International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 4, Issue 1, pp: (85-97) Month: April 2016 - September 2016, Available at: www.researchpublish.com

Numerical Analysis of Thermal Storage Systems Using Phase Change Material

[1]Akhil Johnson, [2]Dr.J. Hussain

[1] Department of Mechanical Engineering, Mohammed Sathak AJ College of Engineering, Chennai,
[2]Head of the Department, Mohammed Sathak AJ College of Engineering

Abstract: **The heat transfer behavior of phase change materials during a charging process by solar heating has to be simulated by CFD modeling. The effect of mass flow rate and effect of inlet temperatures in the phase change materials during a charging process and discharging process by solar heating has to be simulated by CFD modelling. Also we take three different PCMs for the analysis and find out the best one. Transient two dimensional heat transfer problems is to be solved by simulating in ANSYS FLUENT software while heat is stored in phase change material. The governing equations of mass, momentum, solidification models and energy are solved by the finite volume method in the steady-state regime.**

Keywords: **Phase Change Materials (PCMs), Energy Storage, CFD, ANSYS FLUENT.**

1. INTRODUCTION

Energy Storage has only recently been developed to a point where it can have a significant impact on modern technology. In particular energy storage is critically important to the success of any intermittent energy source in meeting demand. Energy storage can contribute significantly to meeting society needs for more efficient, environmentally benign energy uses in building, heating and cooling, aerospace power and utility applications.

The use of energy storage systems has the following benefits:

- Reduced energy costs
- Reduced energy consumption
- Improved indoor air quality
- Reduced initial and maintenance costs
- Reduced equipment size

Energy storage systems have an enormous potential to increase the effectiveness of energy conservation, equipment size and for facilitating large scale fuel substitutions in the world economy. Energy demand in the commercial, Industrial, Public, Residential Varies on a daily, weekly and seasonal basis Energy systems can improve the operation of cogeneration, solar, wind and runoff river hydro facilities. Some details on these ES applications are given below:

- **Utility**- relatively inexperienced base load electricity can be used to charge ES systems during evening or off peak, weekly or seasonal periods.
- **Industry**- High temperature waste heat from various industrial process can be stored for use in pre heating and other heating operations.
- **Cogeneration**: Coupled production of heat and electricity by a cogeneration system rarely matches demand exactly.

Current researches is going on in the field of ES systems such as:

(a) Advanced ES and conversion systems with phase transformation, chemical and electro chemical reactions.

(b) Fundamental phenomena inside a single cell as well as engineering integration of whole battery into vehicles.

(c) High dielectric constant polymers.

(d) High 'K' composites for capacitors.

1.2 ENERGY STORAGE METHOD:

For many technologies, storage is a crucial aspect. If we consider the storage of fuels as the storage of energy embedded in them, then oil is the best example. The massive amounts of petroleum stored worldwide are necessary for the reliable, economic availability of gasoline, fuel, oil and petro chemicals. Electrical utilities generated by thermal power plants drive large electrical motors to pump water uphill to elevated reservoirs during period of low electrical demand. During period of peak demand, the water is allowing to flow back downhill to redeliver the energy through hydroelectric generation. Also electrical energy can be stored in batteries.

ES includes heat storage hold transferred heat before it is put to useful purposes. Advanced new storage devices are often an integral part of new technologies and these sometimes can be made more feasible by innovations in storage.

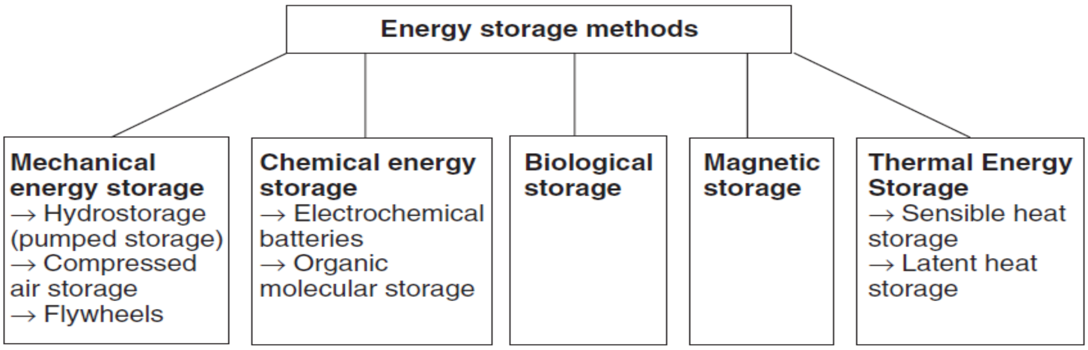


Fig.1.2.1: Types of energy storage methods

1.2.1 Mechanical Energy storage:

It can be stored as the kinetic energy of linear or rotational motion, as the potential energy in an elevated object, as the compression or strain energy of an elastically material.

There are three main mechanical storage types:

(i) Hydro storage

(ii) Compressed air storage

(iii) Fly wheels.

1.2.2 Chemical Energy storage:

Energy may be stored in systems composed of one or more chemical compounds that release or absorb energy when they react to form other compounds. The most familiar chemical energy storage device is battery. Energy stored in batteries are referred to as electro chemical energy because the chemical reactions in the battery are caused by electrical energy and subsequently produced electrical energy.

1.2.3 Biological storage:

Biological storage is the storage of energy in chemical form by means of biological processes and is considered as an important method of storage for long periods of time. If the quantum efficiency of biological processes can be increased by a factor of ten over its present efficiency of about 1 percent interest in bio conversion for ES will likely increased.

1.2.4 Magnetic storage:

Energy can be stored in magnetic field. An advanced scheme that employees superconducting materials is underdevelopment. At temperature near absolute 0, certain metals have almost no electrical resistance and thus large currents can circulate in them with almost no losses. Over all storage efficiencies of 80-90% are anticipated for these superconducting magnetic ES systems. Magnetic storage is considered for two main purposes:

(i) Large superconducting magnets capable of storing (1000-10,000MWh) of electricity would be attractive as load leveling devises.

(ii) Smaller magnet with storage capacities in 10 KWh range.

1.3 THERMAL ENERGY STORAGE:

Thermal energy storage deals with the storage of energy by cooling, heating, melting, solidifying or vaporizing a material, the thermal energy becomes when the process is reversed. Storage by causing a material to raise or lower in temperature is called sensible heat storage, its effectiveness depends on the specific heat of the storage material and if volume is important, on density. Storage by phase change (Transition from solid to liquid or from liquid to vapor with no change in temperature) is a mode of thermal energy storage known as latent heat storage.

Thermal energy storage quantities differ in temperature. As the temperature of a substance increases, the energy content also increases. The energy required E to heat a volume V of a substance from a temperature (T1) to a temperature (T2) is given by:

$E = mc\ (T2\text{-}T1) = \rho\ V\ c\ (T2\text{-}T1)$

Where C' is the specific heat of the substance. The value of 'C' may vary from 1kCal/kg^{0}C. For water to 0.0001kCal/kg^{0}C for some materials at very low temperature.

