

Melting And Simulation of 2-D Rectangular PCM Domain Having Two Side Constant Heat Flux and Other Two Side Insulated Using Ansys Fluent

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Abstract: In this paper we study and analyses the behavior of thermal energy storage using phase change material (PCM). This paper represents the numerical study and simulation of a phase change material using analytical software. The melting of a rectangular 2-D domain (100mm*150mm) whose left and top side is insulated and other two side bottom and right side is perfectly insulated is simulated by ANSYS FLUENT 19.0 software. The assumption, material properties, equations that uses the ANSYS software is discussed in this paper, mainly energy equations uses the enthalpy equation in ANSYS software. In enthalpy equation both sensible and latent energy is used to melt the PCM. The contour of liquid fraction, temperature, density and velocity of a two side PCM rectangular domain at a regular interval of a 15 minutes is represented a total melting time of a 120 minute (2 hours). With the help of a contour we can find the change of shape and motion of melting interference with increase in time. The PCM started to melt after heat flux given and it melts 12% in 15 minutes. It takes 120 minutes to complete melting of PCM rectangular domain. A mushy zone that separates the solid PCM and liquid PCM. This paper represents the % of melting of rectangular domain with respect to the increase in time.

Keywords – phase change material (PCM), Thermal energy, Heat flux

1.1 Introduction

Energy storage is great importance in modern days. In old days and a present we are using conversional energy sources like fossil fuels such as natural gases, petroleum, coal, but they are very limited in our resources, and they will be consumed very fast rate. Fossils fuel are harmful and polluted of environment. One of the most problem in fossil fuel are high cost, oil security, and emission of green houses. They are produce large amount of carbon dioxide and they will produce greenhouse emission. The other alternative of fossil fuel is renewable energy sources like sun, wind, geothermal, ocean. Solar energy has high potential energy and best option of alternative energy sources. Solar energy has constant heat flux 1000 w/m^2 and have enough power to give total world energy. In 2016, 16% of world energy produce by solar energy. The main

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demerit of solar energy is they are intermittent energy sources and use only when they are available. So we need a device that store the energy to utilise further, one of the most prospective technique of storing thermal energy (latent heat) is the application of phase change material. Thermal energy storage reduces the mismatch between supply and demand, and also improve the performance and reliability of energy system and also useful for energy conservation and storing.

Thermal energy storage has high potential and most widely used technology. It can store excess energy and utilise it later whenever needed, it is the bridge of supply and demand b/w day and night time. Energy storage system has increase the effectiveness of energy system, Thermal energy system benefits are: (a) It can reduce energy cost (b) Reduce energy consumption (c) More efficient and effective utilisation of equipment (c) Reduce the size of system (d) Lower the maintenance cost

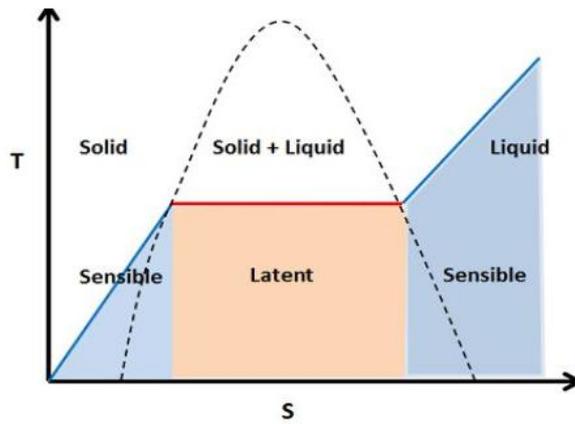


Figure 1.1 heat storage during phase change material

Sensible Heat Storage: In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid or gas. Sensible heat storage system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature changes and the amount of storage material

$$Q = \int_{t_i}^{t_f} mc_p dt = m c_p (t_f - t_i)$$

Latent Heat Storage: Latent heat storage (LHS) is heat storing or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. Latent heat storage is store the energy at constant temperature and store large amount of energy. Latent heat storage limited range of smooth temperature variation, because The change of phase change takes place limited time. It depends on the specific heat of the medium, temperature change, and amount of storage material.

$$Q = \int_{t_i}^{t_f} mc_p dT + mL + \int_{t_i}^{t_f} mc_p dT$$

There are three types of phase change (a) Solid-liquid: This phase change process is an isothermal process, and usually there is a small volume difference between the two phases. (b) Liquid-gas: this phase change process occurs when the large amount of heat is supplied to the system. (c) Solid-solid: this is found to be very less in nature only a few material undergoes to change molecular structure. in this phase change process very less amount of latent heat store. The main three components that have important to latent heat storage system are (i) PCM have melting point and desire temperature range (ii) System have a heat exchanger (iii) System have phase change material container. Latent heat storage is more attractive than sensible heat storage because of high heat storage density with smaller temperature swing.

Phase Change Material: Phase change material are absorbed large amount of latent heat during phase change. It absorbed energy during solid-liquid phase transformation and release heat during liquid to solid phase transformation. Phase change material maintain the temperature nearer the melting point. Generally, phase change absorbed latent heat storage.

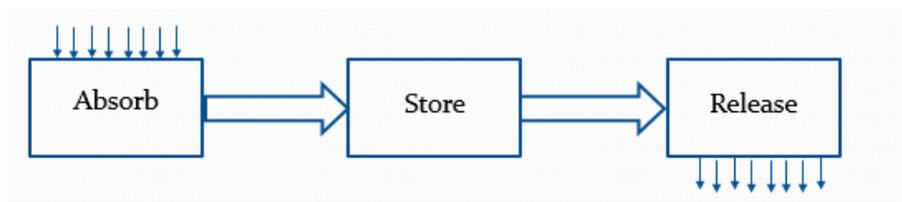


Fig 1.2 block diagram of phase change material

There are variety of PCM available in our markets, but more efficient, that follow the physical and chemical properties. they are : Energy density of the

material., Latent heat of fusion., Ratio of latent to sensible heat capacity, Solidus and Liquidus temperature, Thermo-physical properties : High

thermal conductivity of both phases, Small volume Change in phase transition, Repeatable phase change cycle, large latent heat release and absorption., Large amount of sensible heat per unit volume, Phase change temperature within the range of system. Chemical properties- Reversible solidification/melting process, Non-flammable, non-

toxic, No chemical degradation with number of cycles and Non-corrosive properties

1.2 Classification of Phase Change Material

There are variety of phase change material present in market, they are classified as and they are,

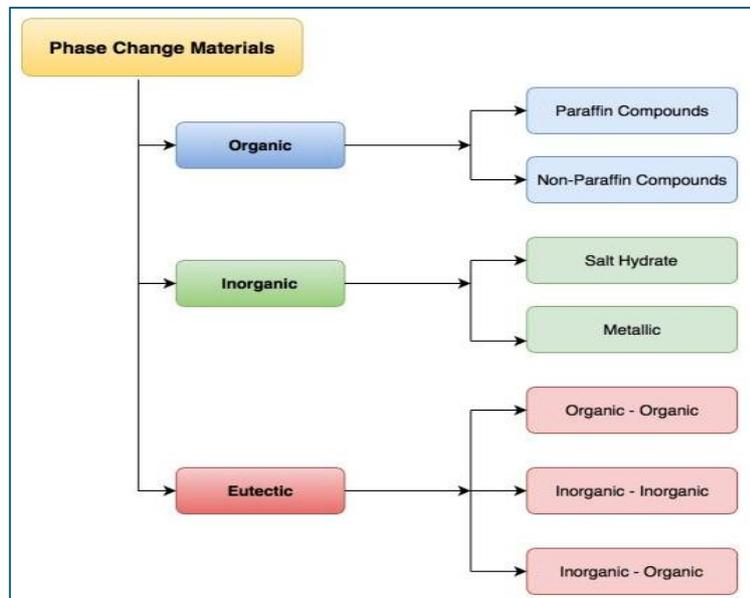


Figure 1.3 classification of PCM

Many application of phase change material is available. They are in the basis of their large amount of latent heat of fusion and storage. In general phase change material are classified on the basis of low temperature and high temperature application. In low temperature melting of phase change material is below 20⁰ C. application of low temperature phase change material are solid food and beverages, pharmaceutical products, electronic circuits, spacecraft, air conditioning and industrial refrigeration. Water is one of the most used substances for low-temperature application due to its properties like low cost, high thermal conductivity, long stability and no toxicity. PCM in Space Craft Heating Application: In recent research and development phase change material is use for space craft system in the area of heat removal and dissipation, the applicable technologies for spacecraft are high thermal conductivity materials, high heat transport devices such as fixed conductance heat pipes, loop heat pipes etc. The simplest form of PCMs thermal control for electronic components is the one that is used for short-duty cycle components in launch or reentry

vehicles. During this process, there is a large amount of heat generated which has to be extracted to avoid over-heating and subsequent failure of the electronic components. This generated heat is absorbed via latent heat of fusion by the PCMs without an appreciable temperature rise of the components. Some application of PCMs in spacecraft are: (a) Using the thermal energy to generate power (b) Improve the efficiency of radiator system and fluid-loop (c) Accurate the dimensional stability (d) Micro/Nano satellite.

PCM Using in Solar Water Heater: in solar water heater is a device that we can used to the water in domestic and industrial purpose. The solar water heater generally it takes heat form solar radiation and utilise the solar heat 40-60% of water in home application likes kitchen, bathroom and industry. Solar water is generally low thermal efficiency to increase the thermal efficiency we can use phase change material (PCM). Paraffin wax type PCM generally we can used in solar water heater. The storage tank utilizes small cylinder which is made by

aluminium. And filled by paraffin wax as the heat storage tank. Fig 1.3 shows the schematic diagram of a sensible latent heat storage unit, it consists of a flat plate solar collector, a cylindrical latent heat storage unit, a circulating pump and pipe. When sun

is shining solar heat is absorbed by heat transfer fluid in the flat plate solar collector, and then hot water is passes through latent heat storage unit (LSHU). In LSHU heat is absorbed and store by the PCM, here HTF is glycol, water, etc.

