase the thermal performance of PCMs, such as; including extended surfaces. In other hand, considering that the melting rate in high Prandtl number PCMs is mainly controlled by natural convection, any increase in the intensity of the natural convection currents can lead to considerable improvement of the melting rate. Nowadays, few studies have addressed the influence of the inclination angle on the thermal behavior and melting rate of PCM in an enclosure, also these studies concern enclosures without any extended surface (fins).

Webb&Viskanta[8]have investigated experimentally the melting heat transferof n-octadecance ($Pr\approx68$) in an inclined rectangular cavity, with a front wall heated at a high temperature. They have found that the inclination promotes natural convective motion.

The experimental investigation of Akgun et al. [9] demonstrates that the melting time can be decreased by 30% when the enclosure is tilted 5° from its vertical position for the case of annular enclosure. The same result was found also by Sharifi et al. [10] in their experimental investigation for a vertical warm cylinder. It was observed that modest tilting of the container significantly affects the temperature distribution.

Kamkari et al.[11]have studied experimentally the phase change material (with high Prandtl number; $Pr\approx100$) melting in a rectangular enclosure at various inclination angles. The enclosure is heated isothermally from one side while the other walls are thermally insulated. The results reveal that the enclosure inclination has a significant effect on the formation of natural convection currents and consequently on the heat transfer rate and melting time of the PCM. As the inclination angle is increased from 0° to 90° the convection currents in the enclosure increases and leads to a considerable enhancement in energy transport from the hot wall of the enclosure to the PCM.

From the above literature review and to the best of our knowledge the effect of the inclination angle on the unsteady conjugate conduction-natural convection in inclined enclosure including extended surfaces (fins) and filled of PCM in melting process is not clear.

This work presents a numerical study of the effect of inclination angle of the PV/PCM system with extended surfaces (fins) on the overall thermal behavior of the assembly. A two-dimensional numerical model of such a system is solved by using the finite volume method. The obtained results focus on the melting behavior of the PCM within the cavity and the temperature time history of the PV panel.

2. Numerical modeling

A schematic 2-D computational domain for all investigated cases is presented in Fig. 1a. The system is comprised of a photovoltaic panel and of a phase change material 'RT25'. Air circulates freely over the PV panel and the back wall of the container of PCM. The PCM is in direct contact with the PV panel and the back wall. The incident energy I_T is absorbed and transformed into heat inside the PV-PCM system. In our case, we use the same geometry considered by Huang et al [5]. Therefore, we use the same boundary and initial conditions of the last authors, which are:

(i) the initial temperature of the system PV/PCM is T_{PV};
(ii) the front and rear surfaces of the system have respectively the valuesh_1 and h_2;
(iii)concerning the top and bottom boundaries, the adiabatic conditions are used.

The thermophysical properties of phase material change "RT25" and Aluminum used in the present investigation are shown in Table 1. As well known, the data of 'RT25' are provided by the manufacturer ''RUBITHERM''. The system was studied by varying its angle $\theta$from the vertical, starting with θ= 0º (system standing vertically) to θ= 90º (horizontal system) by increments of 15º.

The unsteady equations of energy and momentum in 2D which govern such heat transfer, are solved by using the implicit finite volume method of the commercial code fluent 6.3.26. In addition, the Boussineq approximation was adoptedto take account the change in density of the PCM in liquid phase as a function of temperature.

A fixed grid space of 1 mm and a variable time step with a minimum value of 0.01s are used for all simulations. The total number of grid used is 132x48 for all cases under investigation (fig. 1b). The numerical predictions were performed on a PC I5 computer with 4 GB of RAM.

3. Results

The results presented for the PV/PCM system, were obtained for an accuracy of order 10^{-6}. The heat transfer coefficients on the front and rear surfaces are respectively 12.5 and 7.5 $W.m^{-2}.K^{-1}$ and the insolation was 750 Wm^{-2}.

The governing equations of the problem are solved for several configurations of PV/PCM system.