1.3.1 Basic principles of thermal energy storage systems:

Basic principle is same in all TES applications. Energy supplied to a storage system for removal and use at a later time. What mainly varies is the scale of storage and storage method used. Seasonal storage requires immense storage capacity. Seasonal TES requires storing heat in aquifers and another is evacuating Warmed air into underground caverns packed with solids to store sensible heat. TES processes include 3 steps:

(i) Charging

(ii) Storing

(iii) Discharging

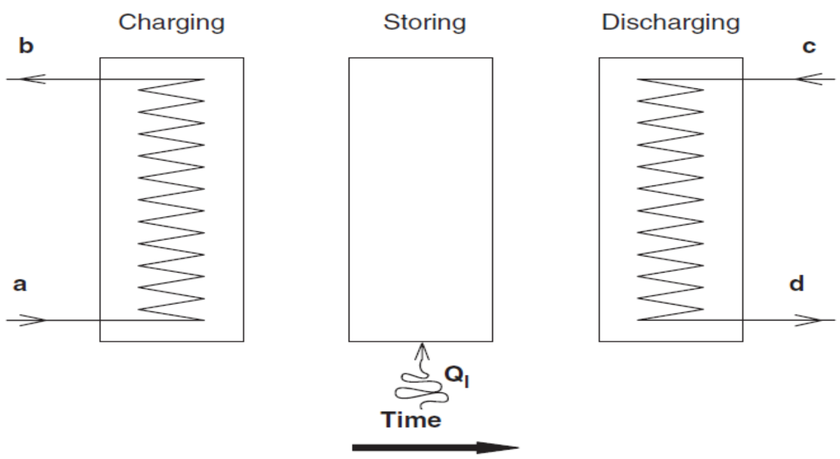


Figure.1.2.2: Thermal energy storage processes

The three processes in a general TES system: charging (left), storing (middle), and discharging (right).The heat Q is infiltrating and is positive in value for a cold thermal and is positive in value for a cold thermal storage. If it is released, it will move towards surroundings, Q will be negative. The heat flow is illustrated for a storing process, but can occur in all three processes.

1.4 SENSIBLE HEAT THERMAL ENERGY STORAGE (SHS):

In sensible TES, energy is stored by changing the temperature of a storage medium such as water, air, oil, rock beds, bricks, sand etc. The amount of energy input into the TES by a sensible heat device is proportional to the difference between the storage final and initial temperatures, the mass of the storage medium and its heat capacity. Sensible TES consists of a storage medium, a container and input, output devices. Containers must both retain the storage material and prevent losses of thermal energy. Sensible TES materials undergo no change in phase over the temperature encountered in storage process.

The amount of heat stored in a mass of a material can be expressed as:

$Q = mCp\ \Delta T = \rho CpV\Delta T$

Cp is the specific heat of the storage material.

ΔT – temperature change

V - Volume of storage material.

ρ- Density of storage material.

The ability to store sensible heat for a given material strongly depends on the value of the quantity ρCp.

Water has a high value and is inexpensive, but being liquid must be contained in a better quality container. Another important parameter in sensible TES is the rate at which the heat can be released and extracted. This characteristic is a function of thermal diffusivity.

1.5 LATENT HEAT THERMAL ENERGY STORAGE (LHS):

Latent Heat storage is based on the heat absorption or release when a storage material undergoes a phase transition from solid to liquid (or) liquid to gas or vice versa. The storage capacity of the LHS system with a Phase change material (PCM) is given by:

$$Q = \int_{T_i}^{T_m} mC_p\,dT + ma_m\Delta h_m + \int_{T_m}^{T_f} mC_p\,dT$$

$$Q = m[C_{sp}(T_m - T_i) + a_m\Delta h_m + C_{lp}(T_f - T_m)]$$

1.5 Classification of PCMs:

A large number of PCMs are available, classification of PCMs is given by:

There are large number of PCMs, which can be identified as PCM from the point of view of melting temperature & latent heat of fusion.

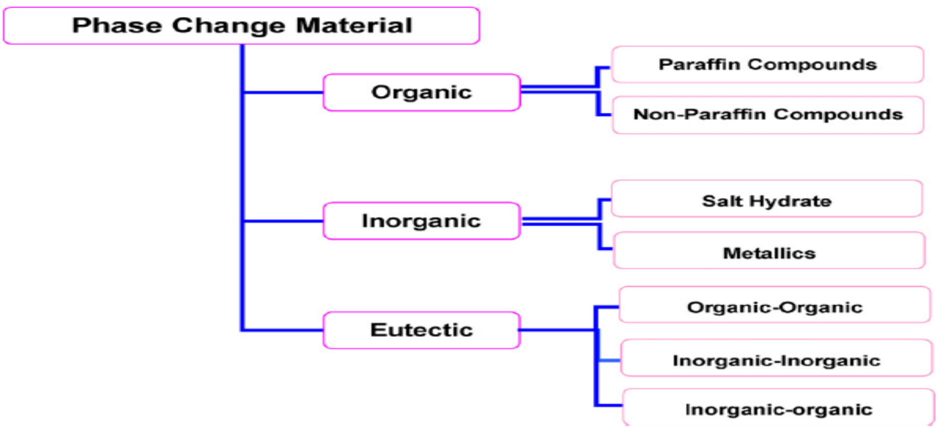


Figure.1.6.1: Classification of PCMs.

1.6.1 Organic phase change materials:

Organic phase change materials are divided as:

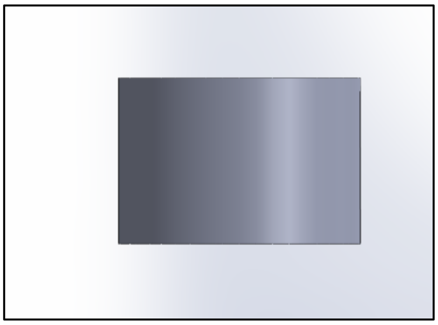
I. Paraffins

II. Non – paraffins.

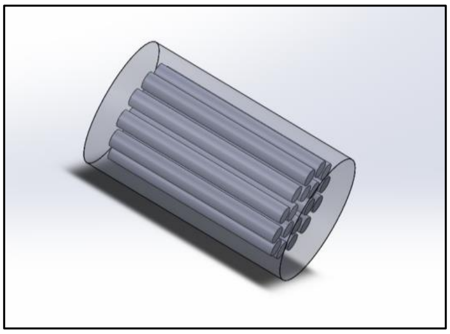
III. Fatty acids

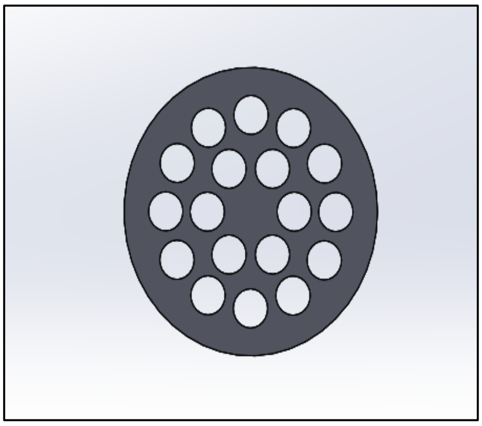
Organic paraffin's include congruent melting means melt and freeze repeatedly without phase segregation without and consequent degradation of their latent heat of fusion, self-nucleation means they crystallize with little or no super cooling and usually non corrosiveness.