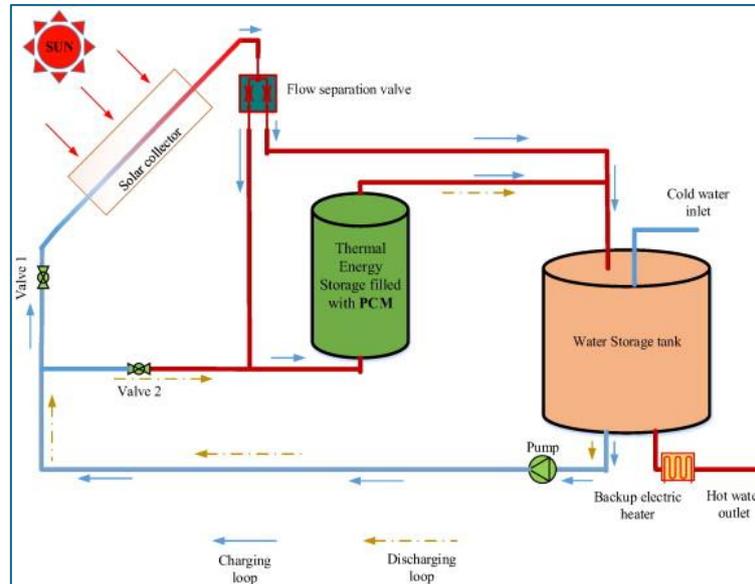


Figure 1.4 solar water heater

PCM in Building Heating: For heating and cooling of building we can use the phase change material for store large amount of latent heat. The application of PCMs in buildings can have two different goals. First, using natural heat that is solar energy for heating or cooling. Second, by using a heat source or sink. Storage of heat is necessary to match the availability and demand with respect to time and with respect to power generated. Mainly two ways to use PCMs for building application : Phase change material in building wall and Phase change material PCMs in heat and cold storage unit example- air conditioner

PCMs can be used to store cold for air conditioning applications, where cold is collected and stored from ambient air during the night, and it is released to the indoor ambient during the hottest hours of the day. This concept is known as free-cooling. PCM having melting temperature above 70 degrees Celsius can be used for the high temperature storage units. The classification of high temperature as the melting temperature of Erytritol PCM is around 120 degrees Celsius. In high temperature PCM is heated by the stove pipe of wood stove to store is to attach this PCM on the walls of wood stove to store heat. The studied

thermal analysis of a novel thermal energy storage based on high-temperature phase change material to improve efficiency in waste-to-energy plants. The study was carried out by replacing the typical refractory brick installed in the combustion chamber with a PCM-based refractory brick capable of storing a variable heat flux and to release it on demand as a steady heat flux. It showed that there was an increase in efficiency up to 34 % from the conventional waste energy

1.2 Literature Survey

Md. Abdullah et al [1] is doing experimentally work where left side wall of rectangular domain(PCM) is given heating surface and other three wall is insulated and investigate the melting time of Phase change material. B. Kamari et al [2] found and investigate experimental study, PCM melting was quantified by visually tracking the shape of the liquid-solid interface and how it changed with time has rectangular side 5 cm width and 12 cm height shape of contour with time. N. Nallusary et al [3] is working experimentally the thermal behavior of energy storage system of a combined sensible and latent heat (TES) unit. They find charging and discharging experiment of varying and constant solar energy as inlet fluid and find the flow rate of

heat transfer fluid on the performance of the storage tank. Jaya Krishna et al [4] is studied the behavior of phase change material like (stearic acid, paraffin wax, meryster acid) based on melting temperature, thermal conductivity, thermal stability, structural stability, specific heat, life span of various phase change material (PCM) is predicted. Also discussed the increase in thermal efficiency with PCM with respect to the conventional solar water heater. Anant Shukla et al [5] is using organic phase change material and studied latent heat storage is more efficient than others. The better thermal efficiency of solar water heater system is using large amount of latent heat and large surface area. The organic phase change material we used are paraffin wax. Emim el et al [6] is used inorganic phase change material and compare simple solar water system to the solar water heater using phase change material and compare their thermal efficiency. The solar water heater using phase change material is more efficient then the simple. and also heat loss is very less. Yong Wang et al [7] is investigate exergy efficiency and thermal storage efficiency and that can be calculated by varying mass flow rate and solar collector area. The phase change used is paraffin wax. The best result obtained is 0.28 kg/s in mass flow rate and solar collector area is 2 m². S D Sharma et al. [8] conducted experiment to study the change in latent heat of fusion, melting temperature and specific heat of paraffin wax, steric acid, Acetamide acid subjected to repeat 300 melt/ freeze cycle and melting temperature, and specific heat of sample were measured after 0,20,50,70,100,150,200,250 and 300 thermal cycle using different scanning calorimeter. Acetamide and paraffin wax are more stable phase change materials (PCMs). Ahmet koca et al [9] design collector combines in single unit solar energy collection and storage. PCM is stored in storage tank, which is located under the collector. A special heat transfer fluid is used heat from collector plate to phase change material. Exergy analysis which is based on second law of thermodynamics and energy analysis, which is based on first law of thermodynamics were applied for evaluation of the of the charging period. The average efficiency is 45% of net energy and 2.2% of exergy efficiency. Murat kenisarin et al [10] give the current study of research in this particular field, with the main focus of thermal properties of various phase change materials, method of heat transfer enhancement and design configuration of the heat storage facilities to be used as a part of solar passive

and active heating systems, greenhouses and solar cooking. Jerol sobium et al [11] ia analyzed the how to melt PCM with in less time, he will have used fin to increased heat transfer rate. He is developed the vertical stovepipe energy storage system with PCM. He is work how to increase the thermal conductivity of the material. His work is mainly influence the fin and observed thermal behavior.

Studding the above Research paper, we found that the two sided constant heat flux in a rectangular domain and 3-D model has been less work and also to increase thermal storage we will used fin and thermal conductivity.

Aim and objective are the following

- a) Analysis of melting of a rectangular phase change material (PCM) domain which is exposed to a left side and top side with a constant heat flux and insulated to other two side. Finding a shape of motion and melting of a motion interference with increase in time.
- b) Comparison of the present model with a rectangular domain having exposed to one face of constant heat flux and perfectly insulated to another three faces.
- c) Comparative study of the both type of rectangular domain and analysis of their motion of melting and shape of melting. Also to find reducing time of the melting process in both the case.

2.1 Methodology

The melting and solidification model of ANSYS (fluent) 19.0 software are used to the melting and solidification of phase change material (PCM). ANSYS fluent are used continuity, Momentum, and energy equation. ANSYS fluent uses the enthalpy porosity method for modelling the melting and solidification process. A term uses liquid fraction (fraction of volume that is in the form of liquid) is associated with each cell in the PCM domain. Based of enthalpy balance the liquid fraction is calculated after each iteration. Phase change is interface shown a mushy zone and the value of liquid fraction change 0 to 1. When the material solidifies the porosity become 0 and the velocity drop to zero in that zone.

Model Description: A geometrical model of the PCM domain used for simulation is shown as fig 3.1. The Phase change material (PCM) domain is 2-D

rectangular domain of length 100 mm and height of 150 mm respectively. The boundary condition of PCM domain as follow: the right and bottom side of the PCM are perfectly insulated and having $q = 0$ w/m^2 and other two side left side and top side of

PCM having constant heat flux $q = 2500$ w/m^2 . The area of the rectangular domain is 15000 mm^2 . Rectangular domain has two side have constant flux and other two side is perfectly insulated.

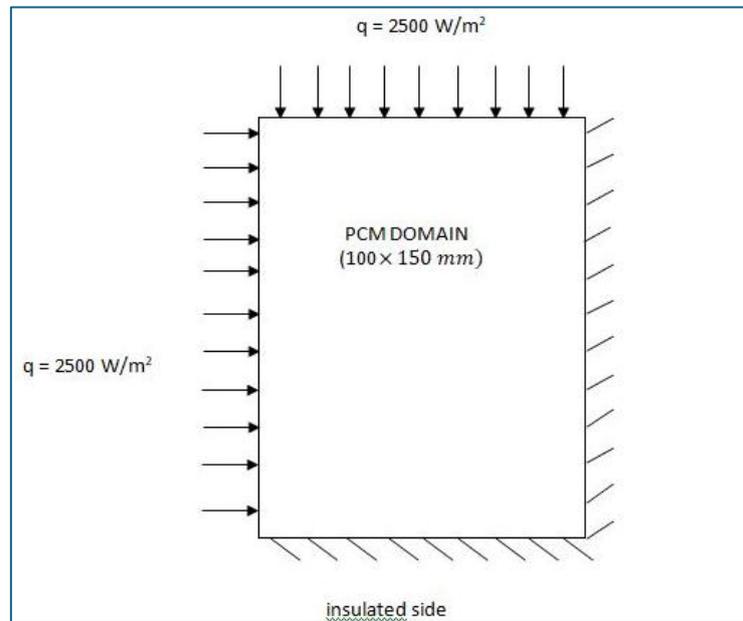


Figure 3.1 Schematic diagram of the model

Assumptions:

- Melting is transient and the shape of the model is 2-D phenomena.
- The motion of PCM in liquid state is Incompressible Non-Newtonian.
- The density and thermal conductivity of PCM is very as piecewise linear.
- Viscosity heating and Volume expansion is ignored.
- No heat generation between the PCM.
- Both solid and liquid phase is assumed to the homogenous and isotropic.
- Flow is considered as unsteady.
- The motion of PCM is turbulent.
- PCM having non-compressible flow.

2.1 Governing Equations

The numerical approach enables predictions of natural convections that occurs during the melt process of phase change material. In this approach we can used to simulate the melting, the flow is considered as steady, turbulent, incompressible and two dimensional.

Continuity equations:

$$\frac{\partial \rho}{\partial x} + \nabla \cdot (\rho V) = 0 \quad (i)$$

Momentum equations:

$$\frac{\partial (\rho V)}{\partial x} + \nabla \cdot (\rho V) = -\nabla p + \mu \nabla^2 V + \rho g + S \quad (ii)$$

Energy equations:

$$\frac{\partial H}{\partial x} + \nabla \cdot (\rho V H) = k \nabla^2 T + S \quad (iii)$$

Where H is enthalpy and ρ is density, V is the velocity of the fluid and S is the source term.

The enthalpy H is calculated as sum of sensible and latent heat.

$$H = h + \nabla H$$

Where H is the sensible enthalpy at a point at a given instant of time and ∇H is the latent heat.

$$h = h_{ref} + \int_{T_{ref}}^T C_p dT$$

where, h_{ref} is the reference enthalpy and T_{ref} is the reference temperature

C_p is the specific heat of the phase change material

$$\nabla H = \beta L$$

Where β is the value of the liquid fraction and L is the latent heat of fusion for the PCM. The value of latent heat is zero when material is purely solid ($\beta = 0$) and L where material is liquid ($\beta = 1$). A mushy

zone is creating between the solid and liquid, that separate the solid and liquid phase

$$\beta = \frac{T - T_{solidus}}{T_{liquidus} - T_{solidus}} \quad \text{if } T_{solidus} < T < T_{liquidus}$$

Where solidus temperature and Liquidus temperature are property of materials

Properties of Material Used: Here two type of material used which is paraffin wax and Aluminium. paraffin wax is used for phase change material and Aluminium is used for solid. The thermal-conductivity, density, specific heat and viscosity for solid and liquid both the material is shown in the table form and the values of the material are,

Table 3.1: Thermo-Physical Properties of Paraffin-Wax.

Property	Value
Density (kg/m ³)	870 at T=300 780 at T=340
Specific heat (J/kg K)	2900
Thermal conductivity (w/m K)	0.24 at T=300 0.22 at T=340
Viscosity (Nm/m ²)	.0057933
Latent heat (J/kg)	190000
Solidus temperature (K)	321
Liquidus temperature (K)	321.8

Table 3.2: Properties of Aluminium.

Properties	Value
Density (kg/m ³)	2719
Thermal conductivity (w/m K)	202.4
Specific heat (J/kg K)	871

The commercial finite volume based CFD code ANSYS fluent 19.0 has been used to simulate fluid dynamics and heat transfer and also solve the conserving equations of continuity, momentum and energy. Geometry mesh generation scheme selection and validation of turbulent model. The detail is given below;

Geometry:

The geometrical domain that can use is 2-D rectangular body, PCM domain is a rectangular domain. Length and height are 100mm and 150mm respectively.

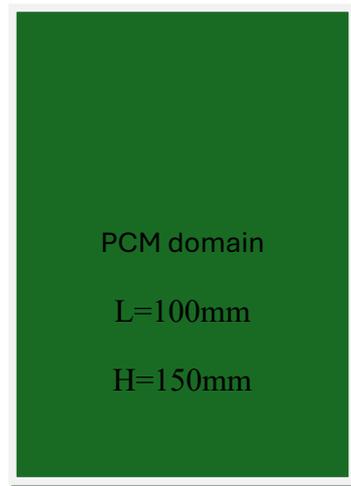


Figure 4.1 Model diagram

Boundary Conditions:

The boundary condition of a rectangular PCM domain are left side and top side is exposed to a

constant heat flux of 2500w/m^2 and other two side bottom and right are perfectly insulated.

Table 4.1: Boundary Conditions.

