

Influence of Orientation Position in a Pcm Capsule With and Without Adding a Fin

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Abstract

This paper summarizes a numerical study investigating the behavior a phase change material PCM filled up a rectangle capsule, with and without adding a fin with changing the orientation position in three times (0° , 45° and 90°). The results have proved that, upon adding a fin the melting time decreased, so the rate of storing the thermal energy would be rapid, as well as the melting and storing energy rate got faster with change the capsule orientation position from 90° , 45° then 0° .

Keywords: PCM; Mushy zone; Melting; Free convection; Thermal energy storage; mushy zone

1. INTRODUCTION

Using phase change material (PCM) on thermal energy storage (TES) applications are the most attractive technique to store the thermal energy, where storing thermal energy for long period to use it at peak time is very difficult, thus, was used specific materials with high thermal capacity with a low melting point, named PCM.

The storage of the thermal energy upon using PCM is based on latent heat technique, where the material melt during gaining the heat and solidified during releasing the heat.

Shapiro et al. [2] set a comparison between two concentric storage units (filled by a PCM) with radial and vertical fins mounted on. Thermal performance got from numerical study were compared with previously conducted experimental set. Results proved that vertically mounted fins configuration gives more thermal efficiency in comparison to the other configuration set. Zeng et al [3] examined the influence of the angular orientation of a rectangular cavity rambled by a PCM without fin, the comparison was made between different angular orientation (0° , 22.5° , 45° , 60° and 90°), results show that the thermal storage rate has been augmented with varying the orientation position from horizontal to vertical position However, another study has made by Baby and Balaji, [4] to compare orientations position effect, their results showed no influence of orientation position on melting rate, that maybe was due to the matrix geometry constraint, which affect on circulation development as what has been concluded by authors.

Lamberg [5] using an approximated analytical model has described two-phase solidification of a fin shaped PCM used for storage purposes.

Present paper focused on investigate the impact of orientation of a capsule ($\theta = 0^\circ$, 45° and 90°) filled by a PCM with and without adding a fin. The mathematical model, based on enthalpy- porosity method (Voller and Prakash model [1]) that is commonly used in phase change application.

2. PROBLEMATIC AND THE MATHEMATICAL MODEL [1], [6]

This study is based on fixed grid enthalpy method (Voller and Prakash model [1]), with using RT-27 (Rubitherm GmbH) as a PCM filled up the cavity, all walls are adiabatic excepted right wall (applied heat flux $Q=1000\text{W/m}^2$) and all walls are no slip. Next case has been added a fin on middle the cavity, where the no slip condition is applied in two side of the fin. The fin is made in aluminum. The proprieties of the fin and the used PCM are listed in Table 1 and Fig 1 presents the problematique schema with the boundary conditions.

Remark

The cavity without fin is $5 \times 9.5\text{cm}$ and with fin is $5 \times 10\text{cm}$, where is taken into consideration, the thickness of the fin that is 0.5cm , so the PCM takes same space in two cases.

Mathematical Model

Conservation of mass

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

Conservation of momentum

$$\frac{\partial \rho u}{\partial t} + u \frac{\partial \rho u}{\partial x} + v \frac{\partial \rho u}{\partial y} = -\frac{\partial p}{\partial x} + \mu \left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right] + S_x \quad (2A)$$

$$\frac{\partial \rho v}{\partial t} + u \frac{\partial \rho v}{\partial x} + v \frac{\partial \rho v}{\partial y} = -\frac{\partial p}{\partial y} + \mu \left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right] + S_y + S_g \quad (2B)$$

where $S_x = A u$ and $S_y = A v$

S_g is the Boussinesq approximation,

$$S_g = \rho_l (1 - \beta(T - T_m)) \vec{g} \quad (3)$$

$$\text{And } \eta = \begin{cases} 1 & \text{if } T > T_l & (\text{liquid fraction}) \\ \frac{T - T_l}{2 \, dT} & \text{if } T_s \leq T \leq T_l & (\text{mushy zone}) \\ 0 & \text{if } T < T_s & (\text{solid fraction}) \end{cases} \quad (4)$$