2. NUMERICAL MODEL

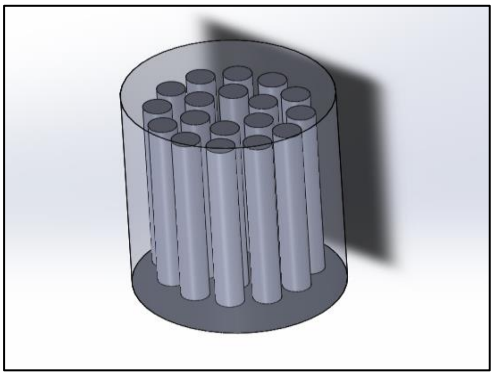


FRONT VIEW





TOP VIEW



OVERVIEW

Workbenches used:

Geometry : Solidworks

Meshing : ANSYS Hyper Mesh 13

Solver : ANSYS FLUENT 16

3. BOUNDARY CONDITION

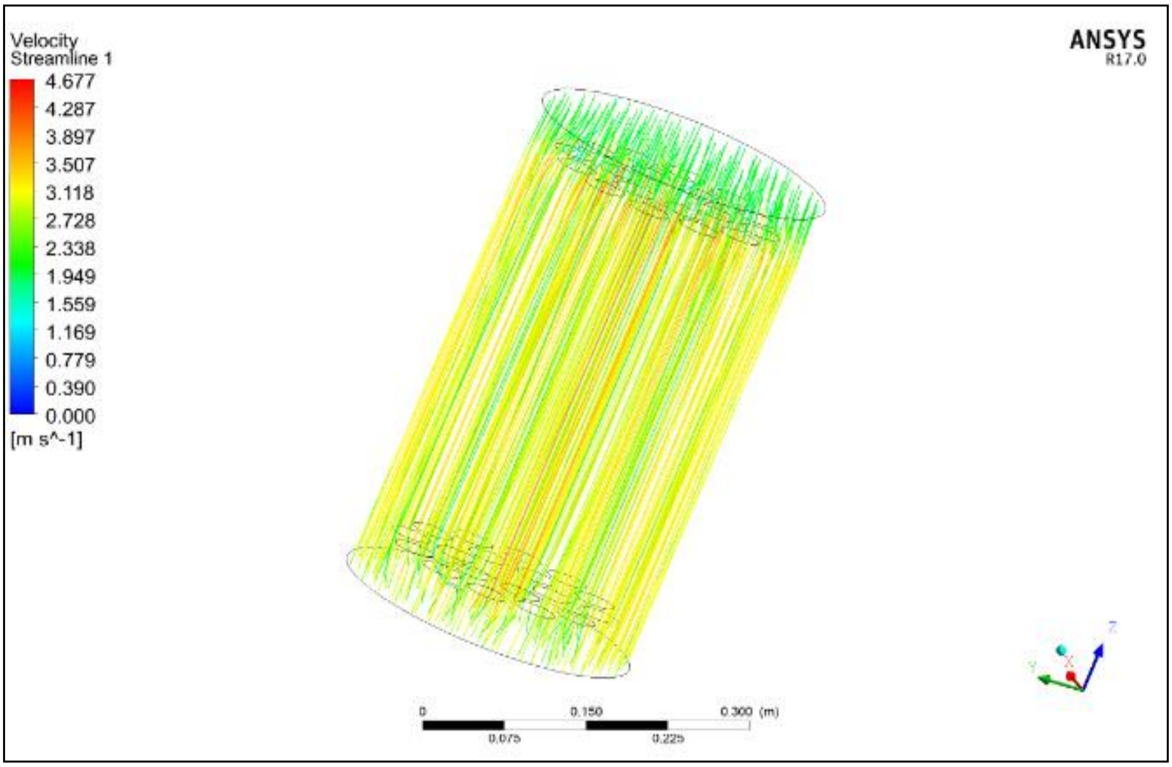
PCM material selected	PARAFFIN WAX	
Liquidus temperature	320	K
Solidius temperature	318	K
Latent heat of fusion	226	KJ/Kg
specific heat (liquid and solid phas	2384 & 1850	J/KgC
Density (liquid and solid phase)	778 & 861	kg/m3
Temperature inlet, cases	325, 330, 336	K
Inlet velocity through the tube	0.5, 1, 1.5, 2, 2.5	m/s

4. RESULT & DISSCUSSION

CASE 1:

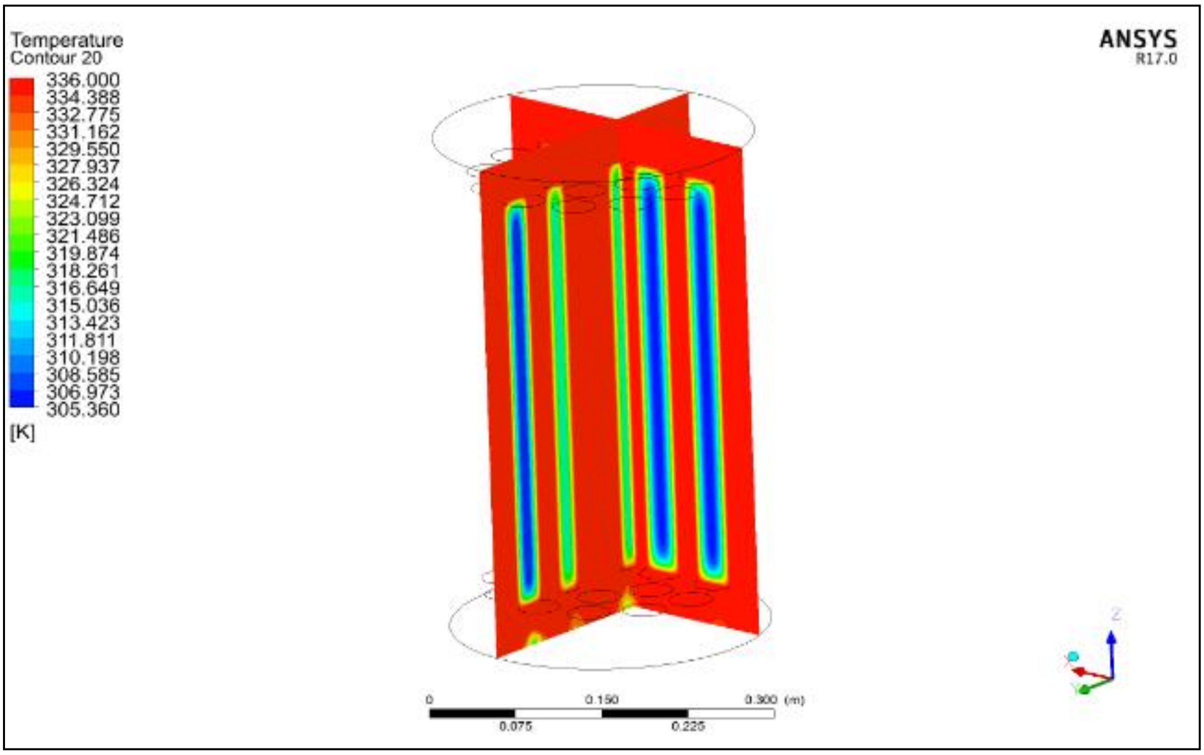
The charging and discharging cycle with mass flow rate **0.5, 1, 1.5, 2, 2.5m/s**