Initial condition	Heat flux (w/m^2)
Left side	$2500 (\text{w/m}^2)$
Right side	$0 (\text{w/m}^2)$
Top side	$2500 (\text{w/m}^2)$
Bottom side	$0 (\text{w/m}^2)$

Mesh descriptions

While solving a numerical solution the quantity of mesh plays a very important role as it directly effects the accuracy and stability of the numerical computations. Hence a closer look was made to have

a sufficient mesh quality. The solution is made by finite volume method using ANSYS fluent 19.0 software. The selection of mesh size is an important during the pre-processing. The total number of node and element are 60501 and 60000 respectively. Edge meshing is used for the meshing shown in table 4.2.

Table 4.2: Statistics

No of nodes	60501
No of elements	60000
Mesh metric	None

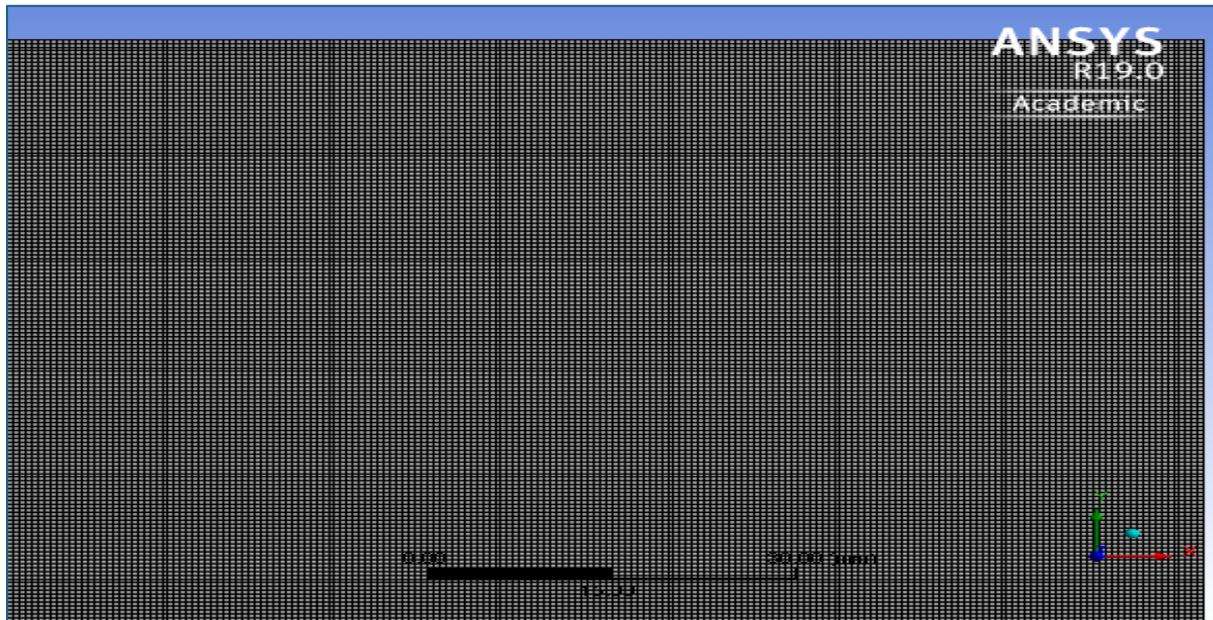


Figure 4.2 Mesh Description

2.3 Computational Methodology

The geometry was created in ANSYS workbench design modular as well as the mesh of the geometry. The meshing is done by ANSYS fluent 19.0. the simulation is run with the 2-D double precision code, two different type of fluid for PCM paraffin

wax and for solid aluminum used. Gravity was set to -9.81 m/s^2 along the y axis to include the natural convection in the PCM during the simulation process.

Setup for Fluent Model:

Table 4.3

Description	Type
Solver	Pressure based
Energy	On
Solidifications and melting	On
Gravity	On

Time	Transient
Model	Turbulent/K- epsilon model
Velocity formulation	Absolute

2.4 Parameter for Converse Solution

The numerical study and observation during the simulation, certain value and parameter are play very important role to reach a converse solution, some of the important parameter are listed below:

- a) **Density**- As the density of the PCM varies with increase or decrease in temperature during its melting and simulation process. The density is set as piecewise linear and as a function of temperature. The ANSYS fluent is adjust the density in mushy zone. Both solid and liquid phase have different value of density according to temperature.
- b) **Reference Value** – The reference value are set to the geometry and the value of PCM, The reference values are: Area .015m², density 870 kg/m³ , length 100 mm, velocity .0001 m/s, temperature 298 K, viscosity .00 1067 ns/m² .
- c) **Melting Temperature Difference** – melting temperature difference is temperature difference between solid and liquid state of PCM. The temperature difference is maintained as .8 K and it's shown instability and very thin layer of mushy zone. When the temperature difference is 1 K PCM has good stability.
- d) **Solution Methods and Scheme** –PESTRO scheme is used for the pressure correction equations, the Semi-Implicit Pressure Linked Equations (SIMPLE) algorithm is used for pressure- velocity compounding. The momentum equations are used for first order scheme, and energy and continuity equations are used second order scheme. Also turbulent and kinetic energy equations are used for first order scheme. The gradient used is least square cell based.

Table 4.4: Solutions methods of scheme

Solution method	Scheme
Pressure	PESTRO
Pressure- velocity compounding	SIMPLE
Momentum equations	2 ND order
Energy and continuity equations	1 ND order
Gradient	Least squire cell based
Turbulent and kinetic energy equations	1 ND order

- e) **Relaxation Factor and Time-Step Size**
The relaxation factor and time- step size is very important factor of Fluent to reached the convergance criteria. The convergence criteria that obtained from the energy, momentum, and energy equations are restricted to less than 10^{-6} , 10^{-4} and 10^{-4} respectively. The time step is set as 6 secs and the number of iteration per time is set as 10. The simulation is performed on the college lab.
- f) **Stefan Number**: Stefan number is the ratio between the sensible heat to the latent heat in phase change material. generally, It's values is lie between .10 to 011. Latent heat storage is 10 times more than the sensible heat storage in PCM.

3.1 Result and discussion

The numerical and CFD fluent analysis of paraffin wax in a rectangular domain of length is 100mm and height of 150mm whose left and top side is given a constant heat flux and value of heat flux is 2500w/m^2 and other two side right and bottom is perfectly

insulant and no heat flux is given. The result of simulation is recorded as a time interval of 15 minute and a complete cycle of 120 minute (2hours). The results are recorded as contours of liquid fraction, temperature, density, and velocity.

3.2 Contours of liquid fractions

The variation of liquid fraction with time as shown in below. No we can easily show the variation of shape and melting interference with respect of time passes. The red zone represented the melting of liquid form ($\beta = 1$) and blue colour represent the material is in solid form ($\beta = 0$). The mushy zone represents the melting in front, it separate solid and liquid region. At the beginning the melting process where $t = 15$ minutes the melting interference is almost parallel to top and left side where heat flux given, in early stage heat transfer is due to conduction mode, at the time increases and passed to 30 minutes. liquid PCM has higher temperature and low density. The PCM start to melting downward and continue to a large cycle. The PCM is completely melt top layer in 30 minute and completely melt in 120 minutes.

