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Solar Driven Air Conditioning System Integrated With Latent Heat Thermal Energy Storage

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Abstract

This work is to investigate and validate of solar thermal storage system integrated with phase change material (PCM). The existing system is suggested to setup a Storage tank with phase change material (PCM), between the Solar concentrate dishes and Vapour absorption machine (VAM). The storage tank was used instead of an Electrical AC compressor, by which the renewable energy can be utilized to its full extent. Numerical Simulation is done and the Total Heat output, Temperature distribution along the bed, Pressure, charging time, discharging time, Mass flow rate are calculated. The storage system contains Erythritol as PCM in HDPE spherical capsule, having the storage capacity 345,121 KJ/hr (for the storage tank capacity) considering the latent heat and sensible heat of the Heat transfer fluid.

Keywords: Vapour Absorption Machine (VAM), Phase Change Materials (PCM), Erithritol, Storage Tank, Numerical Simulation.

1. Introduction

Due to the environment pollution, because of the conventional refrigerants used and the same has ozone depletion and global warming complaints also said by Lof [1]. After the environmental norms has banned use of all these refrigerants for domestic purpose.so they have to move on some other alternative system like vapour absorption and non-hazardous refrigerants also stated by Arivazhagan.[2] Comparing with all other vapour absorption machines are running in less power and harmless to nature Heating and cooling devices are widely used in various industries and domestic application by Chinnappa.[3] The other side there are large quantity of low grade heat energy is being wasted in many industries, which can be reused for cogeneration and the energy wastage can be avoided by Hattem[4] Among all the heat driven devices absorption cycles can use these low grade heat from various sources and also these absorption cycles can be more environment friendly by reducing the emission of chlorofluorocarbon (CFC) and carbon dioxide. It requires very low or no electrical input Al.Karaghouli et al.[5] The physical dimensions of an absorption refrigeration system due to the high heat and mass transfer coefficient of the absorbent for the same cooling capacity Ziegler[6] Although a number of studies have been reported employing various absorption cycles Izquierdo[7]

2. Solar Energy and Thermal Energy Storage

We know that enormous amount of energy is available in solar energy to utilize, but the main drawback is it is an intermittent type of energy Li [8] On cold weather day and even bad weather days we cannot trap the solar energy. To overcome this problem the thermal energy storage technology is introduced by Nguyen[9] One option is cool thermal storage and the other is having alternate electrical driven vapour compression chiller system or direct fired vapour absorption system Chinnappa[3] This implementation can increase the both operational and initial erection cost Yeung et al.[10] But this conventional thermal energy storage with low energy storage density restricts its usage Chen [11]

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2.1 Storage of Thermal Energy

Thermal energy can be stored by sensible heat storage and latent heat storage methods by Atul Sharma [12]

Sensible Heat Storage

Thermal energy is stored by raising the temperature of a solid or a liquid medium by using its heat capacity. The volume of thermal energy kept in the form of sensible heat can be designed by

$$Q = \int_{T1}^{T2} m \times Cp \times dT = m \times Cp \times (T2 - T1) \qquad \text{(i)}$$

Here Q is the value of the thermal energy charged or discharged .T_1,T_2 is the temperature values.

2.2 Latent Heat Storage

A lot of thermal energy is charged or discharged during the phase change period of the materials. It is calculated by Thirugnanasambandam[13]

$$Q = m * LH \qquad \text{(ii)}$$

Here Q is the value of the latent heat energy charged or discharged by the given mass of the materials.

2.3 Solar Concentrate Dish

Here solar parabolic dish is installed. It has the two axis Fresnel lens. Its aperture area is 169 m^2 and a cavity absorber focus point.