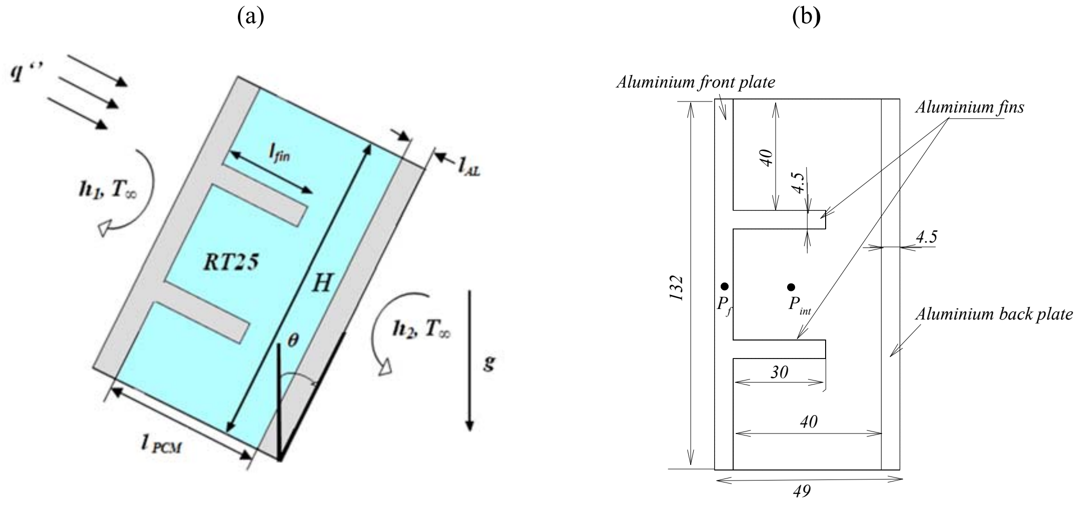

Figure 1: Presentation of the PV/PCM system: a) heat transfer and boundary conditions; b) Geometry of the system (dimensions in mm).

Table 1.Thermophysical properties of ''RT25'' [12], Paraffin wax [13] and Aluminium[14]

Property	Phase change material ''RT25''	Paraffin wax	Aluminium
Density			
Solid, Kgm^{-3}	785	830	2675
Liquid, Kgm^{-3}	749	830	Not used
Specific heat capacity			
Solid, $Jm^{-3}K^{-1}$	1,413,000	1,593,600	2,415,525
Liquid, $Jm^{-3}K^{-1}$	1,797,600	2,705,800	Not used
Thermal conductivity			
Solid, $Wm^{-1}K^{-1}$	0.19	0.514	211
Liquid, $Wm^{-1}K^{-1}$	0.18	0.224	Not used
Melting temperature, °C	26.6	32	Not used
Latent heat of fusion, J kg^{-1}	232,000	251,000	Not used

The numerical results obtained are presented for isothermal contours and time evolution of temperature in Figures 2-6. The present computational procedure is validated against the results of Huang et al [5]. Then, we focus our attention on the effect of the inclination on the cooling of the PV panel along the time by varying the angle θ of the PV-PCM system from the vertical, starting with θ = 0° (system standing vertically) to θ = 90° (horizontal system) by increments of 15°. Through this change in angle, the effect of natural convection within the liquid PCM in the cavity and the overall transient thermal behavior of the system could be investigated and analyzed.

3.1 Validation

The numerical model used was validate against the experimental and numerical data of Huang et al [5] for the isocontours and time history of the temperature (fig. 2 and fig. 3). Concerning the isothermal contours, a good agreement was achieved at 50th minute, as illustrated in Fig. 2, between our results and those of Huang et al [5]. Again, a good agreement was found at the 100th minute for the temperature contours (not shown here).