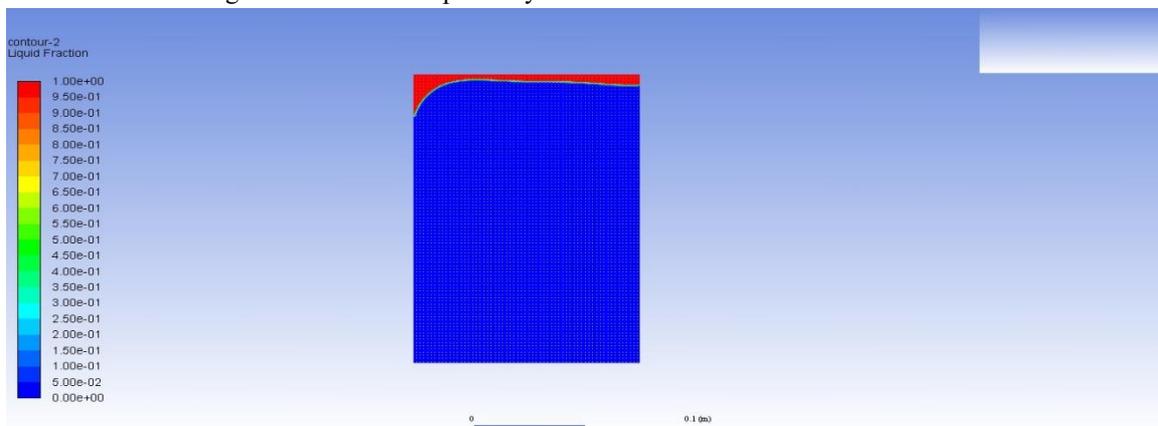


Figure 3.1 Melting Fraction after 15 minutes

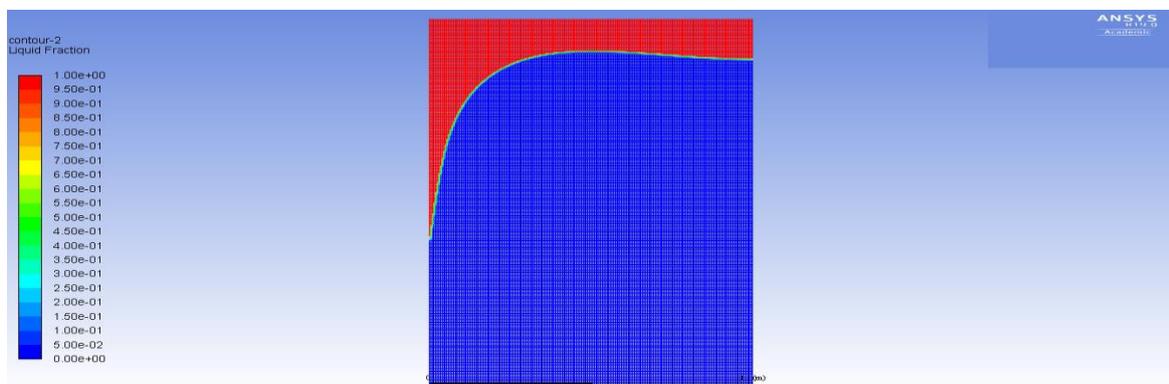


Figure 3.2 Melting Fraction after 30 minutes

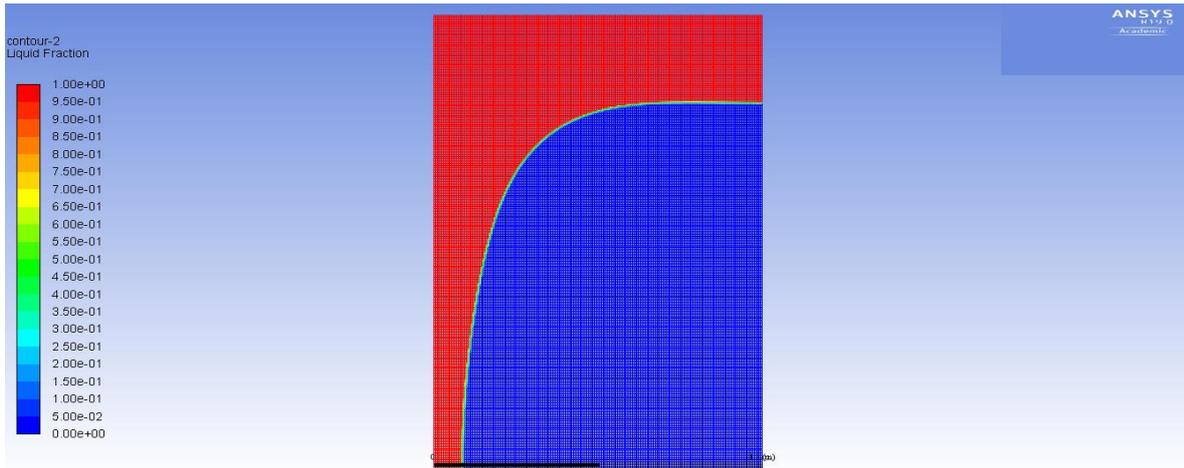


Figure 3.3 Melting Fraction after 45 minutes

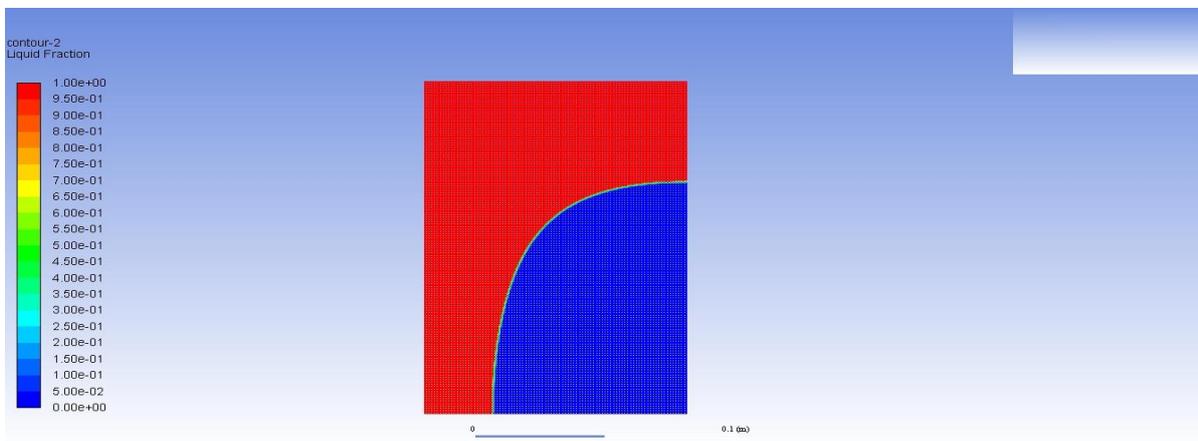


Figure 3.4 Melting Fraction after 60 minutes

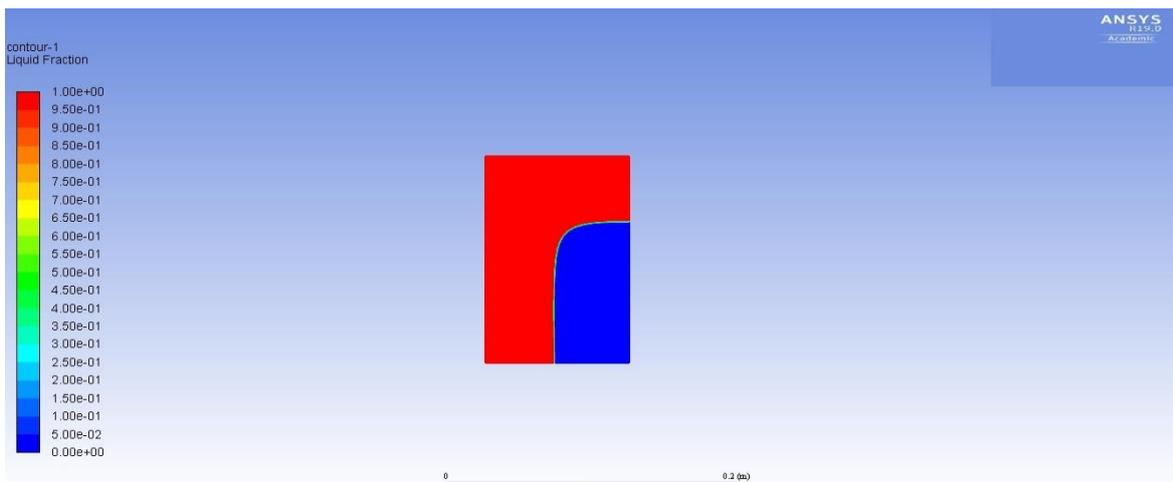


Figure 3.5 Melting Fraction after 75 minutes

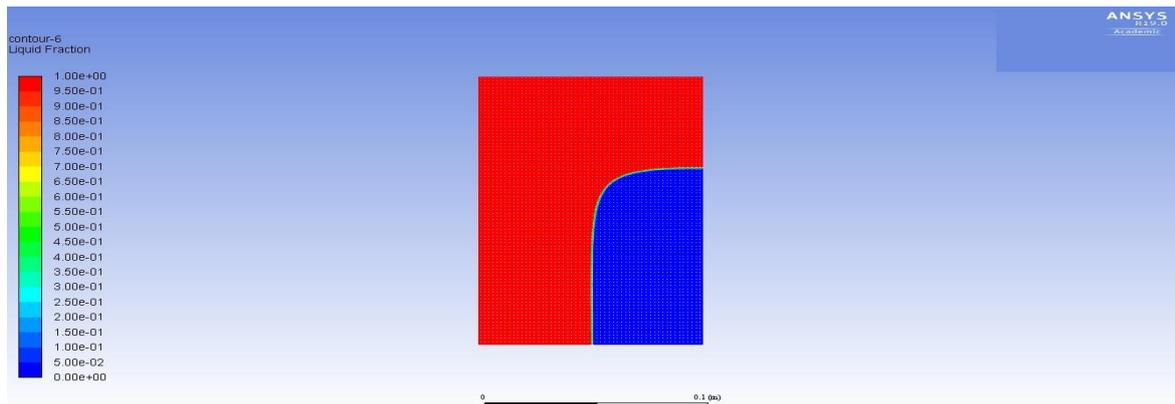


Figure 3.6 Melting Fraction after 90 minutes

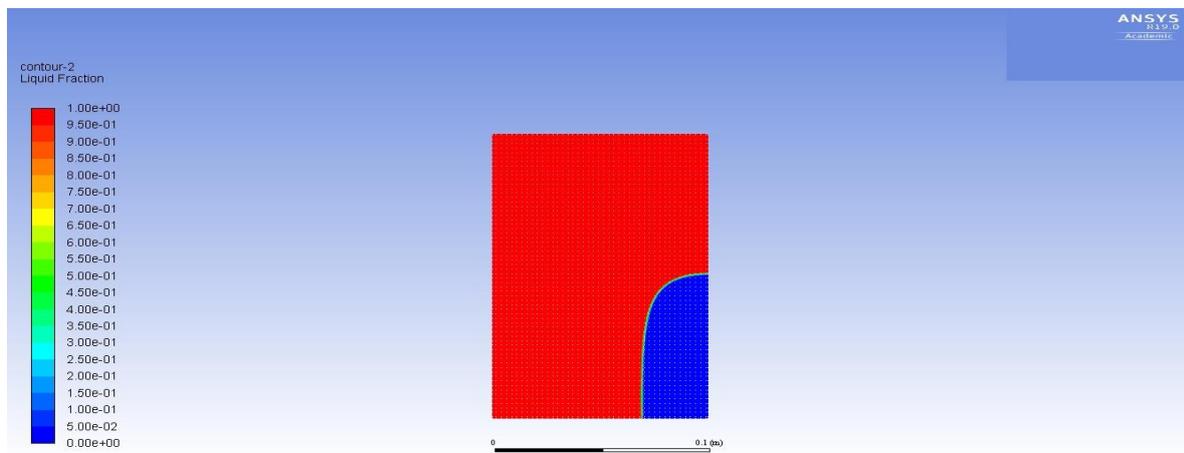


Figure 3.7 Melting Fraction after 105 minutes

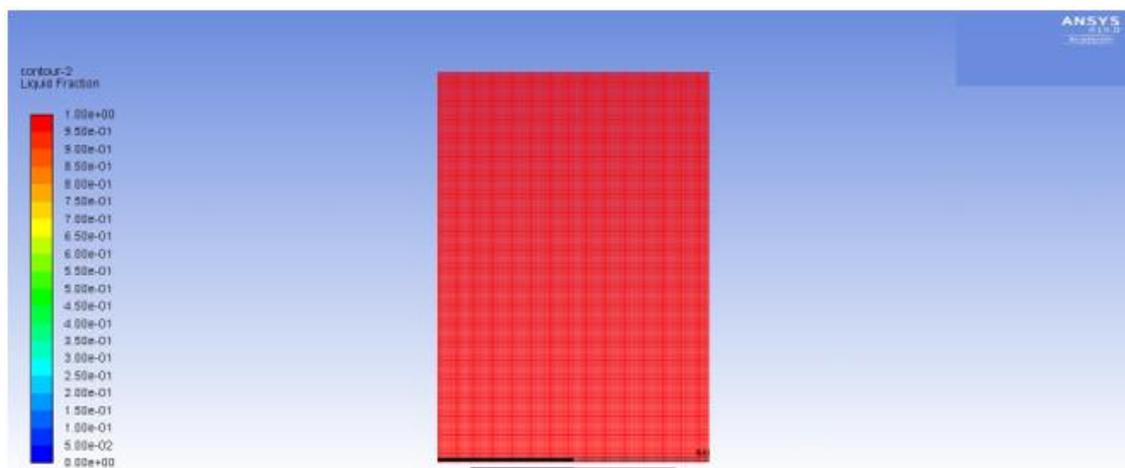


Figure 3.8 Melting Fraction after 120 minutes

Figure 3.1-3.8 shows the melting fraction of phase change material with respect to melting time, here blue color represent the solid phase of phase change material and red color shows the liquid

phase of phase change material. A mushy zone is present in PCM domain which separate the solid and liquid phase. The value of melting fraction is 12%, 23%, 37%, 51%, 63%, 75%, 85% for the

melting time of 15, 30, 45, 60, 75, 90, 105 minutes respectively. At the end of 120 minutes PCM is melted; giving a 100%. The rate of melting is same as a starting of the melting process and its increased in middle and end of the melting process. Melting of phase change material is increased with respect to time and it's increase continuously. In above figure 0 represent the solid body which is not melted and 1 represented the liquid phase of rectangular body. The melting started due to

conduction and with increased with time due to turbulence of natural convection.