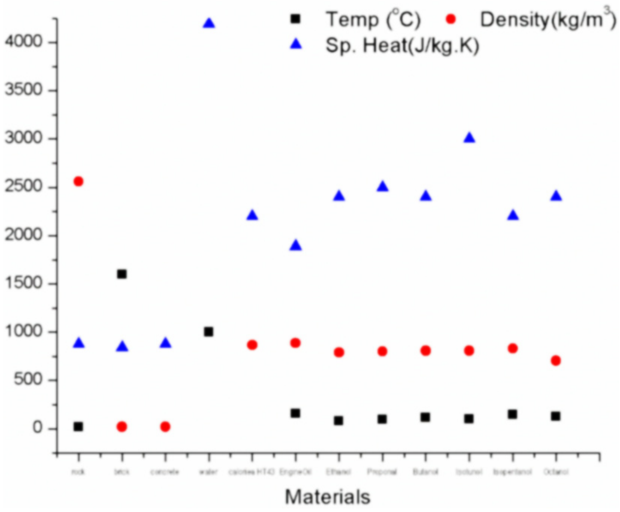

Figure 1. Properties of Sensible Heat Storage Materials.

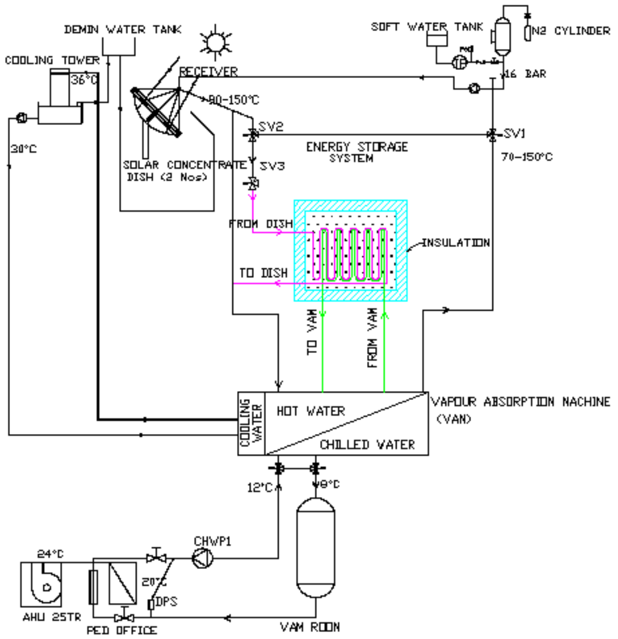

Figure 2. Schematic representation – Recommended System.

Operating parameters of the system:

- Water flow rate to dish supplied by circulating pumps = 5000 Ltr/hr
- Pump inlet pressure (maintained by expansion vessel) = 12 Bar
- Pump Discharge pressure = 15 bar
- Hot water inlet (to dish) temperature = 150°c (design)
- Hot Water Outlet (from dish) temperature = 180 °c (design)
- Chill water outlet VAM = 8 °c
- Chilled water inlet VAM = 12 °c

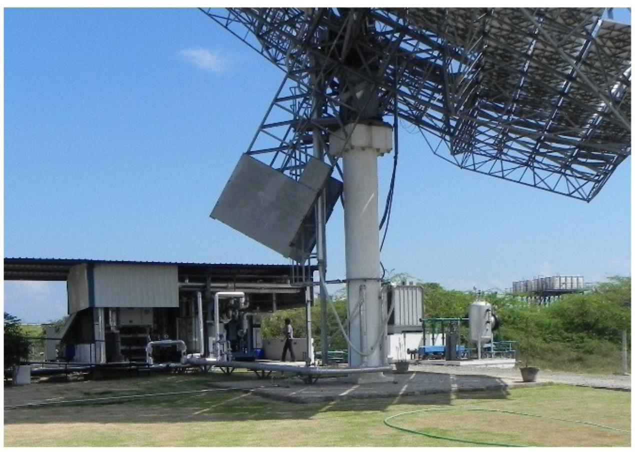

Figure 3. Solar concentrate dish with VAM.

