# Heat Transfer Analysis on PCM Based Heat Sink Incorporated With Air Convection

Azeem Anzar, Azeem Hafiz P A, N R M Ashiq, Mohamed Shaheer S

**Abstract**— Integrated circuits operate best in a limited range of temperature hence their package must be designed in order to remove the excessive heat. As an alternative passive cooling technique means, phase change materials or phase change materials have been widely investigated for such transient cooling applications considering their advantages such as high specific heat, high latent heat of fusion, controllable temperature stability and small volume change during phase changes, etc. This types of PCM based cooling techniques have different application in various devices which are not be operated continuously over a long period of time, but in intermittently using devices like digital cameras ,cellular phones, notebook etc. The PCM absorbs heat from the electronic component when it operates at high temperature and melts, the molten PCM needs to be re-solidified by dissipating or spreading heat to the surroundings while the electronic device are set idle, such a cooling system is applicable only for intermittent use of devices and cannot be used for those in continuous operations. To achieve effective cooling it is important to ensure that the operating duration of the electronic device should not exceed the maximum melting time of PCM. When practical implementations are considered, advanced transient analysis is required for clear understanding of this mechanism. Controlled convective cooling techniques may be implemented for continuous operations in such kind of systems. The present work is a numerical study consisting of thermal analysis of various configurations of finned heat sink with PCM. The configurations considered are finned heat sink with PCM and without PCM, fin filled with half PCM material, towards the fin tip side and cases which includes forced convection for systems which continuously operates. The transient nature of problems were recorded for performing unsteady analyses. Evaluation of design operational time and characteristics of PCM are carried out. By analyzing these different configurations a vivid, valid picture of the physics of heat transfer in PCM based heat sink is imaged out. Keywords: Heat sink, Phase change materials, Thermal management, and electronics cooling.

◆

## 1 INTRODUCTION

Technological enhancements of device, package and system levels have resulted in increased functionality and decreased form factors, but in case of ever-small packages it has squeezed more power . As result of which, thermal management has become more crucial and critical for successful design of electronic devices such as digital cameras, personal digital assistants, notebooks, and cellular phones, etc. Such devices are generally not operated continuously over long periods, to overcome this a phase change material (PCM)-based cooling system has improved potential for applications. Integrated circuits operate best within a limited and specified temperature ranges, hence their packages should be designed to remove the excessive heat.

### 1.1 PHASE CHANGE MATERIALS

The PCMs are heat storage mediums used employed latent heat storage, as it will experience a phase transition during the release process or heat charge. Theoretically, PCM has a phase change point when the phase transition happens but in practical cases the phase change process happens in a certain temperature range instead of one exact point.

$$\frac{dh(T)}{dT} = c_p(T)$$

PCMs can be classified into solid-liquid, liquid-gas and solid-solid PCM. Among these three types of PCM: solid-solid PCM is rarely suitable for thermal storage in buildings , liquid-gas PCM experiences a very significant volume change due to the difference of molecular intervals between the liquid and gas , hence in general only solid-liquid PCM is suitable for the normal applications.

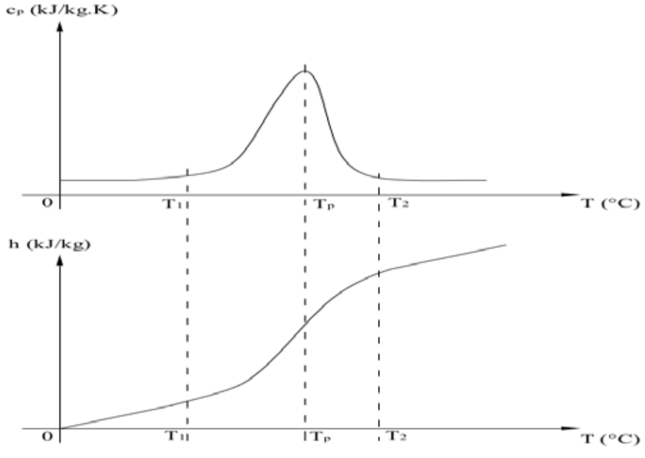

Fig. 1. The specific heat capacity (Cp) - temperature (T) curve, and specific enthalpy (h) - temperature (T) curve of certain PCM.

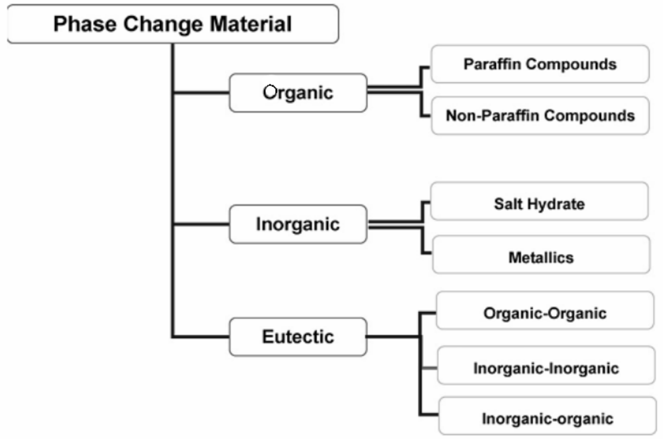

Fig. 2.

TABLE 1

The requirements of PCMs for real applications

| | |
|---|---|
| Thermal requirement | Proper phase change temperature<br>High latent heat storage capacity during phase change process<br>Desirable heat transfer characteristics (eg. good thermal conductivity) |
| Physical requirement | Small volume change during phase change process<br>Low vapor pressure |
| Kinetic requirement | No or limited super cooling<br>Sufficient crystallization rate |
| Chemical requirement | Long term chemical stability<br>Compatible with the storage container or integrated thermal mass<br>No toxicity<br>No fire risk |
| Economical requirement | Plenty of resources<br>Available for application<br>Cost effective for large production |

## 1.2 GENERAL PROPERTIES OF PCM

A phase-change material (PCM) is a substance having a high heat of fusion. It is capable of storing and releasing large amounts of energy. It absorbs heat from the electronic component and melts. It is re-solidified by dissipating heat to the surroundings when device is not functional. PCM preferably be non-poisonous, non-flammable and melting point of the PCM must be in the application Temperature range, small volume change during phase change.

## 1.3 APPLICATIONS OF PCM IN ELECTRONIC COOLING

PCM based cooling system can be implemented or employed in conditions where devices which are not operated continuously over a long period. Like digital cameras, cellular phones, notebook etc.

## 1.4 CURRENT WORK

The present study involves melting of a PCM in a heat sink with internal fins. Constant heat flux is applied to the horizontal base, vertical fins made of aluminum are attached. The study includes unsteady heating and cooling of heat sink consists of fins filled with PCM. Transient numerical simulations are performed using the ANSYS Fluent 14.5 software.

This report consist of literature associated with PCM material area, which includes mathematical modeling and fluent settings associated with this work.

## 2 LITERATURE REVIEW

V. Shatikian, G. Ziskind and R. Letan "Heat accumulation in a PCM-based heat sink with internal fins" In this paper the processes of melting of a phase-change material (PCM), in a heat sink with a constant-heat-flux horizontal base and vertical internal plate fins, have been studied numerically.