➢ Velocity streamline



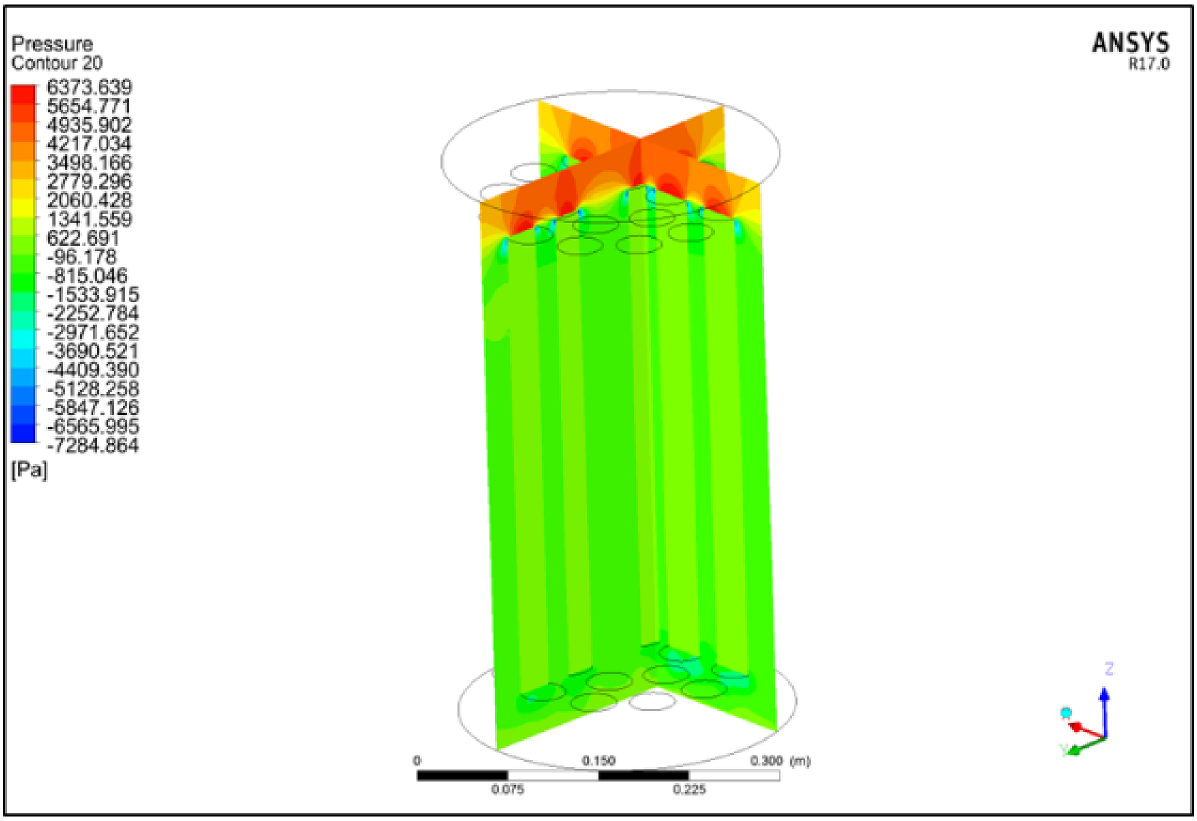
There is no change in the velocity of flow through the tank. The light green colour shows, throughout the length of tank no change in velocity.

➢ Temperature contour for the midplane:



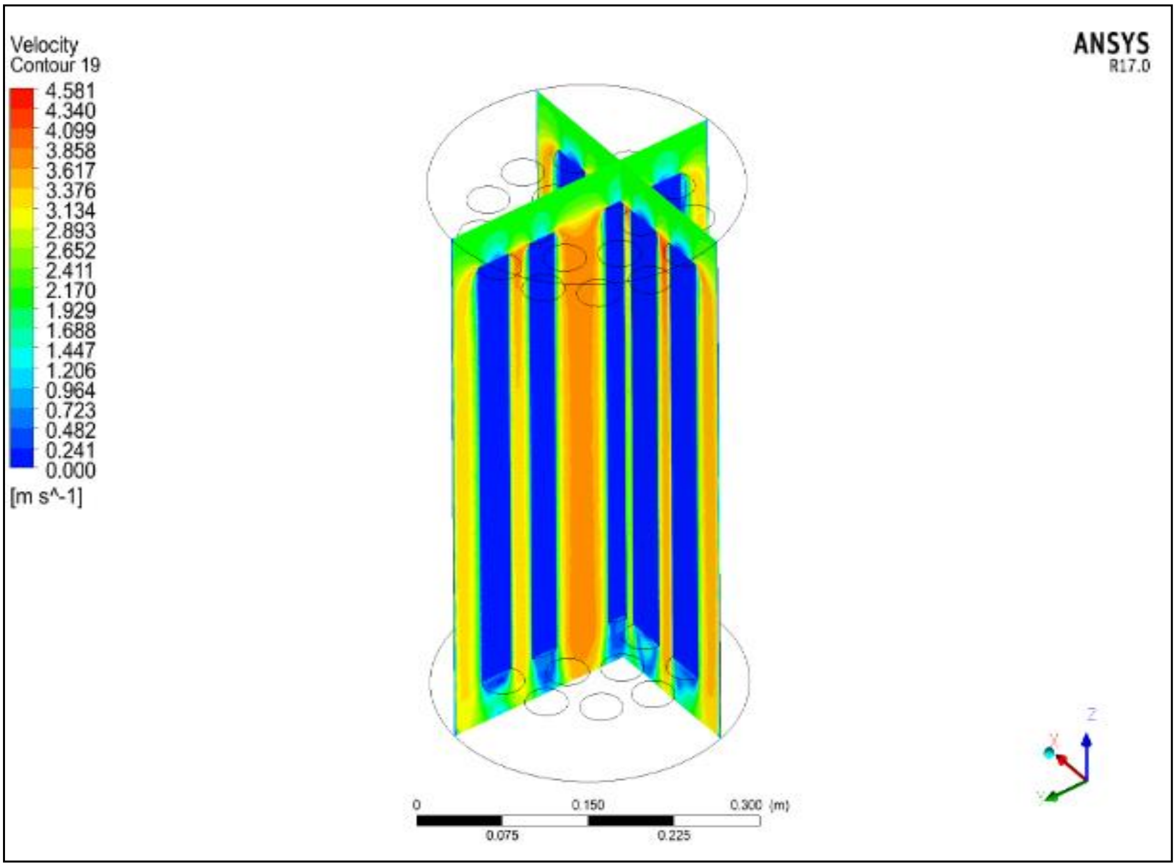
The temperature contour plot shows the temperature variation at different regions of the tank during charging cycle. The red colour shows maximum temperature region. The tubes which are encapsulated with PCM initially absorbs heat from the fluid. At the end of charging cycle both the fluid temperature and PCM temperature will be the same as shown in the above plot.