2.4 Vapour Absorption System

A centrifugal kind pump is used for circulating the water to concentrate dishes. The pump release pressure is enough to circulate through the system. The system is kept pressurized at 15 bar pressure to avoid the steam formation in the circuit. The pressurized water at 15 bar pressure ,without steam is heated upto 180^{o} C through the solar concentrator. It is about 117 KW. Which is adequate for the heat requisite of the vapor absorption machine. An energy storage method to be installed between the Concentrate dishes and VAM to store the solar energy through Phase change material (PCM). The PCM to be selected based on the output of the concentrate dishes. The vapor absorption machine (VAM) installed is hot water driven. Pressurized water at 180°C is essential for the machine to function at an ideal level. The machine with 35 TR capacities requires 5 m^3/hr of the pressurized hot water which can be catered to by 2 Concentrate dishes. The solar circuit is kept pressurized at 15 bar using the nitrogen pressurization system. The nitrogen chambers are connected to the expansion container in the route, for this purpose. Energy storage system is place in between the Concentrate dishes and VAM to utilize the renewable energy during the absence of Sunrays. The Energy storage system is Filled with Phase Change material (PCM) for storing and releasing the energy when required.

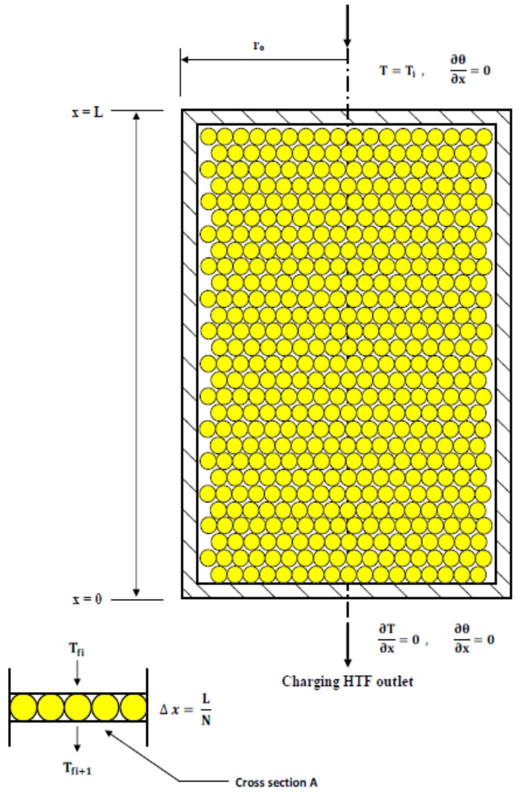

Figure 4. Boundary condition representation of storage tank.

4. Radiant heat transfer between the capsules is negligible.
5. There is no internal heat generation in the bed.

3. Energy Storage Container with Phase Change Material(Erythritol)

The most important issues to be deliberated in the plan of a storage unit having a PCM include Felix Regin.[14,15]

- Temperature restrictions are to be considered.
- Number of Spheroids inside the storage container.
- The storage size of the container.
- The kind of heat transfer fluid.

3.1 Assumptions Involved in the Present Work ,Kyaw Thu[16]

1. The tank is protected and upright with flow from the top when charging and flow from the bottom when discharging.
2. The flow in the container is axial and incompressible.
3. The thermo physical properties of the heat transfer fluid are invariant with temperature.

3.2 System and PCM Selection

- From 40 - 60 deg of heat generation Flat plate collectors are used
- As our system requires heat of 90 – 150 deg Concentrate plate collectors are selected.
- Electrical Energy is required to operate a Vapour Compression Cycle.
- But the Vapour Absorption cycle operates based on the waste heat and renewable energy, so it can be utilized for our system.
- Vapour absorption machine is eco-friendly.
- Latent heat Storage method is better than Sensible heat storage, hence it can be used.
- Phase change material with high thermal conductivity and density should be used.
- Easy availability of phase change material.
- Multiple inlets and outlets to be provided for the storage system to improve the performance (Thermally stratified).