V. Dubovsky, E. Assis, E. Kochavi, G. Ziskind and R. Letan "study of solidification in vertical cylindrical shells" This paper the process of solidification of a phase change material (PCM) in cylindrical geometry has been explored numerically

Gong and Arun S. Mujumadar " A transient cooling of electronics using phase change materials " In this paper a well-designed PCM based heat sink for various power levels was investigated experimentally and numerically.

Bogdan M. Diaconu, Szabolcs Vargaand Armando C. Oliveira "Experimental assessment of heat storage properties and heat transfer characteristics of a phase change material slurry for air conditioning applications". In this paper possible applications of the microencapsulated PCM slurry investigated in this paper include cold storage for air conditioning systems with intermittent energy supply such as solar-driven air conditioning systems.

QIU Yifen, JIANG Nan, WU Wei, ZHANG Guangwei and XIAO Baoliang " Heat Transfer of Heat Sinking Vest with Phase-change material" This paper develops a heat transfer mathematical model about heat sinking vest with PCM by enthalpy method. This model can analyze the heat transfer process and calculate the skin heat flow covered with this vest. On the basis of the human thermo regulation model, dynamic temperature distribution and sweat rate of the body wearing the vest are solved.

## 3 PHYSICAL MODEL

The problem is mainly due to the geometry of finned heat sink. In order to reduce the grid size, domain is simplified by imposing periodic boundary condition. The work is progressed in such a way that the performance of fin is computed by several situations such as, fin filled with PCM material with forced convection, fin only. The geometry of heat sink for different configurations were used in this study. The fin only case, fin fully filled with PCM and fin half filled with PCM are are included.

Case-1 Fin only

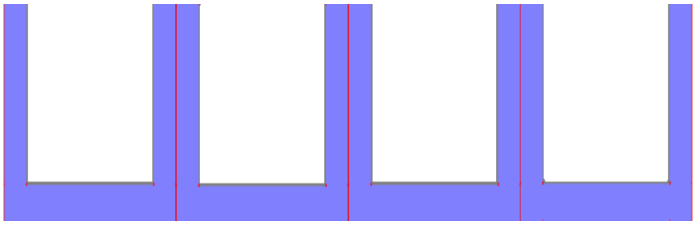

Fig. 3.

Case 2. Fin fully filled with PCM

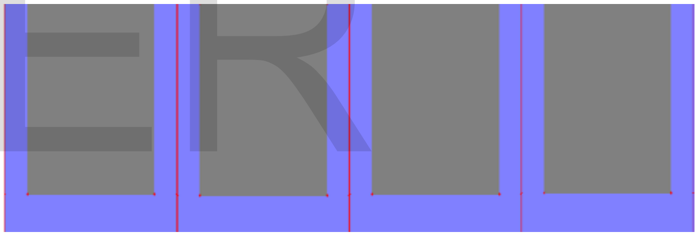

Fig. 4.

Case 3. Fin half-filled with PCM

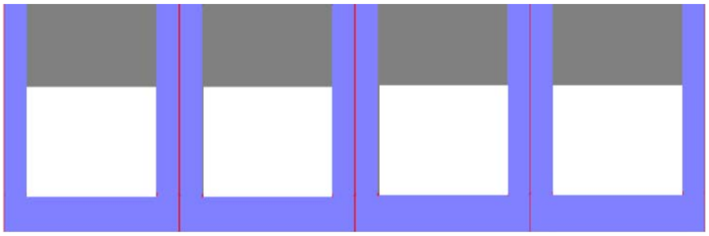

Fig. 5.

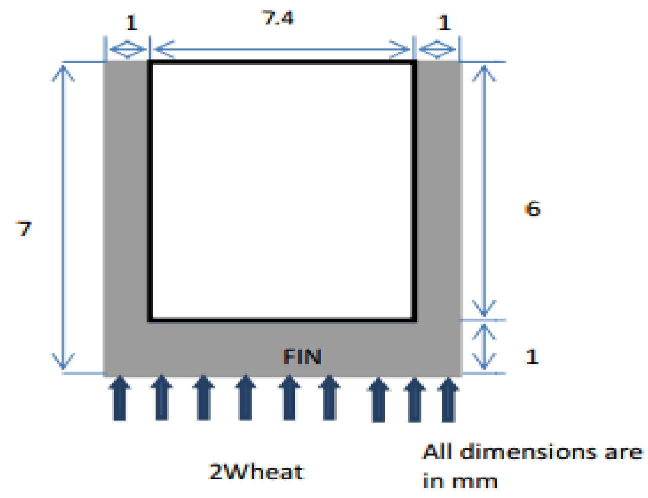

Fig. 6. Translational periodic model of heat sink configuration for forced convection cases.

The figure shows the dimensions of the geometry considered for this study. The all the length presented is in mm. The thickness of fin considered is 2.7 mm and translational periodic condition is applied to mid plane of the fin. Three dimensional study is conducted only for the forced convection cases.

### 3.1 Boundary Condition

Boundary conditions include heat flux value of 200 W/m2applied at bottom of PCM for 3500s heating and 3500s cooling. All other walls are treated as adiabatic shown in fig.4.3 above. The domain interface between PCM and air is considered as wall to avoid the material transfer. The initial conditions set for the entire domain is 180C.

**Heat flux:** The wall at bottom is provided with a heat flux of 200 W/m2.

**Translational periodicity:** The domain is simplified by using translational periodic assumption. The right and left walls are selected as periodic and periodic shadow surfaces.

**Adiabatic wall:** The upper surface and fin tip of PCM are considered as insulated boundary by applying a heat flux value of zero.

**Inlet air velocity:** Different inlet air velocity conditions are applied for various cases.

**Outflow boundary:** The gauge pressure of zero bar is applied for the outlet boundary with a back temperature of atmospheric temperature.

### Initial condition

An initial temperature condition in the domain is set as 18$^{o}$C

### Material

The fin material of aluminum, paraffin wax is used as phase change material and air as fluid for convective cooling.

**Material properties** - In this step, a new material is created and specified its properties, density, including the melting heat, Specific heat, conductivity, solidus temperature, viscosity, and liquidous temperature. Aluminum material for fin, PCM material is paraffin wax and air as forced convection fluid are taken. The settings provide for paraffin wax are provided in the following Table. Specific heat of PCM material is given as a piece wise continuous function of temperature. Material property of Paraffin.

TABLE 2

| Property | Units | Method | Value(s) |
|---|---|---|---|
| Density | kg/m3 | constant | 834.36969 |
| Cp (Specific Heat) | J/kg-K | Piece wise continuous | - |
| Thermal Conductivity | w/m-K | constant | 0.22955 |
| Viscosity | kg/m-s | constant | .0080000004 |
| Melting Heat | J/kg | constant | 70006 |
| Solidus Temperature | °C | constant | 19.04998 |
| Liquidous Temperature | °C | constant | 26.99999 |

TABLE 3

TABLE 4

Material property of Aluminum

| Property | Unit | Method | Value |
|---|---|---|---|
| Density | Kg/m3 | constant | 2719 |
| Cp | J/kg.K | constant | 871 |
| Thermal Conductivity | W/m.K | constant | 202.4 |

### Convergence settings

Momentum, mass and energy equations are monitored and the solution is taken in such a way that the residuals are converged to a value less than 10-6.