➢ Pressure contour for the midplane:



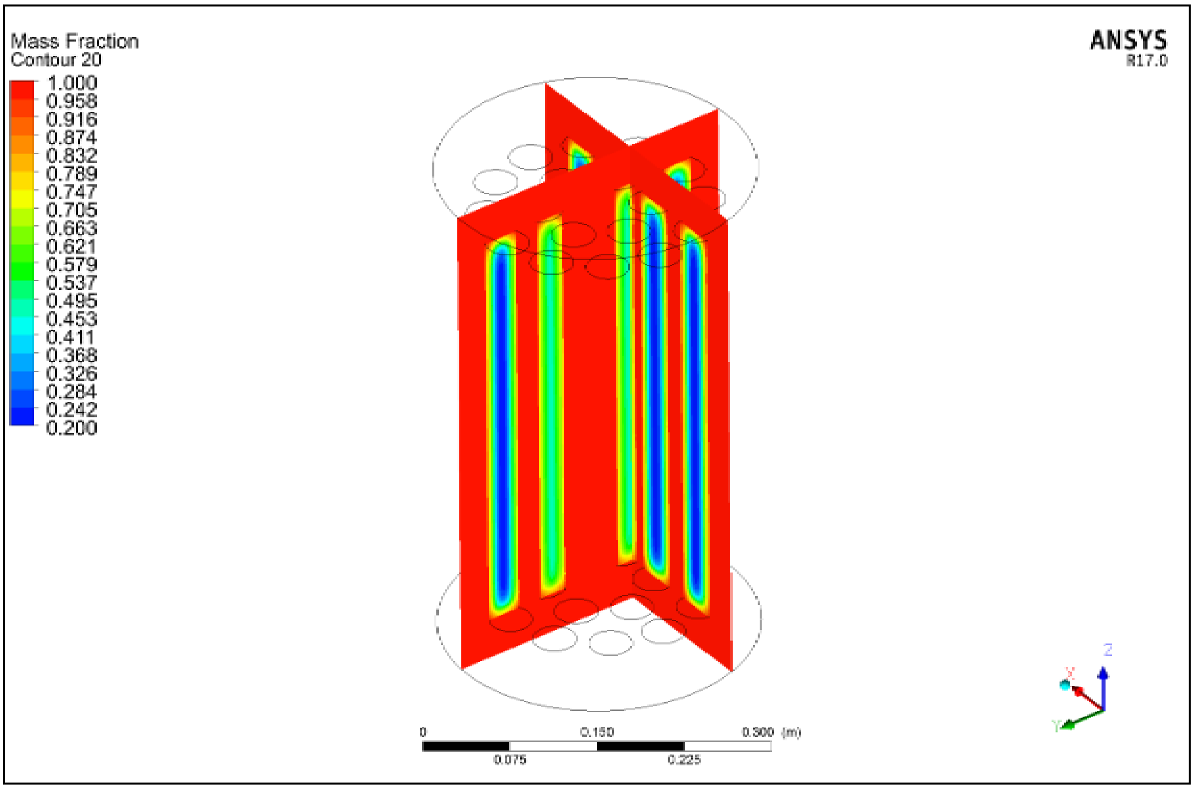
There is no change in pressure throughout the flow through tank and tube.

➢ Velocity contour for the midplane:



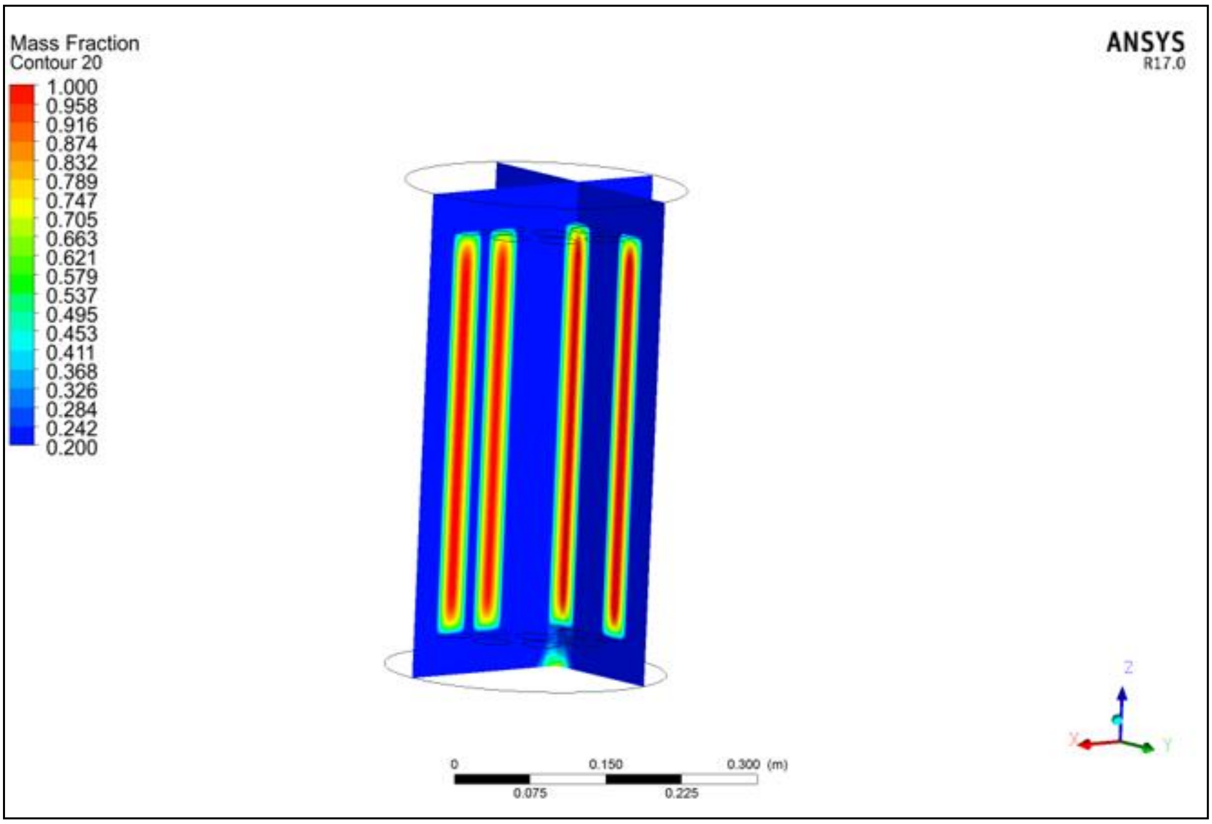
The above figure shows that there is no flow occurring through the tube. The velocity through the tube is zero. There will be flow only through tank expecting the tube.