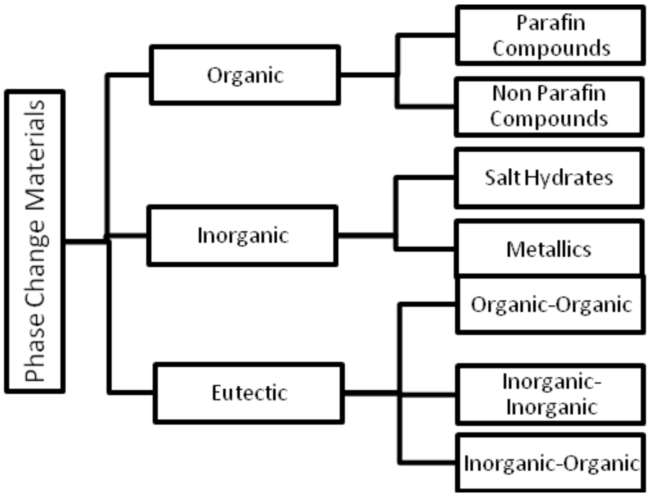

Figure 5. Organization of Phase Change Materials.

3.3 Phase Change Materials

All materials are phase change materials. But the phase change will happen at its own melting and freezing temperature values. They are classified as given in the figure

Erythritol is famously known as sugar alcohol. It is used as an alternative ingredient which can be used instead of sugar.

3.4 Thermal Properties of Erythritol

• Chemical structure	C4H10O4
• Molecular weight	122.2
• Melting point (°C)	118.0
• Heat of fusion (KJ/kg)	339.8
• Flash Point (°C)	245
• Specific heat (KJ/kg. °C) at 20 °C	1.383
• Density at 20 °C	1.48
• Heat conductivity (KJ/m.h. °C)	2.640

4. Mathematical Model

4.1 Introduction

In this chapter, the thermal performance of the heat transfer fluid (HTF) and the phase change material (PCM) spheres in the solar thermal storage system is studied mathematically. The solar system consists mainly of a solar collector and a storage unit. The storage unit is a cylindrical tank loaded with a packed bed of PCM spheres. A theoretical analysis is made for the heat transfer process between the HTF and the PCM spheres during charging and discharging processes.

The mathematical models that have been reported in this for studying the thermal performance of a packed bed LTES are divided into two main groups. The first group is the single phase model where the solid phase and the fluid phase in the packed bed are considered as one phase. The second group called the two phase model where the packed bed is represented by two different phases that are solid and fluid. The continuous solid phase model and the concentric dispersion model are two examples for the two phase model.

Details of these models are discussed as follow:

4.2 Single Phase Model

`The solid and fluid phases have the same instantaneous temperature. The governing energy equation in the 2-D case is given by Siu & Lee[17]:

$$(1-\varepsilon)\rho_s C_s + \varepsilon\rho_f C_f \frac{\partial\varphi}{\partial t} + G\,C_f \frac{\partial\varphi}{\partial x} = k_{fr}\left[\frac{\partial^2\varphi}{\partial r^2} + \frac{1\partial\varphi}{r\,\partial x}\right] \tag{iii}$$

Where, x and r are the axial and radial coordinates inside the packed bed latent energy storage tank.

4.3 Concentric Dispersion Model

The thermal conduction inside the solid spheres is taken into account in the concentric dispersion model (i.e. thermal gradient inside the solid spheres). The energy equation for the fluid phase is

$$\varepsilon\rho_f C_f\left(\frac{\partial T}{\partial t}+u_f\frac{\partial T}{\partial x}\right)=k_{fx}\frac{\partial^2 T}{\partial x^2}+h_p a_p(\vartheta_{\eta=\eta_0}-T)-u_w a_w(T-T_0) \tag{iv}$$

Whereas the energy equation for the solid phase is

$$\rho_s C_s \frac{\partial\vartheta}{\partial t}=k_s\left[\frac{\partial^2\vartheta}{\partial\eta^2}+\frac{2\partial\vartheta}{\eta^{\partial}\eta}\right] \tag{v}$$