### Grid Independence study

Different configurations are made to get a grid independent solution. In the steady 2-D problem the temperature values are plotted for various grid configurations and a grid number of 12500 rectangular grid is selected for the further study. In the case of 3D problems the previously obtained 2-D grid is extruded along flow direction and discretization in the flow direction is accordingly selected. A total number of hexahedral of 625000 element used for 3D analysis.

## 4 NUMERICAL MODELING AND ANALYSIS

### 4.1 Numerical Simulation

FLUENT can be used to solve problems in fluid flow involving solidification and/or melting taking place at a temperature (e.g. in pure metals) or over a temperature ranges (e.g., in binary alloys). Instead of tracking the liquid-solid front explicitly, FLUENT employees an enthalpy-porosity formulation. The liquid-solid mushy zone is treated as a porous zone with porosity equal to its liquid fraction, and appropriate momentum sink terms are added to the momentum equations to account for the drop in pressure caused by the presence of solid material. Sinks are also added to the turbulence equations to account for porosity reduction in the solid regions. FLUENT uses volume control approach to solve the fluid flow problems. In finite volume method, flow domain is discretized into cells and analysis is done by solving governing equations on control points on the cells. The finite volume method represents and evaluates partial differential equations as algebraic equations.

| Temp ºC | 18 | 20 | 22 | 24 | 26 | 28 |
|---|---|---|---|---|---|---|
| Cp | 5352 | 6400 | 7000 | 8067 | 5766 | 5042 |
| Temp ºC | 30 | 32 | 34 | 36 | 38 | 40 |
| Cp | 3808 | 3125 | 2998 | 2960 | 2922 | 2900 |

The instantaneous continuity equation, momentum equation and energy equation for a compressible fluid can be written as:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left[\rho u_j\right] = 0\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Momentum equation

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}\left[\rho u_i u_j + p\delta_{ij} - \tau_{ji}\right] = 0\ldots\ldots\ldots\ldots\ldots (2)$$

Energy equation

$$\frac{\partial}{\partial t}(\rho e_0) + \frac{\partial}{\partial x_j}\left[\rho u_j e_0 + u_j p + q_j - u_i \tau_{ij}\right] = 0\ldots. (3)$$

For a Newtonian fluid, assuming Stokes Law for mono-atomic gases, the viscous stress is given by

$$\tau_{ij} = 2\mu S_{ij}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where the trace-less viscous strain-rate is defined by

$$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{1}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij} \text{ .............................. (5)}$$

The heat-flux, $q_j$, is given by Fourier's law:

$$q_j = -\lambda\frac{\partial T}{\partial x_j} = -C_p\frac{\mu}{Pr}\frac{\partial T}{\partial x_j} \text{.............................. (6)}$$

Where the laminar Prandtl number Pris defined by:

$$Pr = \frac{C_p\mu}{\lambda} \text{.......................................... (7)}$$

To close these equations it is also necessary to specify an equation of state. Assuming a calorically perfect gas the following relations are valid:

$$\gamma = \frac{Cp}{C_v},\ P = \rho RT,\ e = C_vT,\ C_v - C_p = R$$

Where γ, $C_v$, Cp and Rare constant.

The total energy $e_0$ is defined by:

$$e_0 = e + \frac{U_k U_k}{2} \text{........................................ (8)}$$

## 4.2 Favre Averaged Equations

It is not possible to solve the instantaneous equations directly for most engineering applications. At the Reynolds numbers typically present in real cases these equations have very chaotic turbulent solutions, and it is necessary to model the influence of the smallest scales. Most turbulence models are based on one-point averaging of the instantaneous equations. The averaging procedure will be described in the following sections.

Let φ be any dependent variable. It is convenient to define two different types of averaging of φ:

Classical time averaging (Reynolds averaging)

$$\overline{\Phi} = \frac{1}{T}\int \phi(t)\, dt \text{.................................. (9)}$$

$$\phi' = \phi - \overline{\Phi}$$

Density weighted time averaging (Favre averaging):

$$\widetilde{\Phi} = \frac{\overline{\rho\Phi}}{\overline{\rho}} \text{................................................ (10)}$$

$$\Phi'' = \Phi - \widetilde{\Phi}$$

Note that with the above definitions, but

And but $\varnothing \neq 0$

## 4.3 Solidification Modeling

FLUENT can be used to solve fluid flow problems involving solidification and/or melting taking place at one temperature (e.g., in pure metals) or over a range of temperatures (e.g., in binary alloys). Instead of tracking the liquid-solid front explicitly, FLUENT uses an enthalpy-porosity formulation. The liquid-solid mushy zone is treated as a porous zone with porosity equal to the liquid fraction, and appropriate momentum sink terms are added to the momentum equations to account for the pressure drop caused by the presence of solid material. Sinks are also added to the turbulence equations to account for reduced porosity in the solid regions.

The enthalpy of the material is computed as the sum of the sensible enthalpy, h, and the latent heat, H:

$$H = h + \Delta H \text{...................................................... (11)}$$

Where

$$h = h_{ref} + \int_{Tref}^{T} Cp\, dT \text{.....................................12)}$$

And $h_{ref}$= reference enthalpy

$T_{ref}$=reference temperature

$Cp$=specific heat at constant pressure

The liquid fraction, β, can be defined as.

$$\beta = 0 if T < T_{solidus}$$

$$\beta = 1 if T < T_{liquiduss}$$

$$\beta = \frac{T - T_{Solidus}}{T_{liquidus} - T_{Solidus}} if T_{solidus} < T < T_{liquidus} \text{...... (13)}$$

The latent heat content can now be written in terms of the latent heat of the material:

### 4.4 Analysis Procedure

The modeling of flow domain has been completed using geometry and mesh building software, GAMBIT. General sequence of operation involved is:

| Model | Settings |
|---|---|
| Space | 2D/3D |
| Solver | Pressure based |
| Time | Steady / Unsteady, 1st-Order Implicit |
| Viscous | Laminar |
| Heat Transfer | Enabled |
| Solidification and Melting | Enabled |

1) Create full geometry and decompose into mesh able sections.
2) Give meshes required.
3) Continuum and boundary attachment.
4) Export Mesh.

Analysis is done using FLUENT software. General sequence of operation involved is:

1) Importing grid.
2) Checking grid.
3) Setting units.
4) Define solver properties (steady, unsteady, 2D/3D etc.).
5) Define Model (Solidification and heating , turbulent properties)
6) Define material properties (density, viscosity variation etc.).
7) Define operating conditions.
8) Define boundary conditions.
9) Initialization.
10) Setting convergence criteria.
11) Iterating until the solution converges.

### 4.5 Fluent Settings

Geometry is created using GAMBIT. Two dimensional model is created. Discretization is done by using mapped quad mesh with boundary layer on solid fluid interface. Gambit file is exported as .mesh format. The settings of ANSYS Fluent 14 for numerical solution are listed in this section. The discretized geometry is imported into Fluent. Fluent will perform various checks on the mesh and will report the progress in the console. It is needed to make sure that the minimum volume is a positive number. The imported grid is checked and proper scaling is done. The required units are selected.