➢ Mass fraction of liquid in charging cycle:



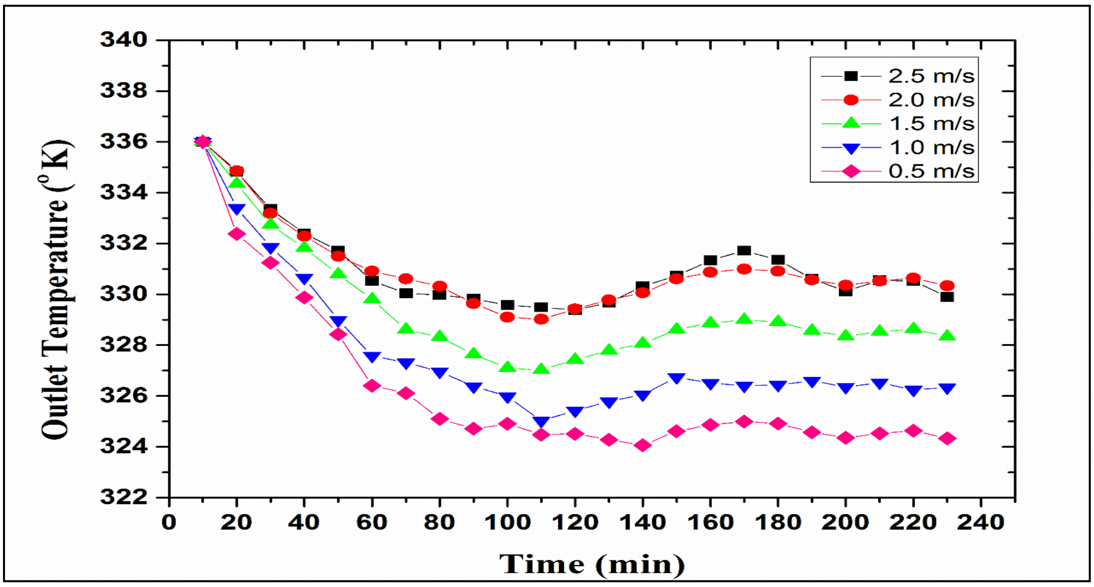
The blue shade indicates solid PCM. It gradually melts as the temperature increases. When the mass fraction reaches 1 the PCM will be in liquid stage, so the temperature of fluid and PCM will be same. Mass fraction indicates the charging cycle is numerically modelled correctly.

- Mass fraction of liquid in discharging cycle:



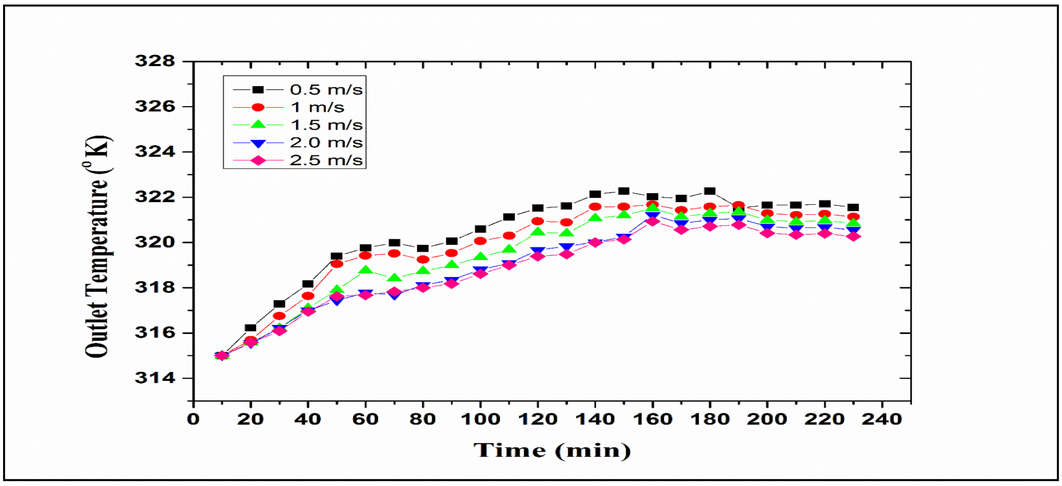
The PCM inside the tube gradually change it phase from liquid to solid when the temperature drops below solidus temperature. The blue shade indicates solid PCM inside the tube.

- Different mass flow rate for charging cycle:



The above graph plots outlet temperature variation when we pass fluid at different mass flow rate with respect to time. When we take a standard outlet temperature 320K, it is better to go with 2.5m/s and 2m/s. But when taking 2.5m/s there will be large fluctuation for the outlet temperature So we take 2m/s as the optimum flow rate.

➢ Different mass flow rate for discharging cycle:

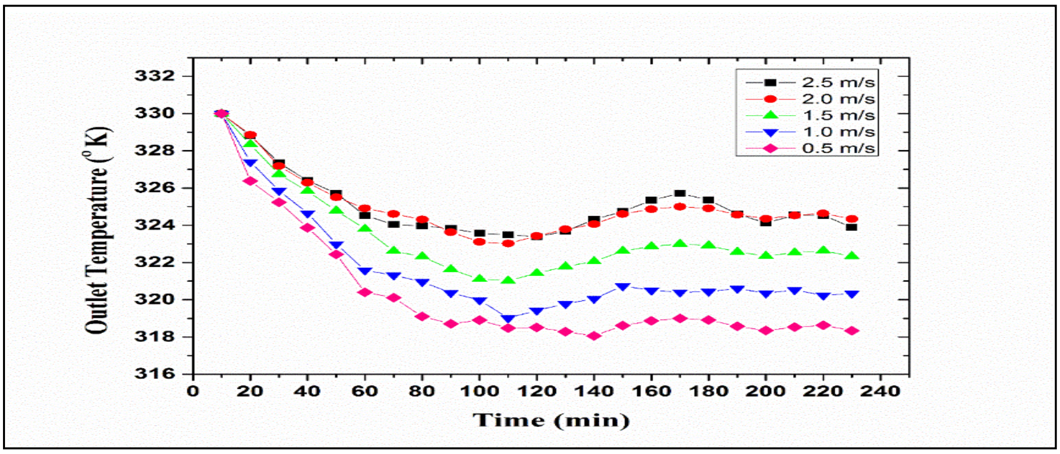


For the discharge cycle we take the initial temperature as 315K. The above graph shows 0.5m/s gives maximum outlet temperature. But 1m/s is the optimum as 0.5 m/s is difficult to maintain in practical conditions. Also the graph shows some fluctuation. This is because of both discharging and charging phase some time occurs.