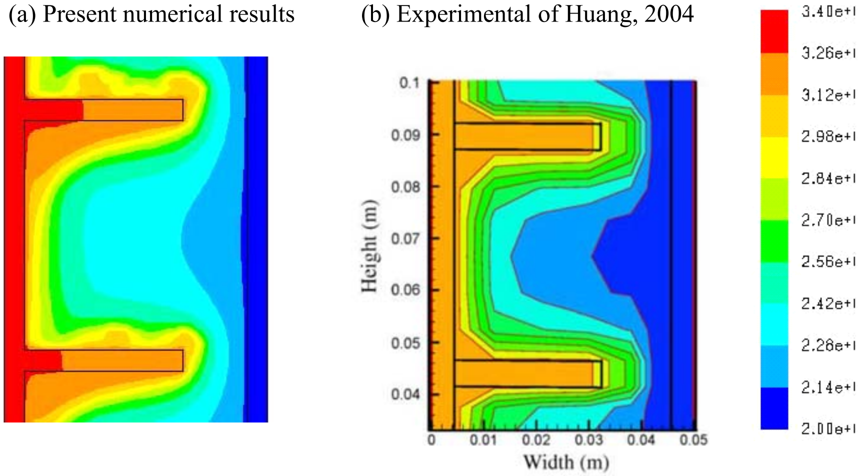
(a) Present numerical results (b) Experimental of Huang, 2004

Figure 2: Comparison between the temperature contours predicted numerically and the measured temperature contours during the 50th minute and for θ = 0º .

(a) (b)

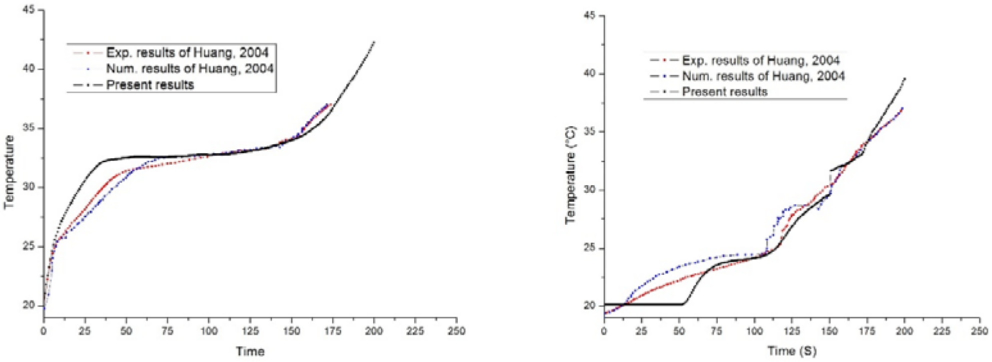

Figure 3: Comparison between the temperatures predicted by the present 2D model and the data of Huang, 2004 for θ = 0º at : a) the front (point P_f), and b) the inside of the PCM (Point P_{int}) .

Further validation has been performed by comparing the local temperature at two different positions, the first one is located in the front of the PV panel and the second one is inside the PCM along the time evolution between the present work and that of Huang. Once again, the comparison reveals good agreement between both results as showed in Fig. 3. These validations reinforce the confidence in our numerical procedure.

3.2 Effect of Inclination

Seven simulations were performed for the PV-PCM system. For each simulation, the angle of the system from the vertical (θ) was chosen from 0 to 90º by 15º increments (0º, 15º, 30º, 45º, 60º, 75º and 90º). All numerical simulations were performed along 200 minutes from the starting initial condition (PCM solid at ambient temperature 20°C). These 200 minutes seem be long enough for every system studied to reach fully melted state.

From all investigated cases the front face is exposed to heat flux, and is in high temperature compared to the back face of the system. However, the PCM starts to melt close to the front face. We have noticed from the simulation that the initial melting of the PCM is driven by conduction but once enough PCM is melted, natural convection in the liquid melt starts to dominate.