3.3 Comparison Between One Side Heat Flux and Two Side Heat Flux in a 2-D Rectangular Domain:

One side heat flux and other three side insulated 2-D Rectangular domain shown in figure 3.3.1

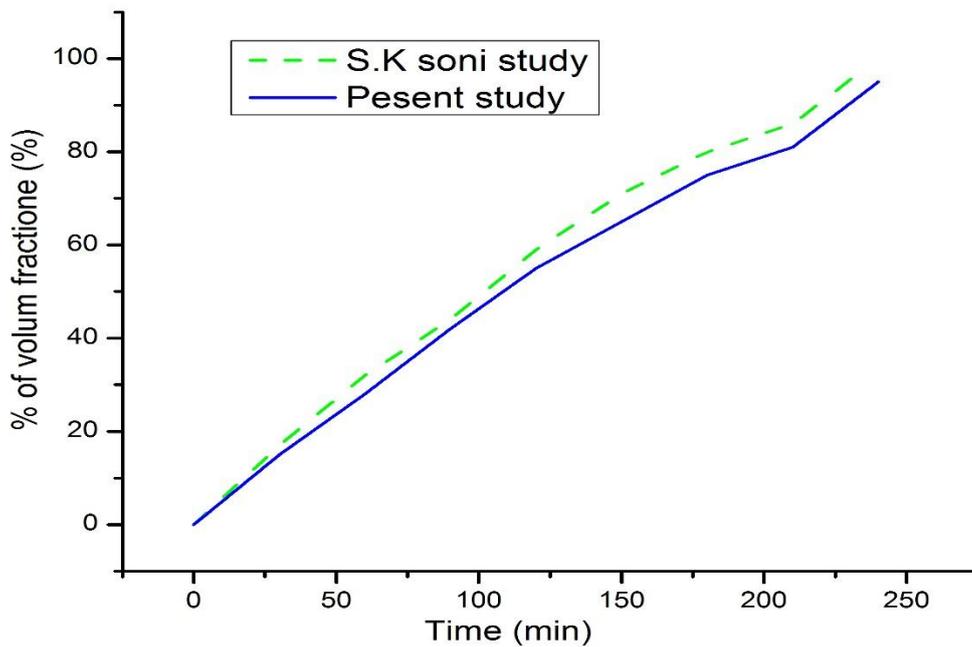


Figure 3.3.1 volume of melting fraction (%) vs time (min)

Table 3.3.1 melting fraction (%) vs time (min) in one side heat flux

Time (min)	Vol of melting fraction (%)	
	Experimental	Analytical
30	17	15
60	32	28
90	44	41
120	59	54
150	71	67

180	80	79
210	86	84
240	100	95

Two side heat flux and other three side insulated 2-D Rectangular domain shown in **figure 3.3.1**

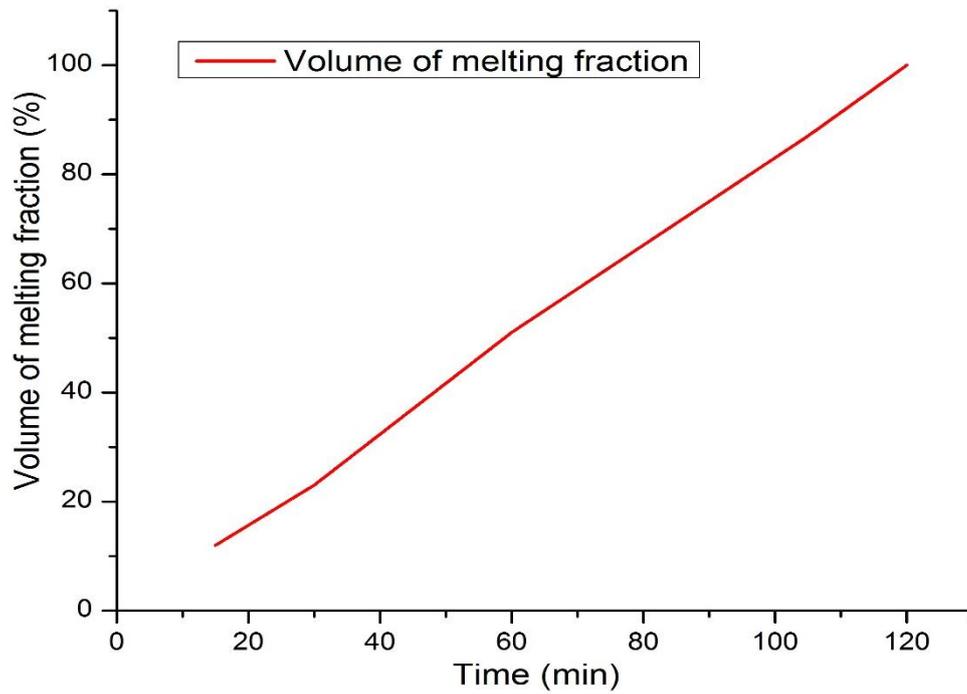


Figure 3.3.1 volume of melting fraction (%) vs time (min)

Table 3.2 Melting fraction (%) vs time (min) in two side heat flux

Time (min)	Vol of melting fraction(%)
15	12
30	23
45	37
60	51
75	63
90	75

105	87
120	99

3.4 Contours of Temperature

The contours of temperature and variations of temperature after regular interval of 15 minutes each. We have found that the maximum temperature achieves at 420 K during initial stage, in middle stage it achieve at 900 K and maximum temperature achieve at 1120 K during when all the PCM melt completely shown in figure **Figure 3.4.1** to **Figure 3.4.8**. When the temperature reaches the Liquidus temperature it starts to melting. The blue colours

shows the low temperature regions and achieve at initial stage during 15 minutes' time. The shape of the zone resembles to the solid state of PCM. After the time has cross 15 minute it started to develop a red zone, and red zone developed at 30 minute nearer the left and top wall. The red zone is gradually increases with time. The red zone is developed in the phase change material due to the turbulence effect (natural convection). At the last when all the phase change material melts completely in liquid phase the property of PCM will be constant.