#### 4.5.1 General settings

The general settings such as solver settings, details of temporal discretization, properties of materials and equations required solving and additional physics required etc. are selected depend on the problem.

TABLE 5

Shows the basic solver settings provided.

## 5 RESULTS AND DISCUSSION

### 5.1 Introduction

The result from the various analysis is reported in this chapter. The various cases such as fin only, fin fully filled with PCM with forced convection etc. are reported one by one. The characteristics of PCM on cooling and heating are analyzed and discussed. The cases with different velocity boundary conditions are compared and a strategy of intermittent use of convective heat transfer is made. The grid, boundary conditions, geometry and numerical settings adopted etc. are discussed in the previous chapters. The results are presented in the form of contours of temperature, liquid fraction and heat transfer coefficient

Heat sink with fin only

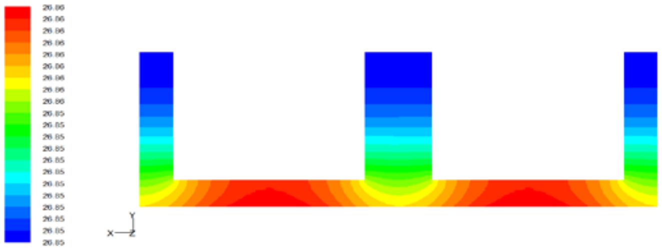

Fig. 7. Temperature (oC) contour at 300 s time In this case an unsteady simulation is carried out. The temperature contour at 300 s is shown in the figure 5.1. The maximum temperature along the heat sink with time is plotted in the figure. Since the walls are adiabatic the supplied heat flux increases the temperature linearly. From the temperature contour it is clearly visible that the isothermal lines are perpendicular with the adiabatic walls. A temperature increase in the rate of 0.03 unit.

### 5.2 The heat Sink with Fin Fully Filled with PCM

In this case an unsteady analysis is carried out for the heat sink with fully filled PCM. Boundary conditions includes heat flux value of 200W/m2 applied at bottom of PCM for 3500s heating and 3500s cooling. All other walls are treated or assumed to be as adiabatic walls. Domain interface between PCM and air is considered as wall to avoid the material transfer. The initial condition set for entire domain is 180C. The time at which entire PCM changes to liquid is find out (liquid fraction becomes one). The cooling is also studied by the implementation of reversing of heat flux direction. The temperature characteristics at various location of the computational domain is studied. The characteristics on PCM material on cooling and heating process is analyzed. It is observed that for a time of 53 minute the temperature of the domain can be controlled by PCM. At around 3200 sec the entire PCM is melted and further accommodation of heat in the PCM is not possible. After that period the domain temperature increases linearly.

| Location | Notation |
|---|---|
| Base of fin | P1 |
| Geometric center of PCM | P2 |
| Top of PCM | P3 |

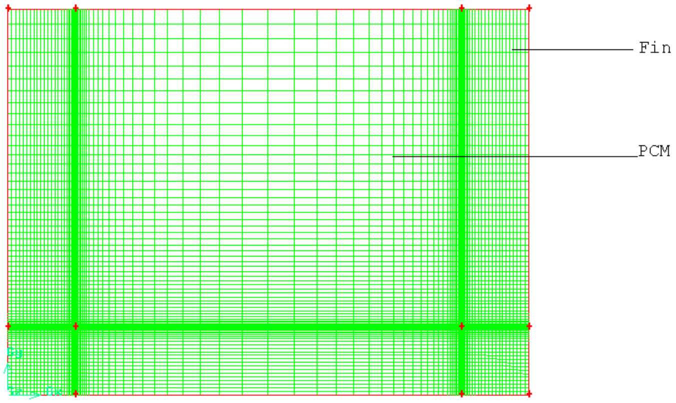

Fig. 8. Grid used for fin with fully filled PCM

### 5.2.1 Maximum Temperature change with time

The below figure shows the temperature verses time graph in both heating and cooling step for different locations P1 and P2 as in the fig

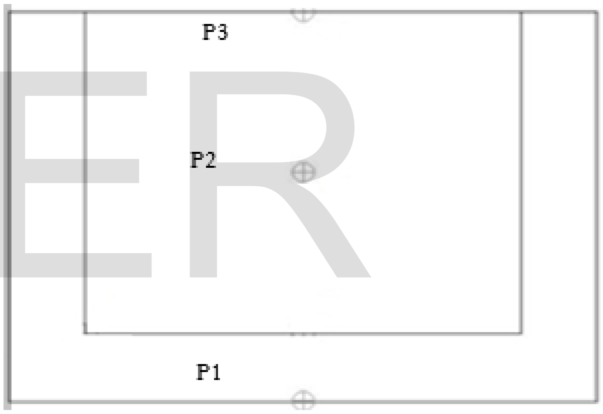

**Fig. 9.**

Table 6

The different location selected for temperature comparison the figure shows the temperature variation with time for different locations as mentioned in figure. The variation in the slop indicates the presence of PCM up to 3200 sec. The specific heat of PCM various with temperature, hence at time above 100s the PCM start phase change and which is having large heat storage capacity. After complication of the phase transformation the heat storage capacity becomes linear in nature. In the cooling process the pcm material releases heat energy and transformed into solid phase.

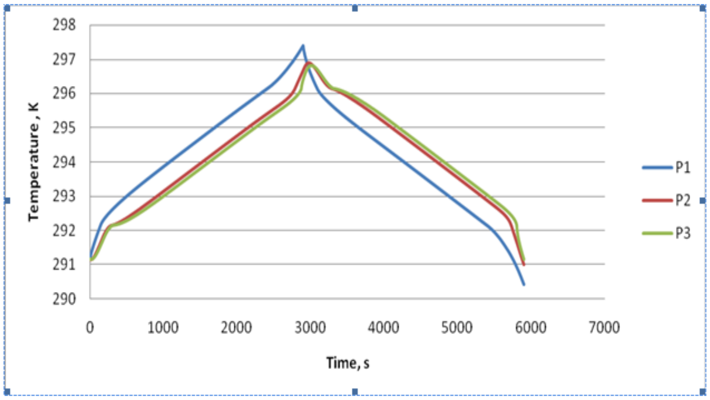

Fig. 10. Temperature variation with time for different locations considered.

Contours of Temperature at various T1 Figure shows the contours of temperature and liquid fraction at 500 sec in the fin with fully filled PCM configuration. The PCM in solid face started liquefying near the interface region. The corner portion liquid for because of the large interface area in the corner region. The temperature contour is seems to be perpendicular to the top wall of the PCM, indicate an insulated boundary condition. The maximum temperature reaches at 19.10C at 500 sec.