Figure 4 shows the distribution of the isothermal contours

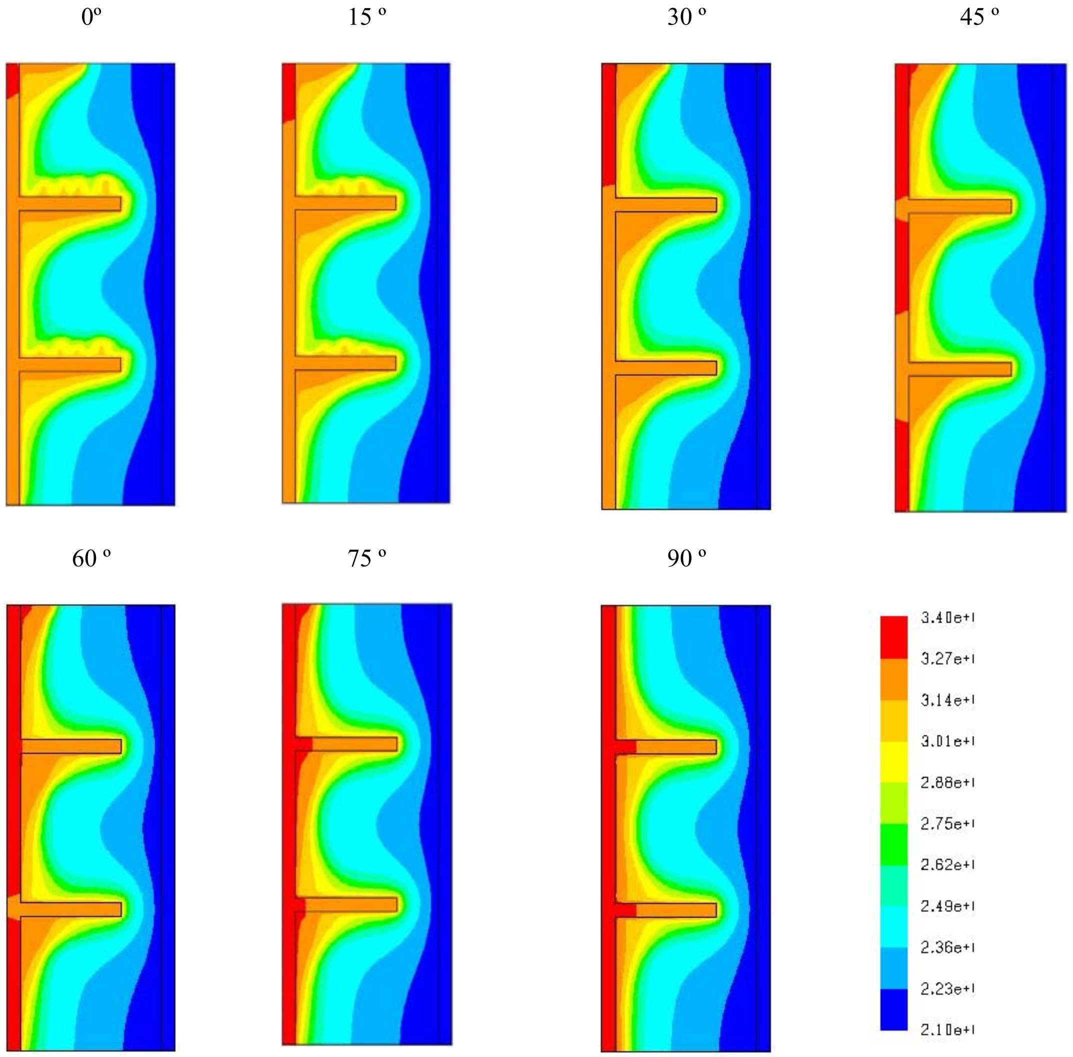

Figure 4: Effect of the inclination (0º ; 15º ; 30º ; 45º ; 60º ; 75º and 90º) on the on the temperature profiles at the time 50th minute during melting.

for the cases under investigation at the 50 th minute. As well known the front is in high temperature, we notice that the temperature decreases from the front to the back of the system. It is clearly noticed from this figure that for all angles of inclination, three cells of driven natural flow are created close to front face, which are smaller compared to the case without fins [15]. These three cells are practically of the same size. They guarantee a better distribution of the heat load in the PCM and reinforce the thermal homogeneity in the system. From the inclination 0 º to 45 º we remark the increase of the size of these three cells and consequently the increase of heat transfer via convection. In contrast, for the orientations higher than 45º, the size of these cells reduces and consequently reduction of heat transfer via convection until the case of pure conduction for the horizontal orientation of the system. From these plots, we notice that the temperature of the front face increases with the increase of inclination.