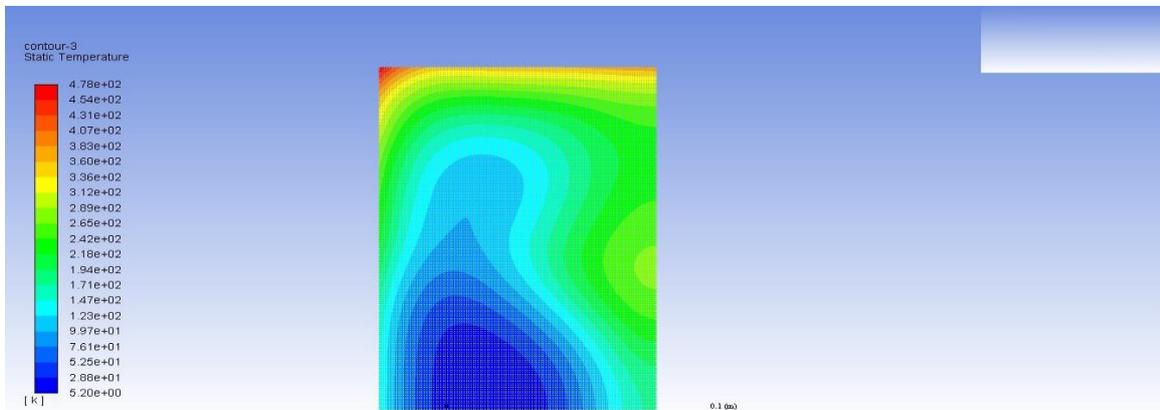


Figure 3.4.1 Temperature Contour after 15 minutes

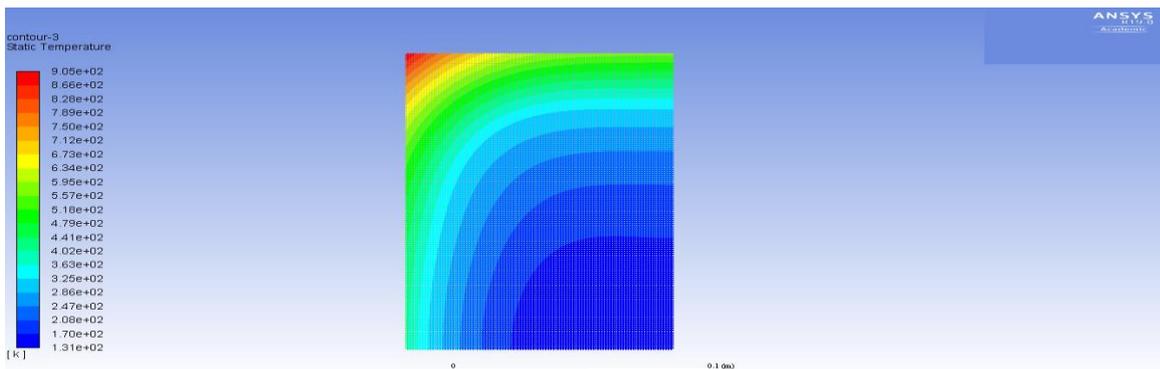


Figure 3.4.2 Temperature Contour after 30 minutes

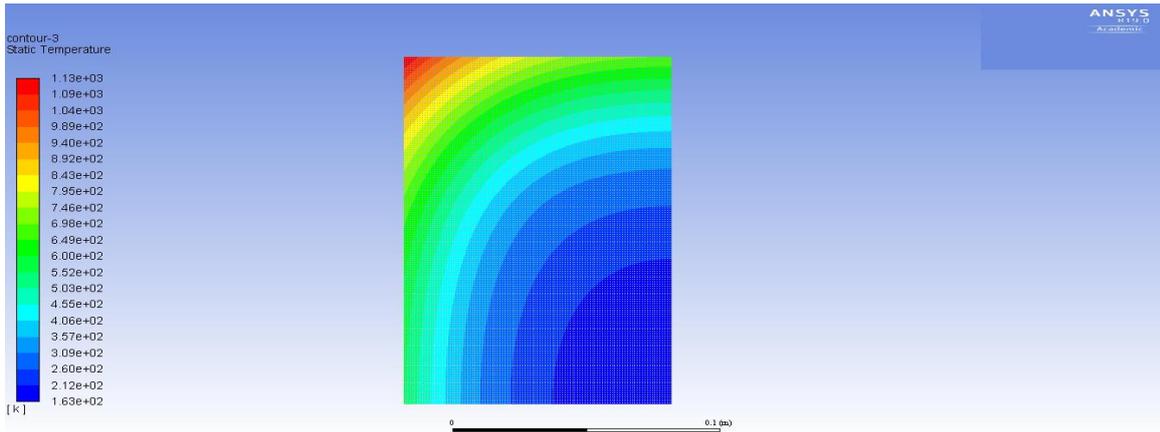


Figure 3.4.3 Temperature Contour after 45 minutes

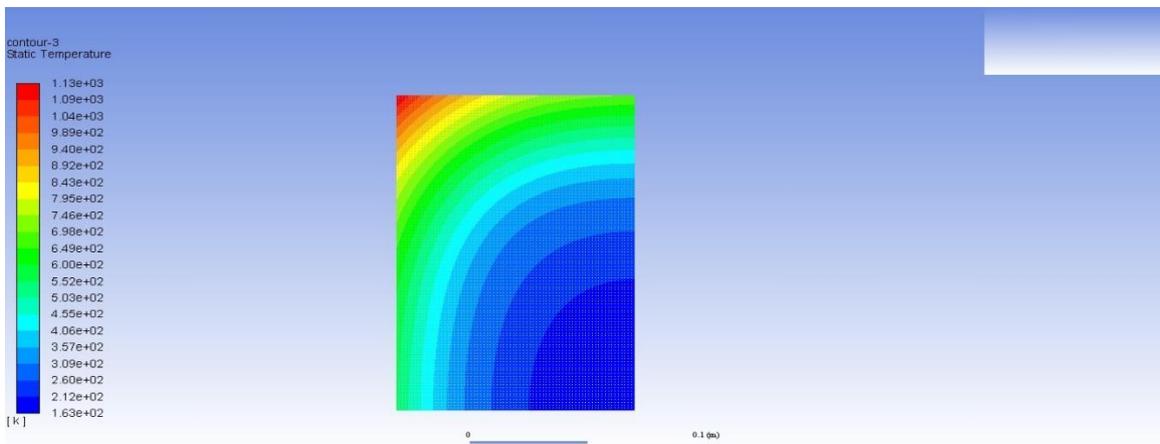


Figure 3.4.4 Temperature Contour after 60 minutes

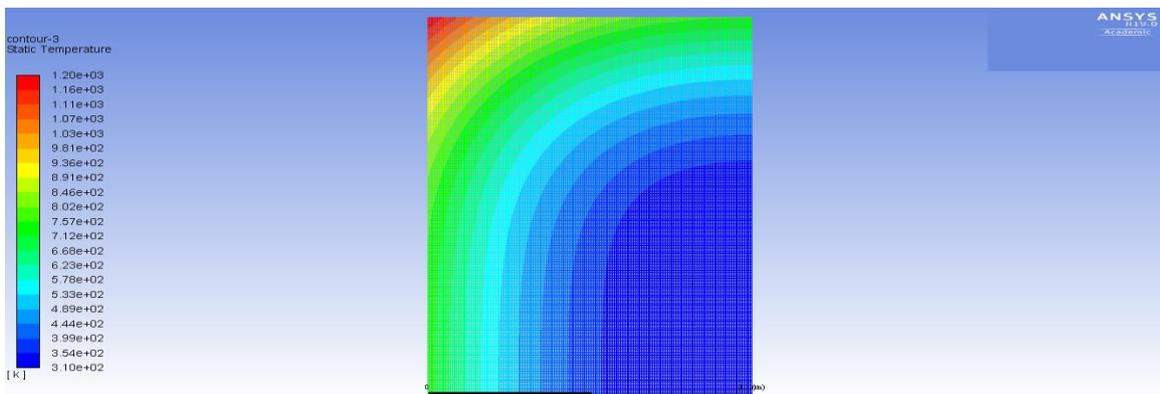


Figure 3.4.5 Temperature Contour after 75 minutes

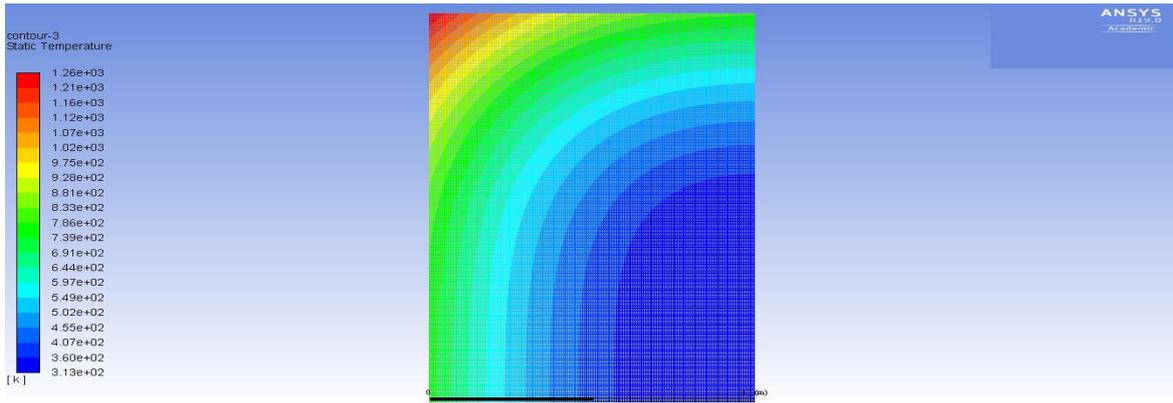


Figure 3.4.6 Temperature Contour after 90 minutes

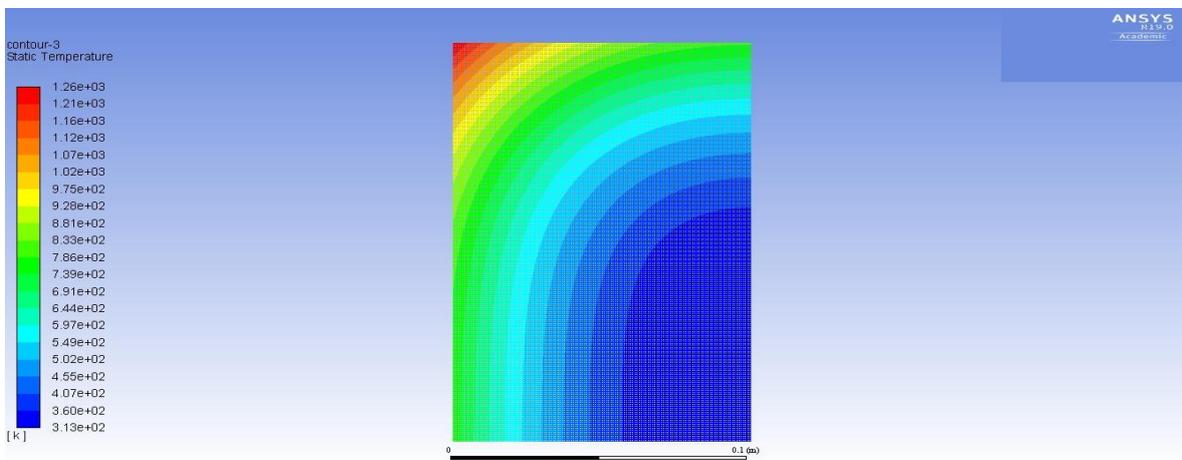


Figure 3.4.7 Temperature Contour after 105 minutes

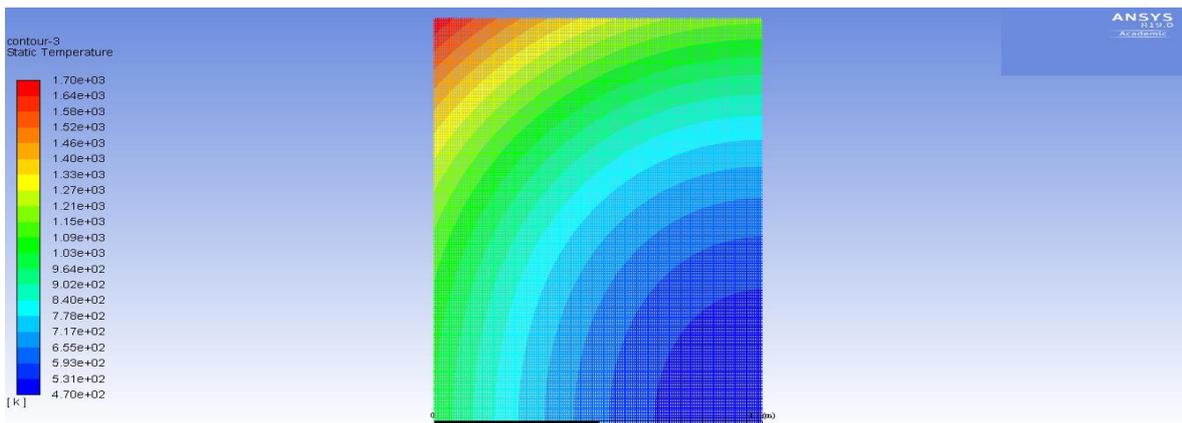


Figure 3.4.8 Temperature Contour after 120 minutes

5.5 Contours of density

Below the figure show the contour of density. The density of phase change material varies as a Piecewise linear with temperature. The density of phase change material decreases when the temperature increases, the density of PCM due to heat flux rise

up and accumulated due to top face, which shown the blue color in the fig. in the starting of PCM density is 870 kg/m^3 and at the end of melting the density of PCM is constant and the value of density of PCM is 780 kg/m^3 at 120 minutes described in in Figure 3.5.1 to Figure 3.5.8.