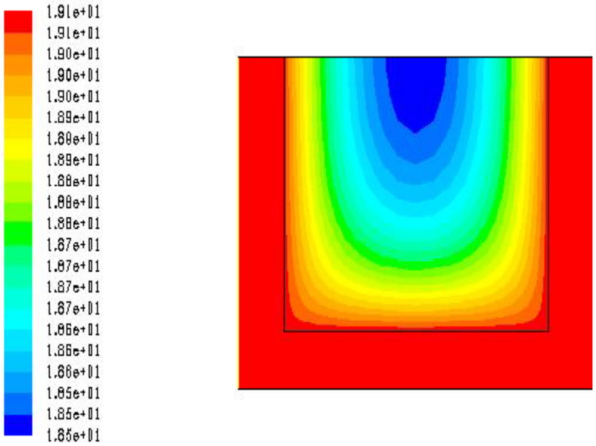

Fig. 11.

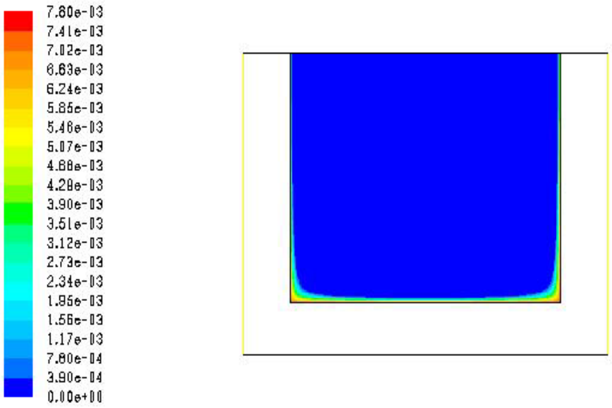

Fig. 12.

Figures. Contours of temperature and liquid fraction at 500 sec Figure shows the contours of temperature and liquid fraction at 2200 sec in the fin with fully filled PCM configuration. Above 50% volume of PCM is having a liquid fraction more than 0.5. The maximum temperature reaches at 22.60C at 2200 sec.

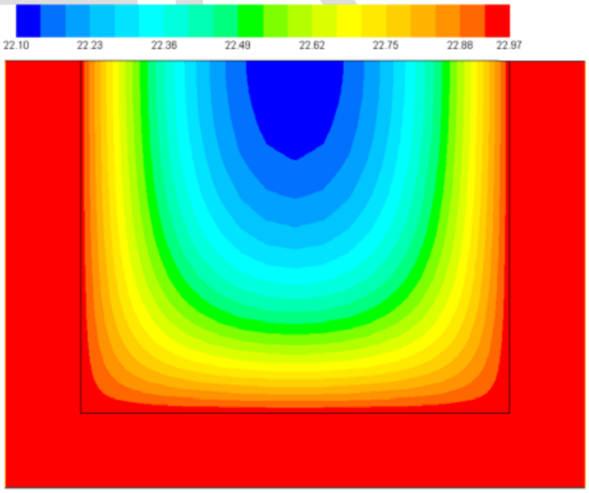

Fig. 13.

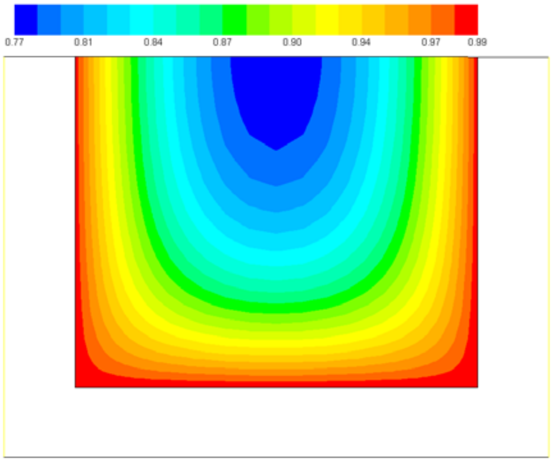

Fig. 14. Contours of temperature and liquid fraction at 2200 sec

Figure shows the contours of temperature and liquid fraction at 3500 sec in the fin with fully filled PCM configuration. It can be seen that the minimum temperature in the PCM domain is 25.20C (above the melting limit) and hence the entire portion of PCM is converted in to liquid and at/after that the variation in the temperature of system changed linearly.

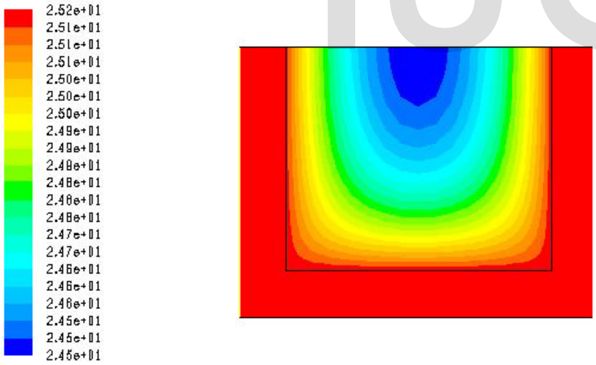

Fig. 15.

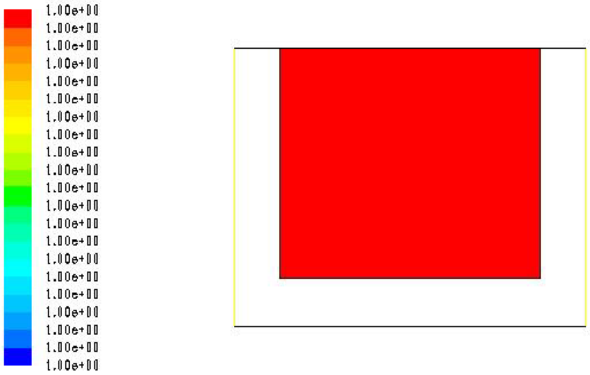

Fig. 16. Contours of temperature and liquid fraction at 3500 sec

### 5.3 Heat sink with fin half filled with PCM

In this section the result of the half- filled PCM with forced convection is studied in detail. The domain created is three dimensional. The figure shows the transitional periodic model of grid used for this study.

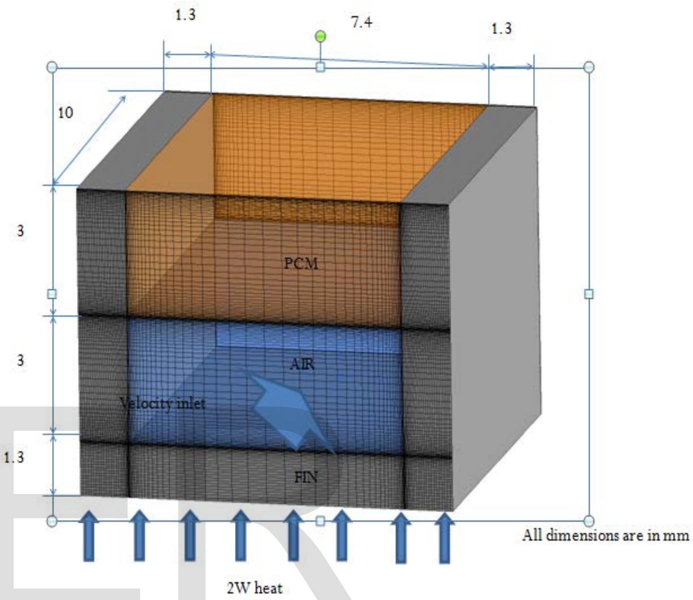

Fig. 17. Computational domain used for half-filled PCM with forced convection

The below figure shows the velocity vector in a cross-sectional plane for an inlet air velocity of about 0 m/s. A natural convection phenomena can be seen. The flow direction indicates two major loop which meets at the central portion of the domain with a high velocity magnitude. There exist 4 small loops along the corner portion of plane. The maximum velocity of air is reached at about 0.15 m/s due to the buoyant force.