With taking C as so $C = 10^6 \text{ kg / m}^3 \cdot \text{s}$ [7]

and $A = \frac{(1 - \eta)^2}{(\eta^3 + 10^{-3})} C$ (for more details about the expression “A” and this model see ref [5])

$$\frac{\partial \rho h}{\partial t} + u \frac{\partial \rho h}{\partial x} + v \frac{\partial \rho h}{\partial y} = \frac{k}{c_p} \left[\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} \right] - S_h \quad (5)$$

Energy equation

Where

$$S_h = \frac{\partial(\rho \Delta H)}{\partial t} + \nabla \cdot (\rho \mathbf{u} \Delta H) = \frac{\partial(\rho \Delta H)}{\partial t} + \mathbf{u} \cdot \nabla(\rho \Delta H) \quad (6)$$

Table 1 The Properties Of RT-27 (Rubitherm GmbH) [8] And Aluminum [9]

Properties material		RT-27	Aluminum
melting point, T_m , (K)		302.15	NA*
latent heat of fusion, ΔH , (kJ/kg)		179	NA*
thermal conductivity, k , (W/m K)	Liquid	0.15	
	solid	0.24	180
density, ρ , (kg/m ³)	liquid	760	
	solid	870	2713
dynamic viscosity, μ , (Pa s)		$3.42 \cdot 10^{-3}$	NA*
thermal expansion coefficient, β , (1/K)		0.0005	NA*
specific heat, c_p , (kJ/kg K)	liquid	2.4	
	solid	1.8	0.96

* Not Applicable.

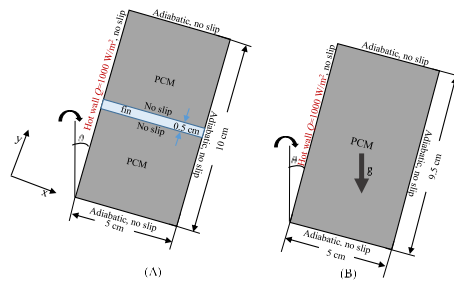


Fig. 1 Schema of the calculation domain, (A): capsule with fin (B): capsule without fin.

2. RESULTS AND DISCUSSION

Present study has been solved by using the computation commercial program, COMSOL-MULTYPHISICS [10]. Figure 2 shows the computation grid that built through COMSOL-MULTYPHISICS, where in enthalpy-porosity method is used fixed grid technique. It must be whole the mesh of computation refiner in PCM region as is shown to follow the liquid-solid interface section (mushy zone).

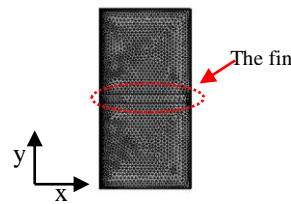


Fig. 2 the computation grid.

2.1. Liquid Fraction Development And Behavior Of Movement In The Liquid Section

Figure 3 shows the liquid fraction and the movement in it at different time steps ($t=25, 50, 75$ and 100 min) upon different rotation angle position ($\theta = 0^\circ, 45^\circ$ and 90°). Has been noticed that the evolution of the liquid fraction increases with passing time, also it observed that the liquid fraction decreases once the orientation position changes from 0° to 90° . It is can add that, the shape of liquid part takes an irregular shape, is being wider on top side than rest part as what it is clearly shown with cases of “ 90° and 45° ” but in case of 0° (horizontal position), the liquid fraction takes a regular shape, so from that it can say the conduction heat transfer mode is dominant in horizontal position, but on others cases the free convection was dominant. The liquid-solid interface section called mushy zone.

The arrows are shown the movement in the liquid (melt), the movement of the liquid takes a rotational movement in “ 90° and 45° ” cases, however, in horizontal position case has not been observed movement in the liquid, so the free convection has an effect in “ 90° and 45° ” cases and it does not have any influence in horizontal position case (0°).