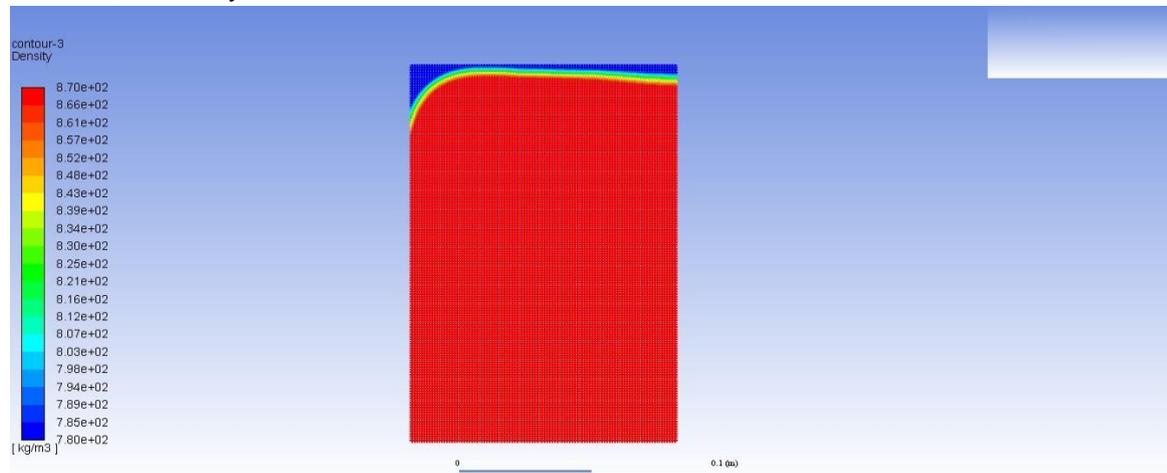


Figure 3.5.1 Density Contour after 15 minutes

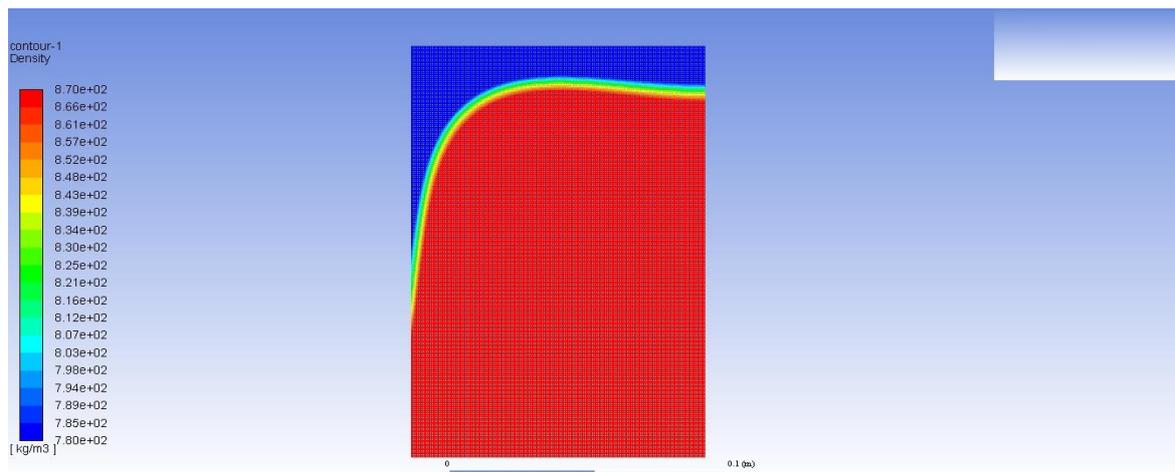


Figure 3.5.2 Density Contour after 30 minutes

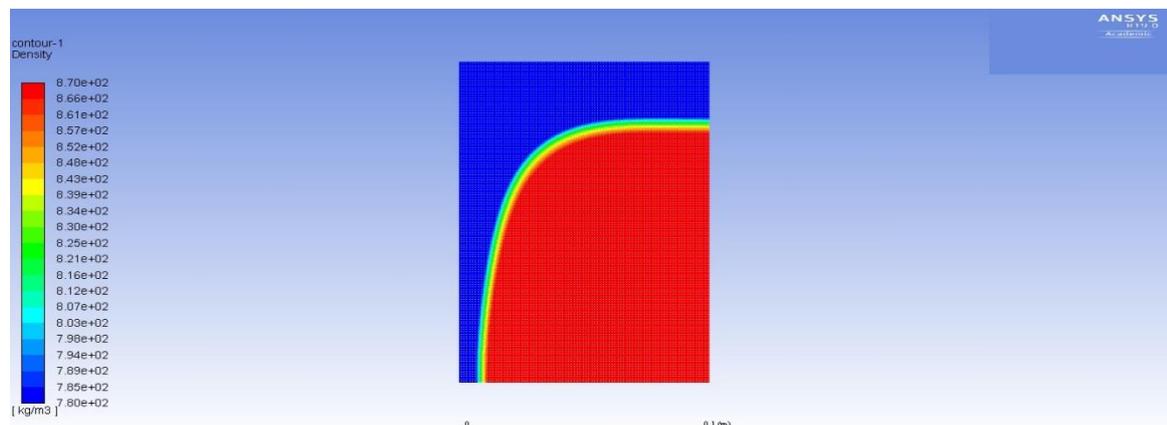


Figure 3.5.3 Density Contour after 45 minutes

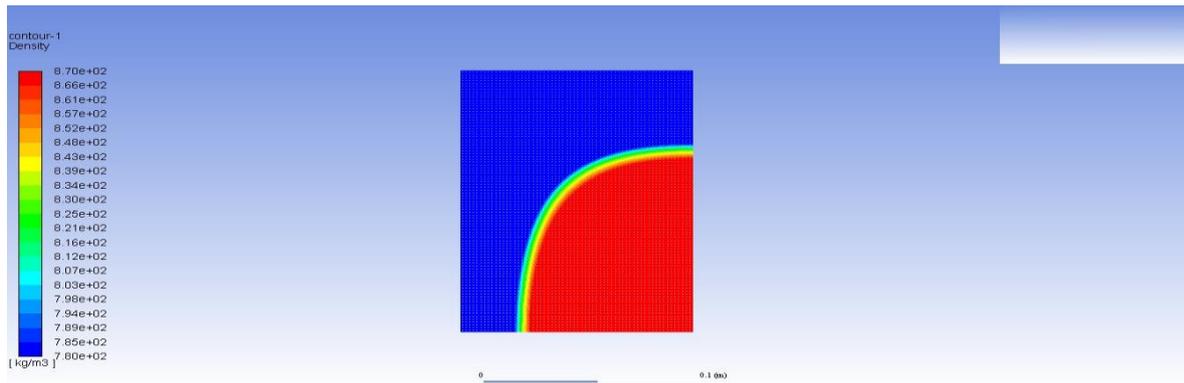


Figure 3.5.4 Density Contour after 60 minutes

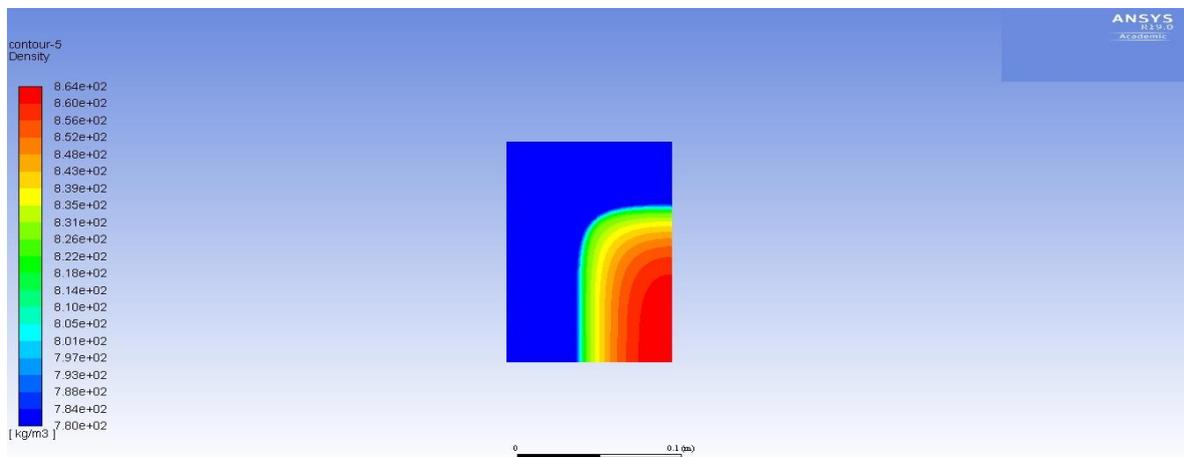


Figure 3.5.5 Density Contour after 75 minutes

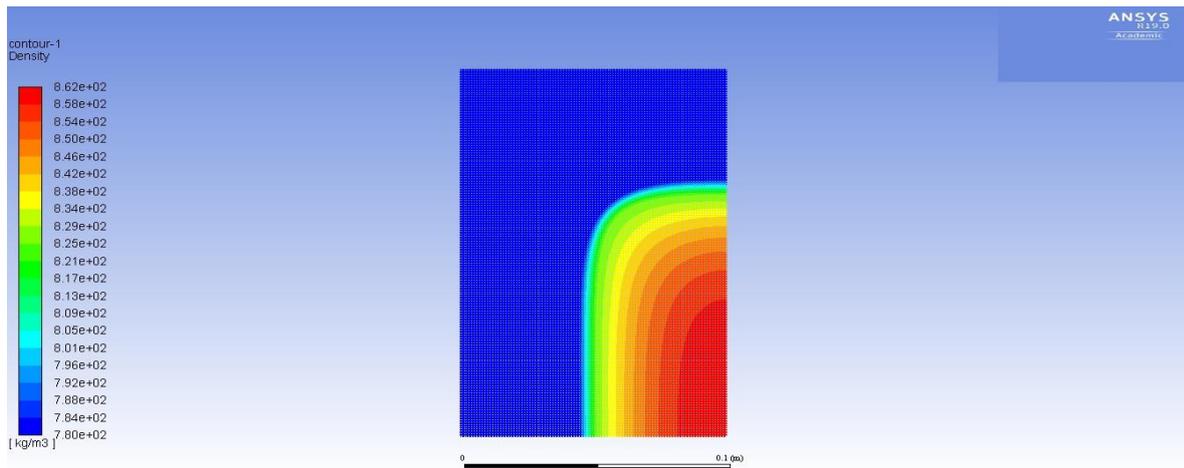


Figure 3.5.6 Density Contour after 90 minutes

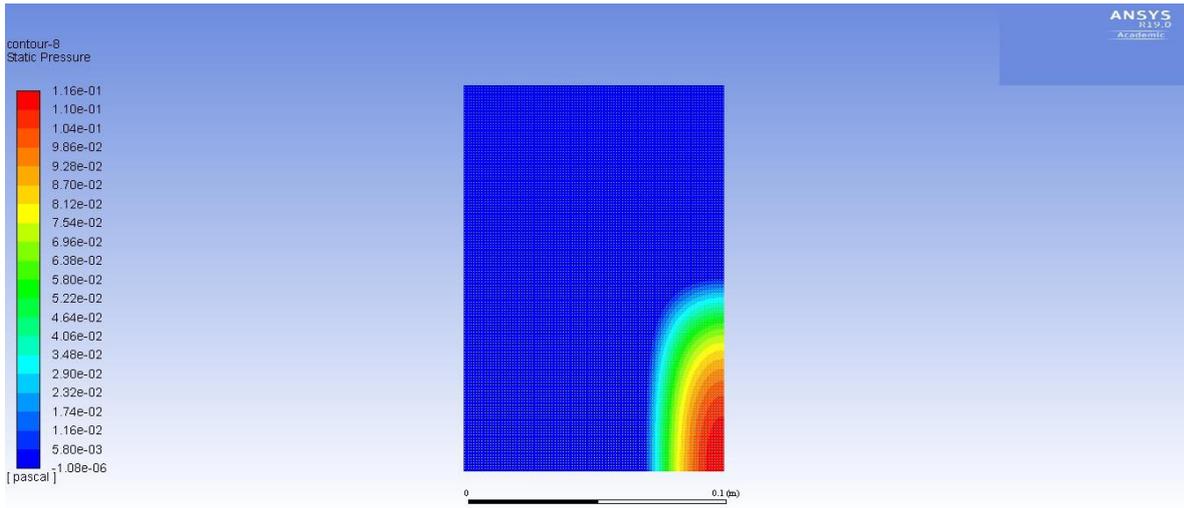


Figure 3.5.7 Density Contour after 105 minutes

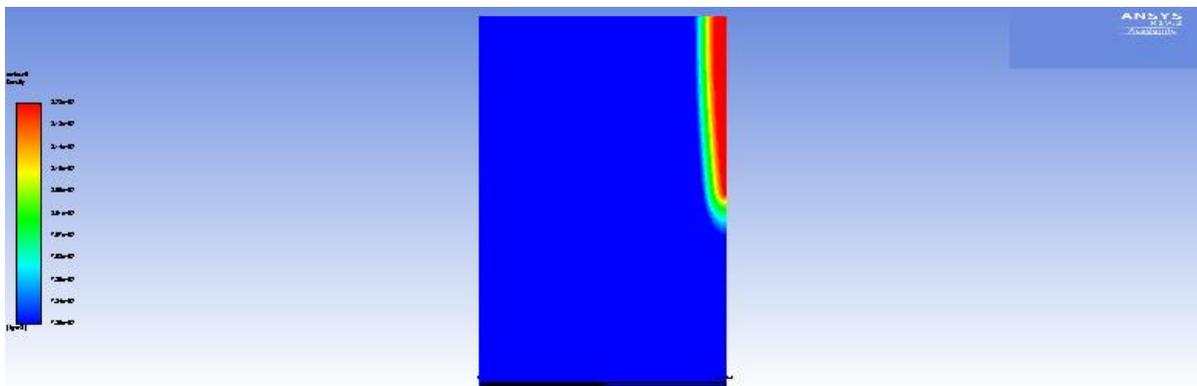


Figure 3.5.8 Density Contour after 120 minutes

3.6 Contours of velocity

Contour of velocity represent the velocity vector and the variation of velocity in a regular interval of 15 minute each described in figure 5.6.1 to figure 5.5.8. The analyse shows that red zone in the liquid phase change material near the left and top faces where heat flux is given and have highest magnitude of

velocity. At the end of the melting process the complete melting of PCM in liquid state and also density become constant. When the PCM melt completely the buoyancy effect become zero. After the complete melting of solid PCM to liquid PCM all the molecule in the rectangular domain becomes at rest. The velocity is nearly zero in this process.