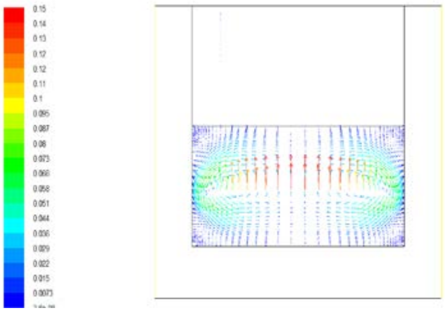

Fig. 18. Vector of the cross-section on air flow for an inlet velocity of zero.

The velocity vector on the cross section of air flow domain is depictured in the figure below shows two recirculation loops. A temperature driven with a maximum velocity of 0.14 m/s is obtained in the flow.

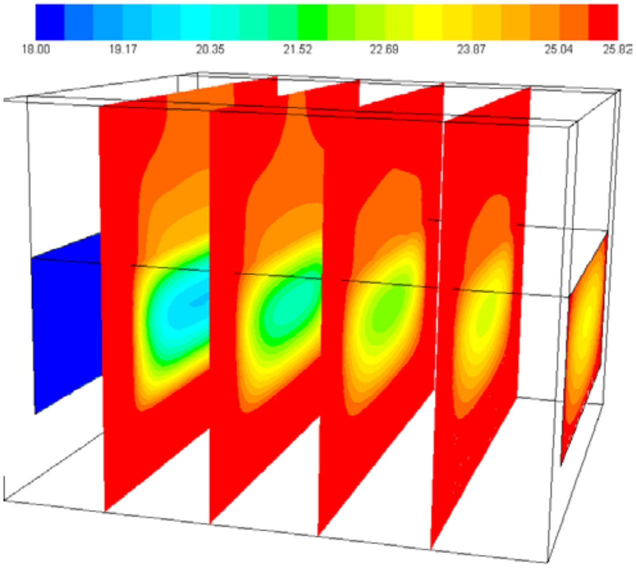

Fig. 19. Air inlet velocity = 10 cm/s

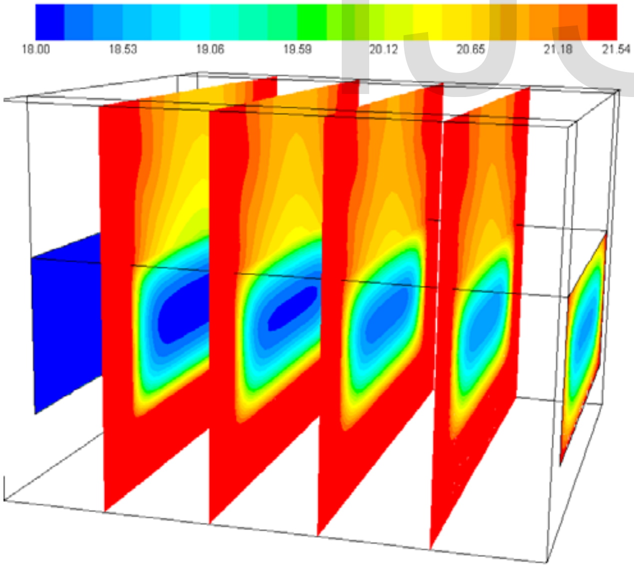

Fig. 20. Air inlet velocity = 50 cm/s

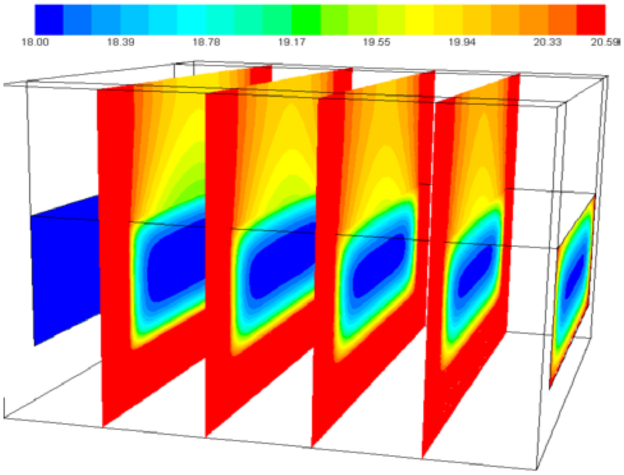

Fig. 21. Air inlet velocity = 100 cm/s

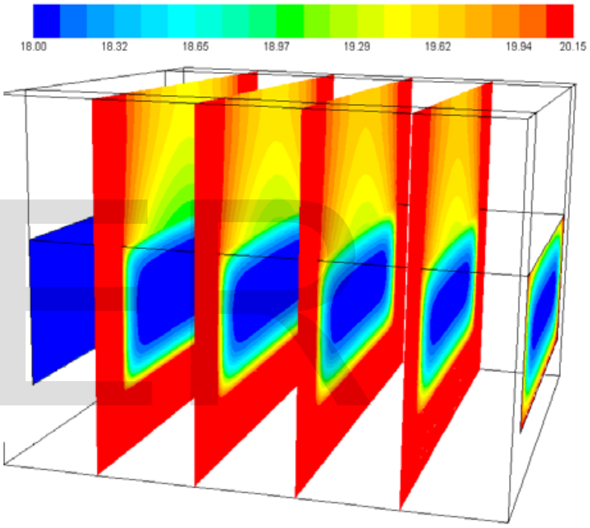

Fig. 22. Air inlet velocity = 150 cm/s

Temperature contour at locations of inlet, 2,4,6,8 mm from inlet, outlet plane.

In the case of the forced convection flow, steady flow analysis is carried out for an inlet velocity of about 0.1 m/s- 2 m/s. The Figure below shows the temperature and liquid fraction for various inlet velocity at various axial locations such as 2, 4, 6, 8 mm from inlet and outlet boundary. It can be noted that the air becomes hot as it flow through the path. As the flow velocity increases the maximum temperature is reduced.

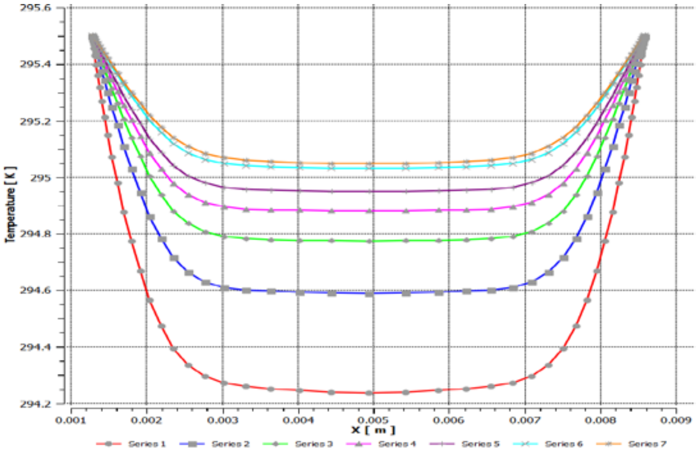

Fig. 23. Temperature at the interface between PCM and air at different axial location 1,2,3,4,5,6,7 mm from inlet for air velocity of 10cm/sat 7 mm from the inlet.