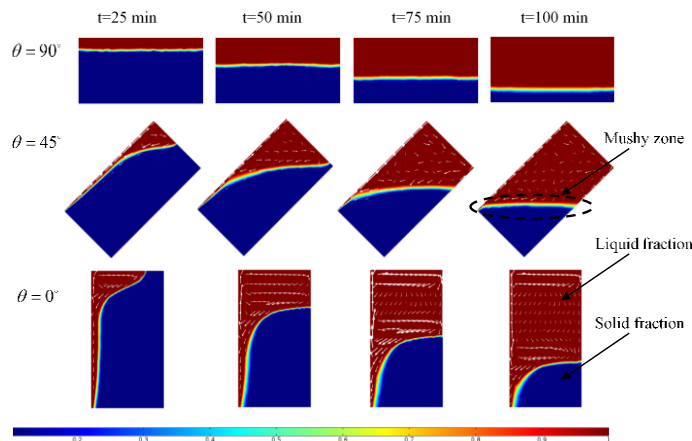


Fig. 3 The liquid fraction development and the streamlines.

2.2. Isothermal development

Figure 4 shows the isothermal of each cavity rotation cases ($\theta = 0^\circ, 45^\circ$ and 90°) at different time steps ($t= 25, 50, 75$ and 100 min). The isothermal lines take a curvy shape in “ 90° and 45° ” cases matching with liquid formed (see Fig 3), but in horizontal position case, the isothermal lines have a regular shape. Last remark prove that, conduction heat transfer mode is dominate as what mentioned above.

3.3. Comparison Between Capsule With And Without Fin

The curves in Fig 5 present comparison the average of the liquid fraction inside the capsule with and without fin during time with changing the orientation position as well. It can say as what is observing from the curves, the melting advancement decreases with changing the orientation position from 0° to 90° . In addition to with adding the fin inside the capsule the liquid fraction rate goes up only in horizontal position case (90°) and with 45° case, where the free convection plays a great role upon adding the fin in these cases.

Figure 6 shows the plot of the liquid-solid fraction, the streamlines and the isothermal lines at same time step ($t=100$ min) in different orientation position ($\theta = 0^\circ, 45^\circ$ and 90°) with and without adding fin.

The interesting remark most be discuss it, is: in case $\theta = 90^\circ$ with adding the fin the liquid moves with rotational moves, opposite what observed from case without fin, and the isothermal lines are matching with position of the liquid-solid region and it takes a curvy shape in the bottom part (see Fig 6 case “ 90° ”).

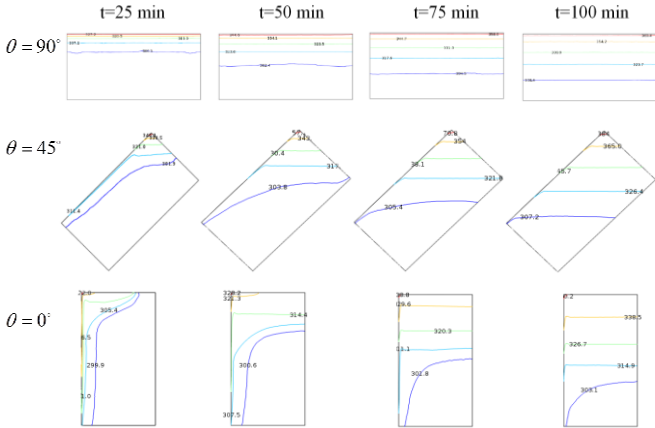


Fig. 4 The isothermal lines

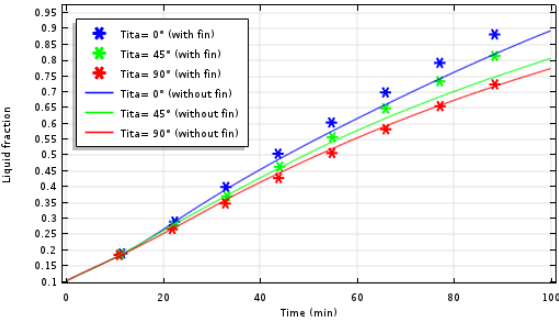


Fig. 5 liquid fraction in different orientation position with and without fin

The curves in Fig 7 show the gained thermal energy average during melting with passing time during changing the orientation position with and without fin. The thermal energy quantity that stored by the PCM is increased with changed the orientation position from 0° to 90° and with using fin, the rate of storing the energy is better than without using fin.