Concerning Figure 5, which displays distribution of the isothermal contours for the cases under investigation at the 100 th minute, we observe the same behavior for the temperature distribution as mentioned in figure 4 at 50 th minute. Furthermore, we notice the increase of the size of these three cells due to the increase of the volume of PCM melted at this time. As observed previously at time 50th minute, we notice always the increase of heat transfer in convection mode with the increase of the orientation in the range from 0º0º to 45 º and an increase of heat transfer via conduction mode for the inclinations higher than 45 º. Also, it can see from the plots of this figure that the temperature the PV (front) increases with the increase of inclination.

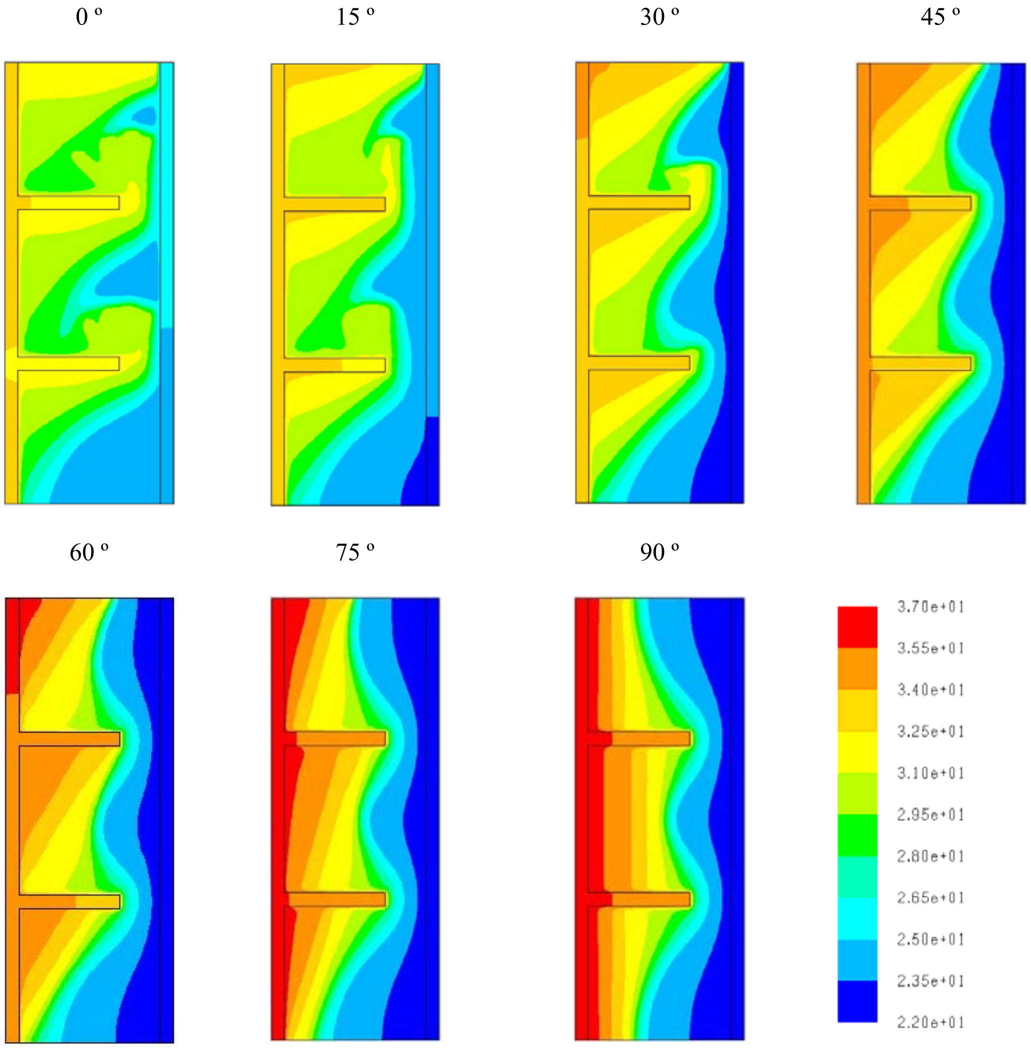

Figure5: Effect of the inclination (0° ; 15° ; 30° ; 45° ; 60° ; 75° and 90°) on the on the temperature profiles at the time 100th minute during melting.

From figure 6, which shows the isothermal contours at the 150 th minute for all inclinations, we remark always the same behavior for the temperature distribution and an increase of the volume melted of the PCM compared to cases at 100 th minute. In the other hand, we notice also the increase of convection phenomena with the increase of angle of inclination until 45°. However, for angle inclination higher that 45 ° we notice the increase of conduction phenomena as mentioned in the precedent time of simulation. We can observe for the inclinations higher than 45° for the cases of figure 5 and 6, a kind of stratification of the temperature due to the domination more and more of the conduction.

Figure 7 shows the temporal evolution of the temperature of PV panel in a middle point, along 200 minutes of simulation for different inclinations that are under investigation. From this figure, it is clear that the temperature increases with the increase of the inclination as already mentioned in Fig. 4; 5 and 6. We can notice that the small inclinations (lower than 45 °) allow for a better cooling of the PV panel, where the maximum temperature (45° C) is reached at the 200th minute. This is due to high activity of heat transfer dominated by convection for the cases of inclinations lower than 45°, compared to the cases of the inclinations higher than 45° which have activity of heat transfer dominated more and more by conduction(low thermal conductivity of PCM $\lambda \approx 0.\ 2\ Wm^{-1}K^{-1}$).