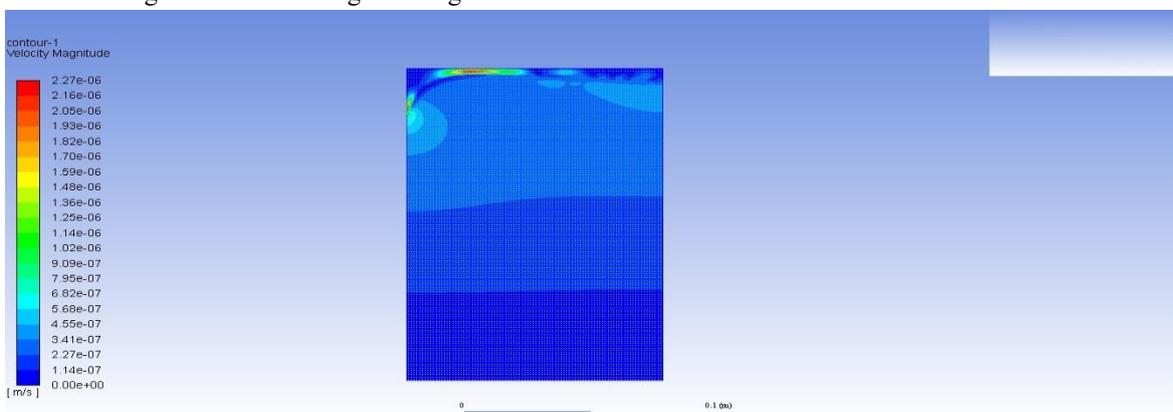


Figure 3.6.1 Velocity Contour after 15 minutes

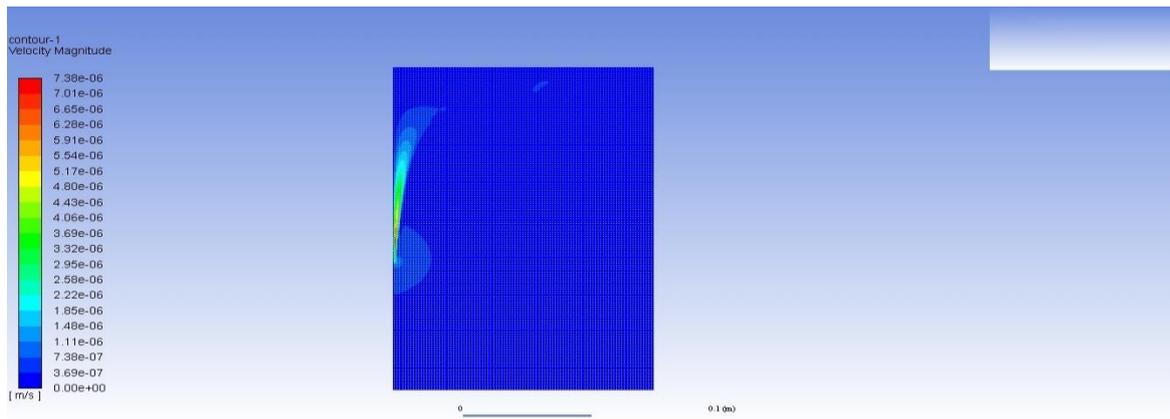


Figure 3.6.2 Velocity Contour after 30 minutes

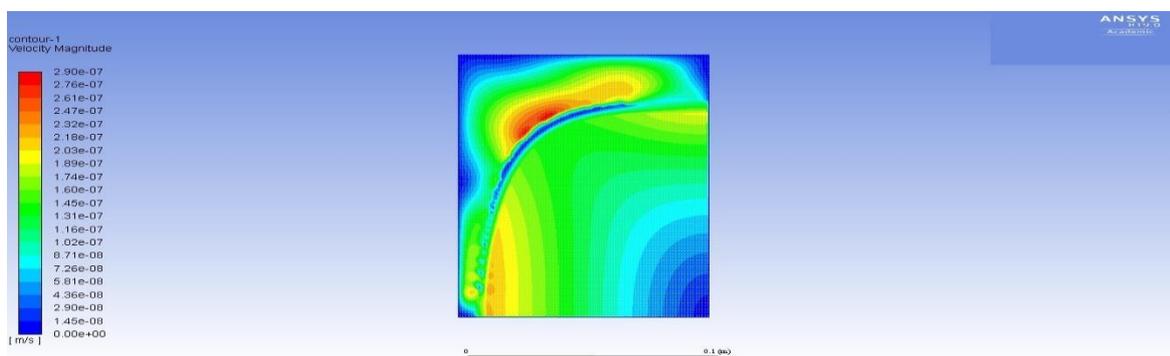


Figure 3.6.3 Velocity Contour after 45 minutes

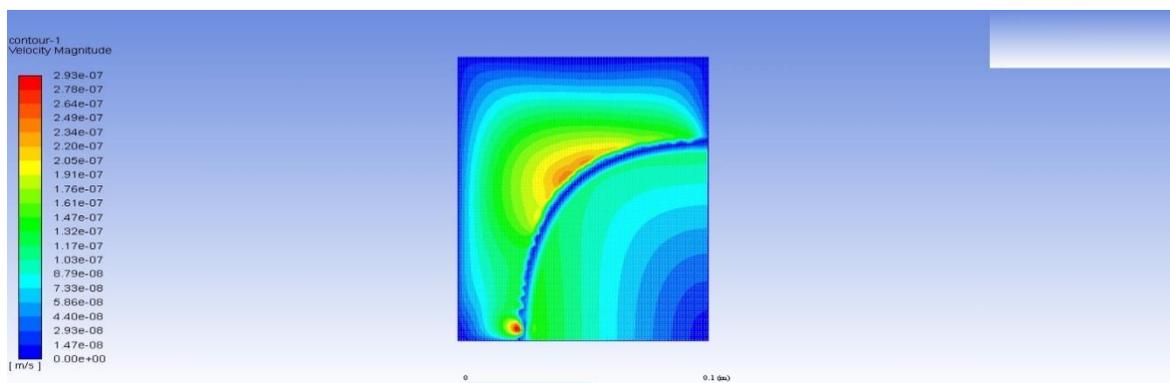


Figure 3.6.4 Velocity Contour after 60 minutes

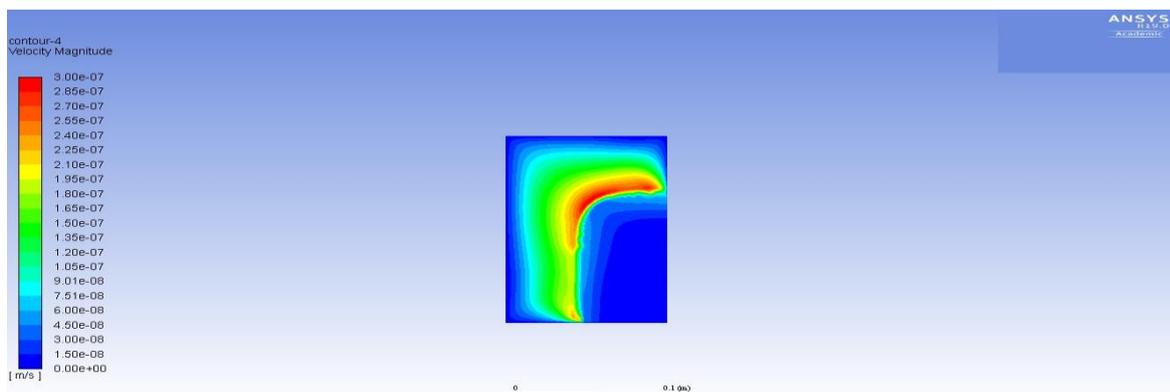


Figure 3.6.5 Velocity Contour after 75 minutes

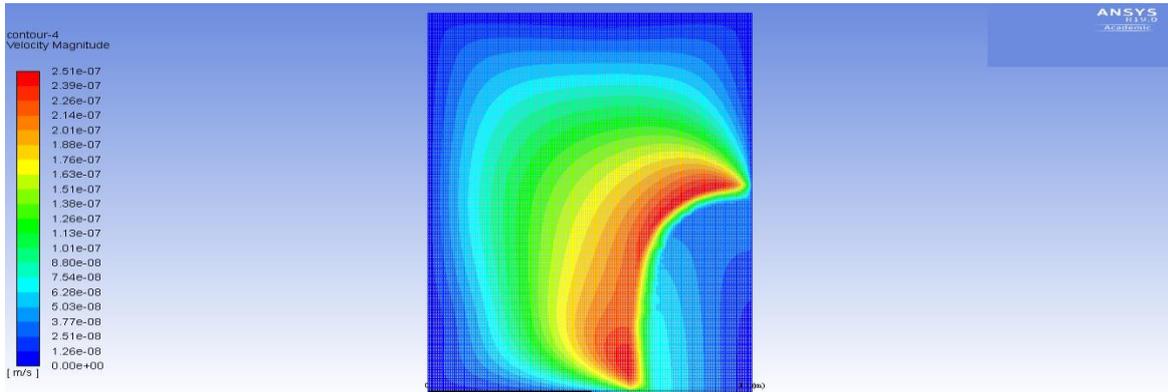


Figure 3.6.6 Velocity Contour after 90 minutes

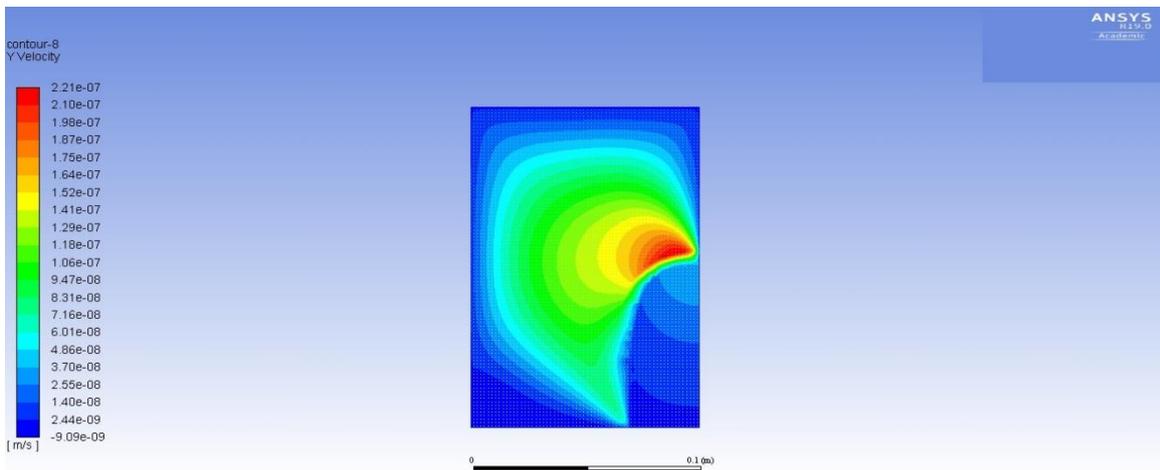


Figure 3.6.7 Velocity Contour after 105 minutes

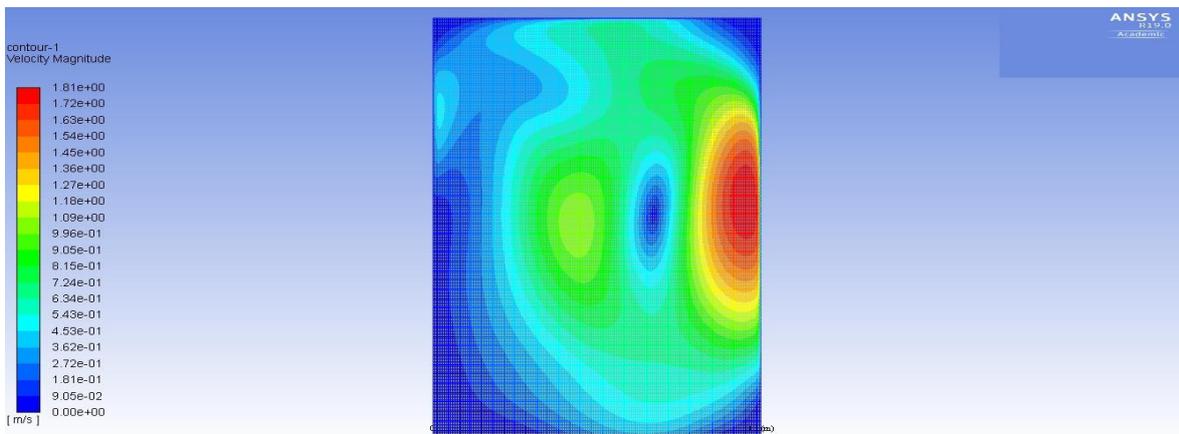


Figure 3.6.8 Velocity Contour after 120 minute

4 Conclusion and future scope

The numerical modelling and simulation of a rectangular PCM domain having constant heat flux in two side and other two side is insulated, following conclusion are found, they are,

- In the beginning of simulation melting is started from where heat flux given like top and left side of wall and melting start from top to bottom.
- In the starting of melting the heat transfer is due to conduction mainly in 15 minutes, after that heat transfer is due to natural convection in turbulence effect.
- The melting time of phase change material is uniform it start to increase melting when time is increase.
- The melting fraction value in phase change material is 16% in first 15 minute and its completely melt the phase change material in 120 minutes.
- In compression to single side constant heat flux in a rectangular domain, the two side constant heat flux it's take less than 50% time to complete melting of a phase change material. In single side constant heat flux and other three side is insulated it take 240 minute to complete the melting of phase change material.
- The energy storage due to latent heat is more due to high temperature after the complete melting of phase change material.

Scope for Future Work

- We are work on a 3-D model to analyses and simulate the model and finds their contours with phase change materials PCMs \.
- Reduce the thickness of the phase change materials PCMs and perform the simulation to overcomes the solidification during charging.
- Increase the thermal conductivity of phase change materials to increase heat transfer, that why we reduce the melting's time.
- Different design like use fins, porous media of the heat exchanger should be

taken into the consideration, to increase the thermal efficiency.

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