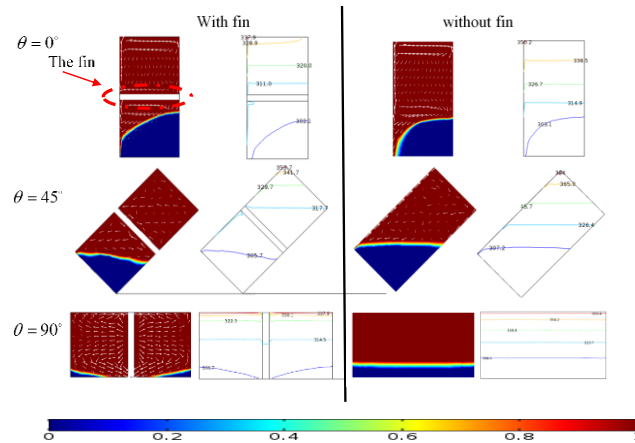


Fig. 6 liquid fraction and the isothermal lines in different orientation case and with-without fin

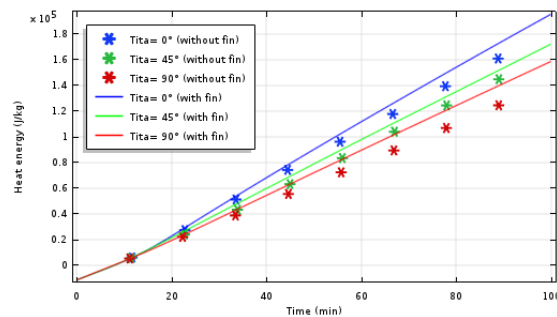


Fig. 7 Thermal energy quantity.

4. Conclusion

From discussion, the results of this investigation we can conclude that:

- With adding a fin inside the PCM, the heat transfer is got better, where the fin aids the heat distribution into the PCM.
- The storing energy that links with the melting rate increases with increasing the domination of the heat transfer by free convection mode.
- The buoyancy force of the free convection mode increases upon the more approaching to the vertical position.

REFERENCES

- [1] Voller V, Prakash C, A fixed grid numerical modelling methodology for convection–diffusion mushy region phase change problems. *Int J Heat Mass Transf* 1987, 30(8):1709–1719
- [2] M.M. Shapiro, D. Feldman, D. Hawes, D. Banu ” PCM thermal storage in wallboard.” . *Proceedings of the 12th Passive Solar Conference, Portland*, 1987, pp. 45-48
- [3] Zeng L, Numerical study of the influences of geometry orientation on phase change material is melting process, *Advances in Mechanical Engineering* 2017, Vol. 9(10) 1–11.
- [4] Baby R and Balaji C. Experimental investigations on thermal performance enhancement and effect of orientation on porous matrix filled PCM based heat sink. *Int Commun Heat Mass* 2013; 46: 27–30.
DOI:10.1177/1687814017720084
- [5] Lamberg P, Approximate analytical model for two-phase solidification problem in a finned phase-change material storage, *Applied Energy* 2004, 77, 131 -152.
- [6] BOUZENNADA T, MECHIGHEL F. Numerical study on the importance of the mixed convection and the impact of the cooling rate on the solidification of a pure material. *J. Fundam. Appl. Sci.*, 2019, 11(3), 1188-1211
- [7] P.H. Biwole, P. Eclache, F. Kuznik, Phase-change materials to improve solar panel’s performance, *Energy Build.* 62 (2013) 59–67,
DOI: [http://dx.doi.org/ 10.1016/j.enbuild.2013.02.059](http://dx.doi.org/10.1016/j.enbuild.2013.02.059)
- [8] R. A. A. Darzi, H. H. Afrouzi, M. Khaki and M. Abbasi, "Unconstrained melting and solidification inside rectangular enclosure," *J. Applied Science*, pp. 436-451(2015)
DOI: 10.1016/0017-9310(87)90317-6

- [9] K. Karunesh, A. Shukla, S. Atul, H. B. Pascal, "Melting and solidification behaviour of phase change materials with cyclic heating and cooling," *Journal of Energy Storage*, 15, 274–282 (2018).
- [10] COMSOL Multiphysics User's Guide, Comsol, (2018) . [Http://www.comsol.com](http://www.comsol.com)