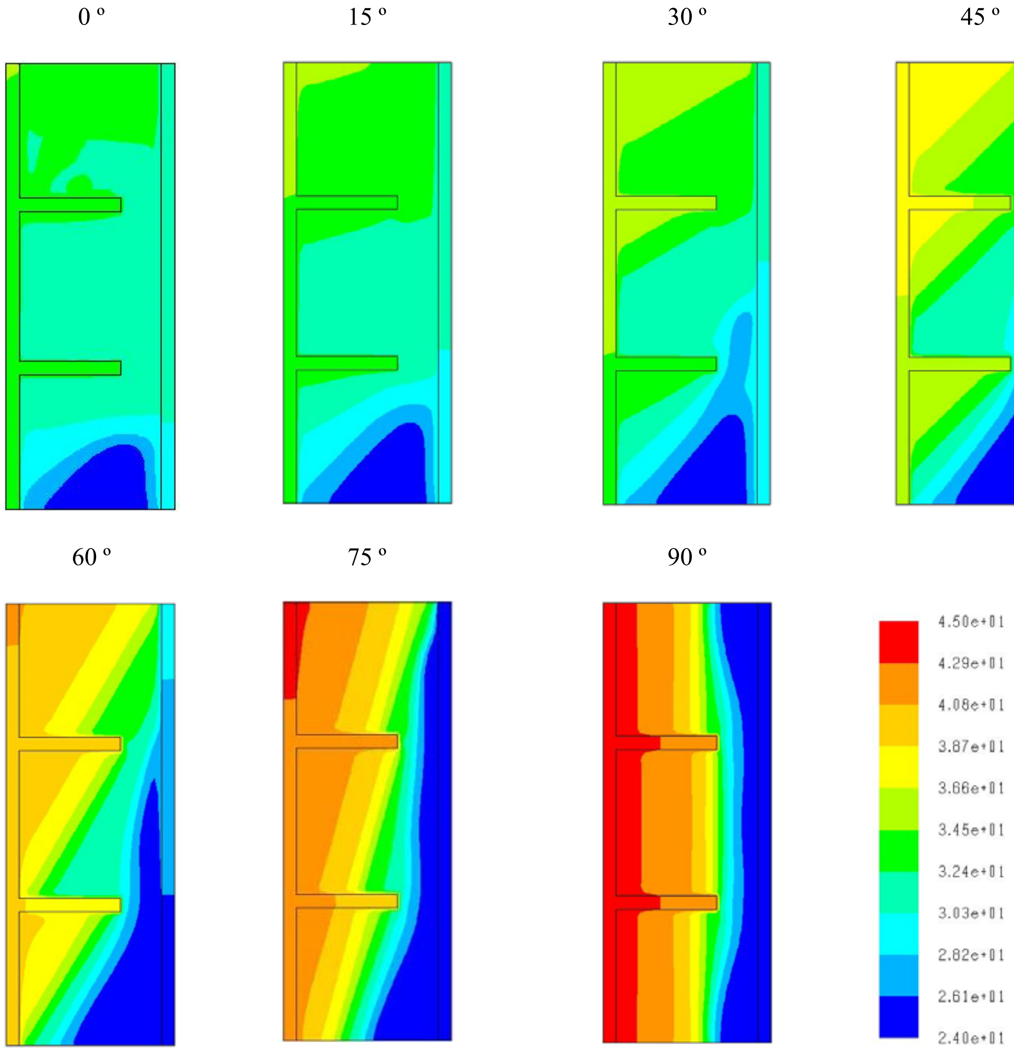

Figure 6: Effect of the inclination (0º ; 15º ; 30º ; 45º ; 60º ; 75º and 90º) on the on the temperature profiles at the time 150th minute during melting.

5. Conclusion

As well known the efficiency of solar photovoltaic (PV) panels decreases when their temperature increases under the sun. In this investigation, we tried to maintain the PV's temperature at a low value by incorporating a solid–liquid PCM and inner fins. The used PCM (RT25) melts at the characterizing temperature of the PV, 25 °C. The aim of this work is to investigate numerically the melting behaviors and performance under the effects of the angle of inclination. Doing this, the Commercial CFD code (Fluent 6.3) was been used to solve the conservation equations of mass, momentum and energy. The numerical studies were performed on this system for seven inclination angles varying from 0°(vertical) to 90° (horizontal) by 15° interval.