Figure below shows the temperature plot at the interface region of PCM and air at various axial locations series1 from 1mm from the inlet and series7 locations. Heat transfer is maximum at inlet region of the flow. In the figure below mass flow averaged temperature of the outlet for different velocities are plotted. It can be noted that increasing of velocity above 1.5 m/s doesn't give any further temperature change (reduction) in the system. The velocity vs liquid fraction plotted in the figure below also proves this point. If the velocity range is above 1.5 m/s the change in liquid fraction with velocity is less.

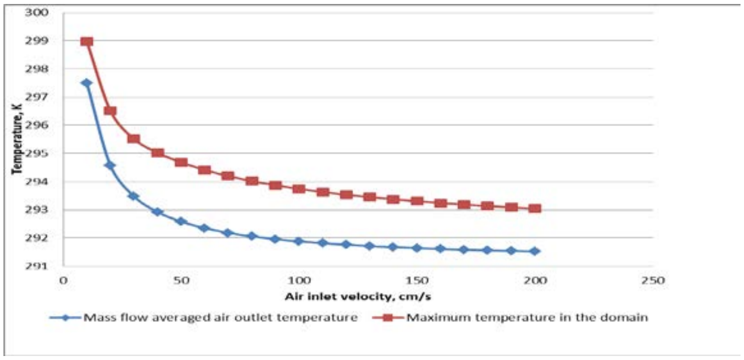

Fig. 24.

Mass flow averaged and maximum temperature in the domain for different axial velocities

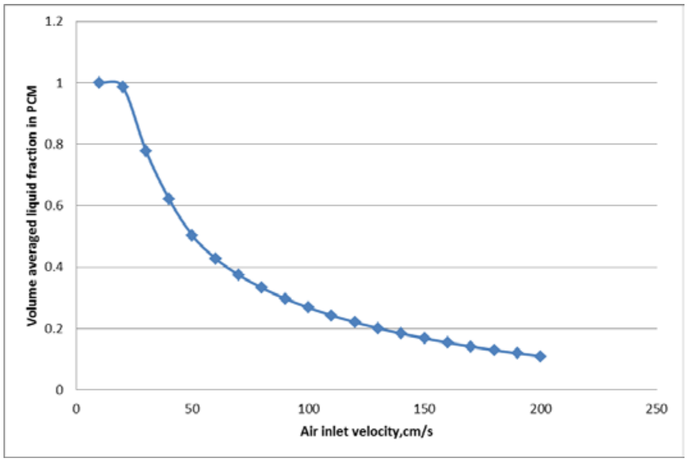

Fig. 25. Volume averaged liquid fraction for various axial velocities

The unsteady analysis is done for various velocity inlets. Initially the analysis is carried out for a time up to volume averaged liquid fraction of one with zero velocity at inlet. Later various analyses for various velocities are carried out by using the first result. Figure (a) and (b) shows the minimum domain temperature and liquid fraction of PCM along with the time. The effect air velocity up to 0.2m/s is considered as negligible and further increase in velocity stabilizes the temperature and liquid fraction.

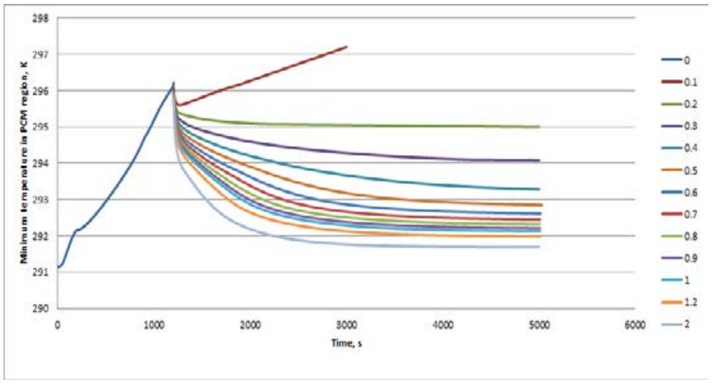

Fig. 26. Minimum temperature in PCM region with time for different inlet velocity (m/s).

| LF % | 0.8 m/s | 1.0 m/s | 1.2 m/s | 1.4 m/s | 1.6 m/s | 2.0 m/s |
|---|---|---|---|---|---|---|
| 20 | - | - | - | - | 3800 | 2000 |
| 30 | - | - | 3000 | 1800 | 1400 | 1000 |
| 40 | 3800 | 1800 | 1300 | 1020 | 880 | 700 |
| 50 | 1500 | 1050 | 830 | 700 | 630 | 500 |

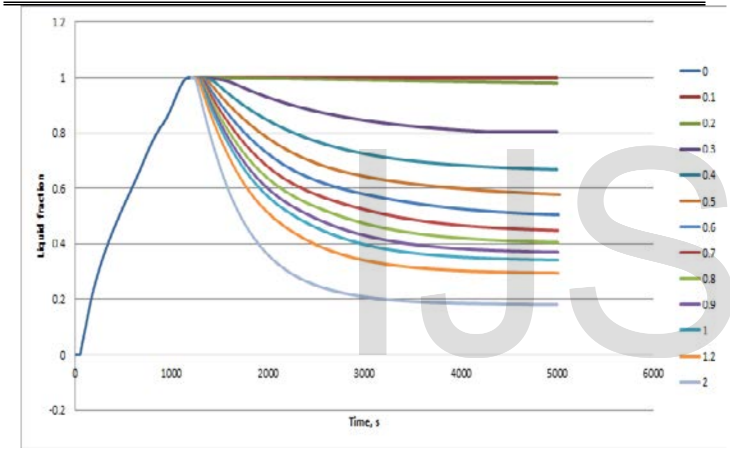

Fig. 27. Liquid fraction in PCM region with time for different inlet velocity (m/s).

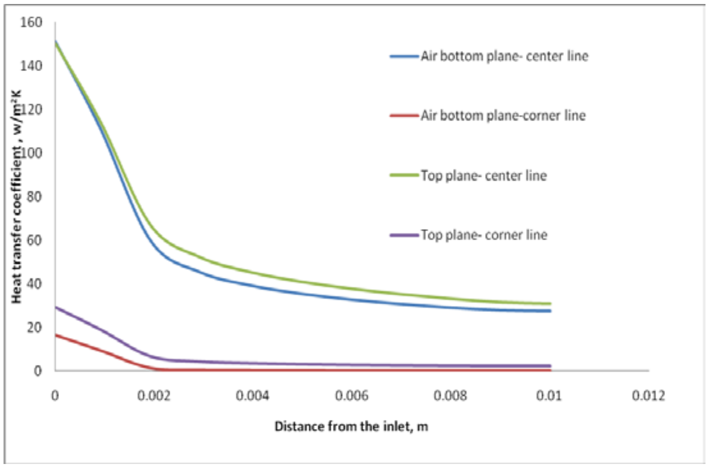

Fig. 28. Heat transfer coefficient along the flow direction for an inlet velocity of 1m/s

Heat transfer coefficient along axial distance at various locations is shown in figure. The heat transfer coefficient at the center location of the air flow passage is higher than that at the corner locations. The top air PCM interface is having higher than that at bottom air fin interface. This is due to the difference in temperature gradients in their corresponding locations.