CASE 2:

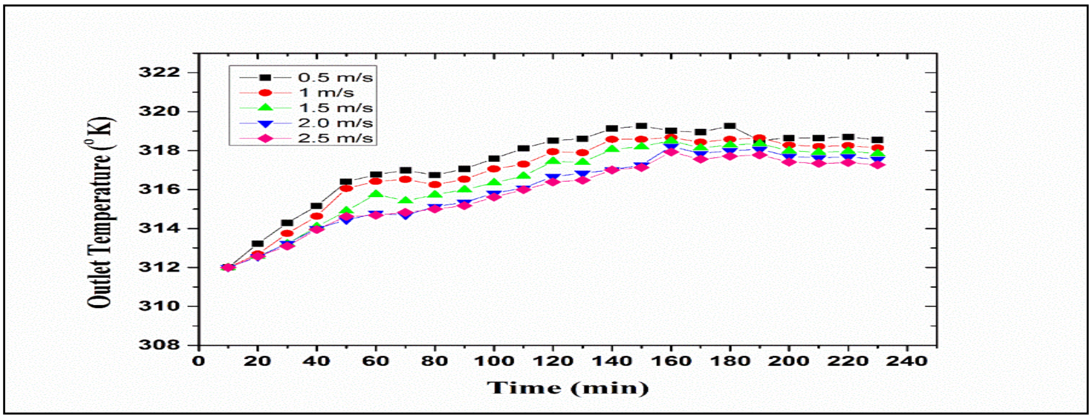
Changing inlet temperature: (336K, 330 K, 325 K):

Charging cycle (330K):



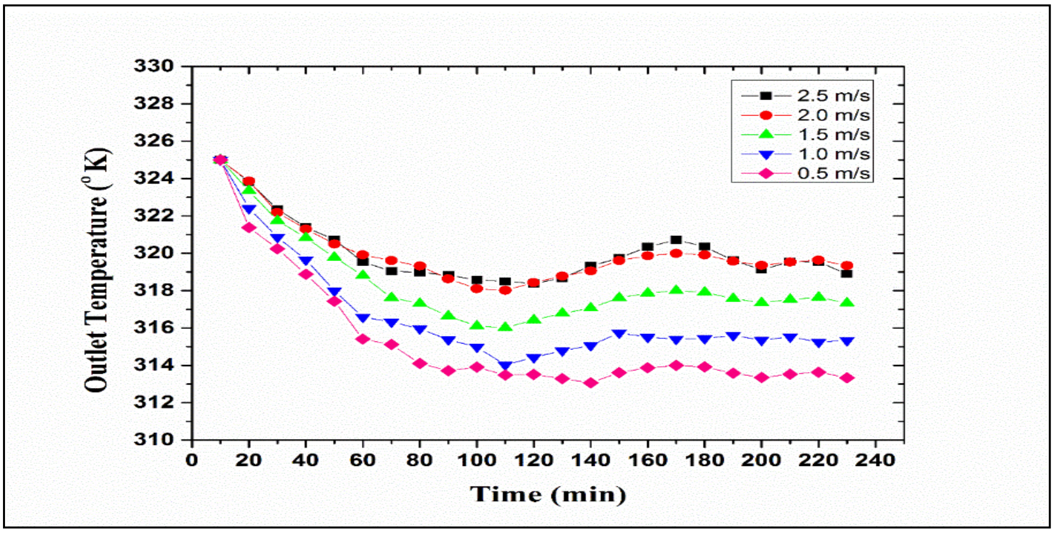
2m/s is the optimum as 2.5m/s shows more fluctuation

Discharging cycle (330K):



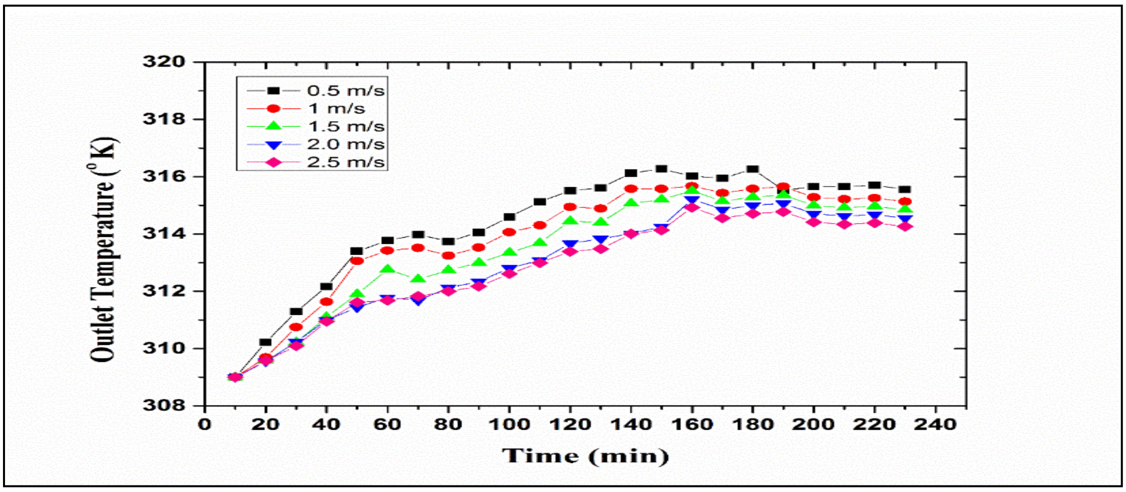
1 m/s is the optimum as 0.5 m/s is difficult to maintain in practical conditions

Charging cycle (325K):



2m/s is the optimum.

Discharging cycle (325K):



1 m/s is the optimum as 0.5 m/s is difficult to maintain in practical conditions

With all temperature inlets, the pattern followed is same and thus it can be concluded that the inlet velocity 2m/s is the optimum for charging cycle and 1m/s for discharging cycle.