A good agreement was obtained between the results of the present investigation and those of the literature for the vertical case ($\theta = 0^o$), for both the isothermal contours and time evolution of the temperature.

The obtained results reveal that the heat transfer is done by conduction and convection inside cavity. However, the bulk of the PCM melting within the system is dominated by natural convection for angle inclination lower than 45 º.In contrast, for the inclinations higher than 45º the heat transfer in conduction mode dominates until at 90º, where the natural convection disappears completely.

Our results reveal also that the temperature of the PV panel increases with the increase of the inclination, and the small inclinations (lower than 45 º) allow a better cooling of this panel.

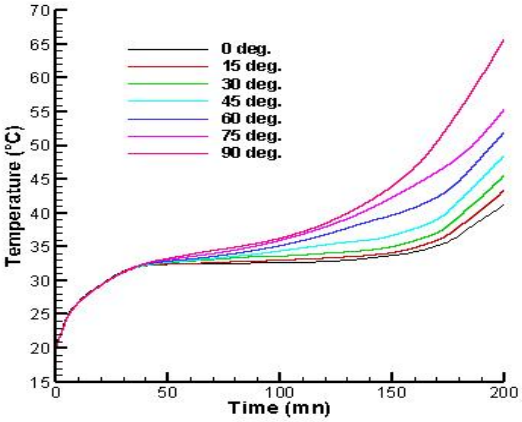

Figure7: The effect of inclination on the time history of the Temperature of the PV panel.

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