TABLE 6.

Time requirement for solidification for different inlet velocities

The time requirement for controlling the temperature of the PCM to various liquid fraction levels for various air inlet velocity is listed in the Table below. Based on the usage of the device the air flow velocities can be varied as per the requirements. From the tabular result it is clear that to obtain a liquid fraction of 20 % it is necessary to set a minimum air velocity of about 1.6 m/s similarly for 30% liquid fraction it is about 1.2 m/s. Increasing velocities above 1.6m/s gives only a very small improvement in the performance. Hence these results can be used as an easy-to-use design guidance line for the PCM based heat sinks, in terms of the forced convective conditions.

## 6. CONCLUSIONS

The PCM based cooling techniques have a great potential application in electronic devices. In this work study and analysis of PCM based heat sinks are carried out. Numerical analysis is done by using FLUENT 14.0. The works includes the study on characteristics of PCM and its applications are carried out. Here we conducted three configuration of heat sinks such as fin filled with PCM material, fin filled with half PCM material, fin only .The characteristics of Heat sink with PCM is analyzed in both melting process and solidification and find out the time in which PCM controls temperature up to 2400s for full filled PCM. Performance of heat sink for continuous operation is carried out for different air flow conditions. The time requirements for control the temperature of PCM for different forced convection conditions to various liquid fraction levels are tabulated, which can be used as an easy-to-use design guide line for PCM based heat sinks with forced convection.

## ACKNOWLEDGEMENT

We the authors would like to thank Dr Farukh Sayeed, Principal, ACE College Of Engineering for his kind co-operation and support for completing this journal. We would also like to thank the coordinators of IDEAS 2016 conducted by UKF College of Engineering And Technology.

## REFERENCE

1. V. Shatikian, G. Ziskind, R. Letan, Numerical investigation of a PCM-based heat sink with internal fins, International Journal of Heat Mass Transfer 48, 3689-3706,2005
2. V.Dubovsky,E.Assis,E.kochavi,G.Ziskind and R.Letan,Study of solidification in vertical cylindrical shells, International Communications in Heat and Mass Transfer 34 (2007) 62–71
3. Gong and Arun.S. Mujumdar, A transient cooling of electronics using phase change materials,ASME Journal of Solar Energy Engineering 117, 215-220, 1995.
4. Bogdan M. Diaconu [a,b,*], Szabolcs Varga [a], Armando C. Oliveira [a] Experimental assessment of heat storage properties and heat transfer characteristics of a phase change material slurry for air conditioning applications, Applied Energy 87 (2010) 620–628
5. X. Duan, G.F. Naterer, Heat transfer in phase change materials for thermal management of electric vehicle battery modules, Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada.
6. QIU Yifena, JIANG Nanb, WU Weia, ZHANG Guangweia, Heat Transfer of Heat Sinking Vest with Phase-change Material,China Aerospace Life-support Industries, Ltd., 2011.
7. Paisarn Naphon, Laminar convective heat transfer and pressure drop in the corrugated channels, International Communications in Heat and Mass Transfer 34 (2007) 62–71
8. Mónica Delgado*, Ana Lázaro, Javier Mazo, José María Marín, Belén Zalba, Experimental analysis of a microencapsulated PCM slurry as thermal storage system and as heat transfer fluid in laminar flow, Applied Thermal Engineering 36 (2012) 370-377
9. Mohammad M. Mansoor , Kok-Cheong Wong , Mansoor Siddique, Numerical investigation of fluid flow and heat transfer under high heat flux using rectangular micro-channels, International Communications in Heat and Mass Transfer 39 (2012) 291–297
10. S V. Garimella, A Novel Hybrid Heat Sink using Phase Change Materials for Transient Thermal Management of Electronics, (2005). CTRC Research Publications. Paper 66.
11. R. Kandasamy, X.Q. Wang, A.S. Mujumdar, Application of phase change materials in thermal management of electronics, Applied Thermal Engineering, in press, 2006.
12. B. Zalba, J.M. Marin, L.F. Cabeza, H. Mehlin, Free-cooling of building with phase change materials, International Journal of Refrigeration 27 (2004) 839–849.
13. S. Krishnan, S. Garimella, S. Kang, A novel hybrid heat sink using phase change materials for transient thermal management of electronics, in: Proceedings of 2004 Inter Society Conference on Thermal Phenomena (ITHER M04), 2004, pp. 310–318.
14. X.-Q. Wang, C. Yap, A.S. Mujumdar, Cyclic melting and freezing heat transfer using paired phase change materials, in: B. Thorat, S.Devahastin, G. Chen (Eds.), Topics Heat and Mass Transfer, 2004.
15. R. Akhilesh, A. Narasimhan, C. Balaji, Method to improve geometry for heat transfer enhancement in PCM composite heat sinks, International Journal of Heat and Mass Transfer 48 (13) (2005)2759–2770.
16. A.Brent, V.Voller, K. Reid, Enthalpy-porosity technique for modeling convection diffusion phase

change: application to the melting of a pure metal, Numerical Heat Transfer, Part A 13 (1988)297–318.

17. R. Reid, J. Prausnitz, B. Poling, The Properties of Gases and Liquids, McGraw-Hill, New York, 1987.
18. Inaba H, Zhang Y, Horibe A. Numerical simulation of natural convection of latent heat phase-change-material micocapsulate slurry packed in a horizontal rectangular enclosure heated from below and cooled from above. Heat Mass Trans 2007; 43:459–70.
19. Bhattacharya M, Basak T, Ayappa K G. A fixed-grid finite element based enthalpy formulation for generalized phase change problems: role of superficial mushy region. International Journal of Heat and Mass Transfer 2002, 45(24): 4881-4898.
20. Voller V R. Fast implicit finite-difference method for the analysis of phase change problems. Numerical Heat Transfer Part B: Fundamental 1990, 17(2): 155-169.
21. ZengY, Tian H Z, Yu P, et al. The study on effective heat transfer coefficient in the math model of energy storage system with solid-liquid phase change by theory and experiments. Fluid Machinery 2002, 30(6): 44-48.
22. Costa M, Buddhi D, Oliva A. Numerical simulation of latent heat thermal energy storage system with enhanced heat conduction. Energy Conversion & Management1998, 39(3-4): 319-330.
23. Azeem Anzar , Shine.k
    Transient Thermal Analysis of Phase Change Material Based Heat SinksEISSN: 2319-1163/pISSN: 23(703-714).