CASE 3:

With Different PCM Materials:

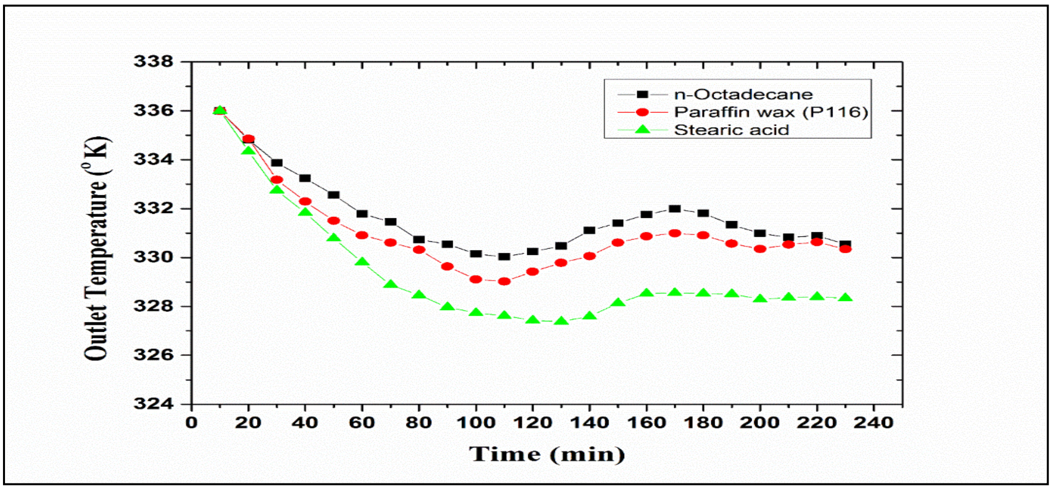
We choose three different PCM materials which are easily available in the market. The properties of this PCM are given below;

Thermophysical properties of phase change materials.

	ρ (kg/m^3)	c (J/kg K)	k_s, k_l (W/m K)	ΔH (kJ/kg)	T_m (°C)
n-Octadecane	771	2222	0.358, 0.148	243.5	27.5
Paraffin wax (P116)	802	2510	0.358, 0.24	226	47
Stearic acid	903	1590	0.29, 0.29	169	58

With this three PCM we analysis only the charging cycle After analysing we will get the graph as shown below;

International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 4, Issue 1, pp: (85-97) Month: April 2016 - September 2016, Available at: www.researchpublish.com



This graph shows n-Octadecane will give maximum outlet temperature when the mass flow rate at 2m/s. But considering the cost we will choose paraffin wax as the PCM inside the tube.

CASE 4:

Efficiency of different PCM:

Formula for calculating efficiency of PCM;

$\eta = Q/SAdt$

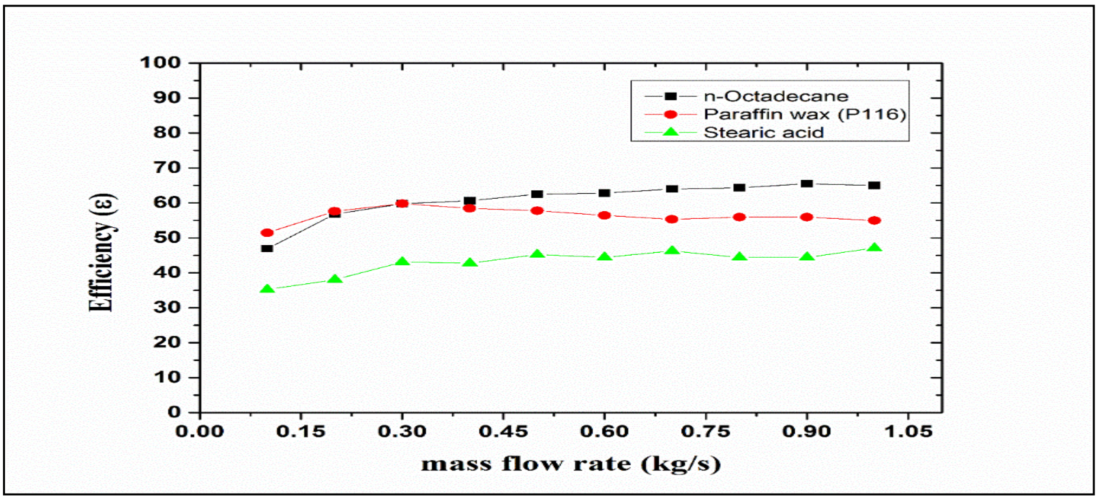
where,

Q – Heat stored in PCM

S – Radiation by sunlight on solar panel

A – Area of solar panel

dt – change in temperature



Efficiency curve suggest that n-Octadecane is the best material from the selected one. When the mass flow rate is around 1m/s there will be maximum efficiency for all selected PCM. But considering the expense we stick on with paraffin wax.

5. CONCLUSION

The study is undertaken to conduct the numerical analysis of thermal storage system using phase change materials. In phase II analysis of PCM materials is done with CFD software – ANSYS Fluent. With a flow rate of 2m/s in the charging phase and 1m/s in the discharging phase will give maximum output temperature. Also there will be no change in the pattern of output temperature for the input temperatures 325, 330, 336. When we take different PCM such as n-

Octadecane, Paraffin wax, Stearic acid; n-Octadecane will give maximum efficiency around 65%, but considering the cost of PCM we stick with Paraffin wax which gives an efficiency around 60%.

REFERENCES

[1] Saitoh, T., Hirose, K., 1986. "High performance phase-change thermal energy storage using spherical capsules".*Chemical Engg. Commun*, 41: 39-58.

[2] Takayaki Watanabe, Hisashi Kikuchi and Atsushi Kanzawa, 1993, "Enhancement of charging and discharging rates in a Latent Heat Storage System by use of PCM with different melting temperatures", *Heat Recovery Systems & CHP*, 13: 57-66

[3] Velraj, R. and Seeniraj, R.V., 1999, "Heat transfer studies during solidification of PCM inside an internally finned tube", *Journal of Heat Transfer*, 121: 493-497

[4] Keumnam Cho and Choi, S.H., 2000, "Thermal characteristics of paraffin in a spherical capsule during freeing and melting processes", *Int. J. Heat and Mass Transfer*, 43: 3183-3196

[5] Nallusamy, N., 2003, "Effective utilization of solar energy for water heating applications using combined sensible and Latent heat storage system", Proc. of the International Conference on New Millennium Alternate Energy Solutions for sustainable development", PSG Tech, pp- 103-108.

[6] Bellecci, C., Conti, M., 1993a, "Phase change thermal storgae: transient behaviour analysis of a solar receiver/storage module using the enthalpy method", *Int. J. Heat Mass Transfer*, 36: 2157-2163.

[7] Mehling, H., Cabeza, L.F., Hippeli, S., Hiebler, S., 2003, "PCM-module to improve hot water heat stores with stratification", *Renewable Energy*, 28(5): 699-711.

[8] Ghoneim, A.A., Klein, S.A., 1989, "The effect of phase-change material properties on the performance of solar air-based heating systems", *Solar Energy*, 42(6): 441 – 447.

[9] Hoogendoorn, C.J., Bart, G. C. J., 1992, "Performance and modelling of latent heat stores", *Solar Energy*, 48(1): 53-58.

[10] H.K Versteeg & W Malalasekera., "An Introduction To Computational Fluid Dynamics".