Where T and ϑ are the temperatures of the fluid phase and the solid phase, respectively. η is the radial coordinate inside the solid sphere. If the temperature gradient is considered inside the solid sphere, the following two boundary conditions are required

$$k_s\frac{\partial\vartheta}{\partial\eta}=h_p\,(T-\vartheta_{\eta=\eta_o})\ \text{at}\ \eta=\eta_o \tag{vi}$$

$$\frac{\partial\vartheta}{\partial\eta}=0\ \text{at}\ \eta=0 \qquad \text{(vi)}$$

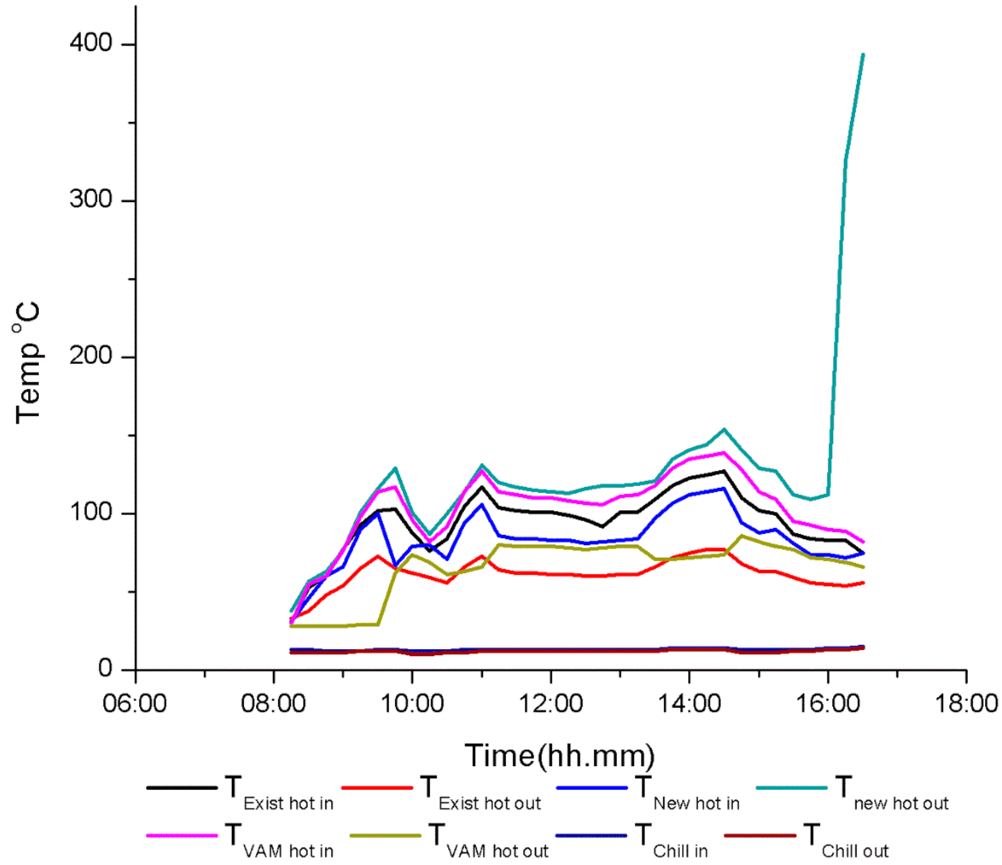

Figure 6. Existing Vs New System Hot water in/out Temperatures.

These two boundary conditions assume a thermal equilibrium between the PCM spheres and the flowing flow.

Solar Running Time	= 9 Hours
VAM running Time	= 6 Hours
Chiller Power Consumption	= 51.3 KWH
Temperature difference	= 30 deg
Maximum required power	= 30,5152 KJ/HR.

4.4 Capacity of Storage Tank Calculation

System requirement

Capacity Requirement for our system to run the vapor absorption system is 35 TR.

1TR =12660.6702 KJ/HR

25TR=316516.755KJ/HR

Hence, the storage tank to be designed based on the above requirement.

Thermophysical properties of Erythritol

CHEMICAL FORMULA	: $C_4 H_{10} O_4$
Melting point	: 118.0^0c
Latent Heat	: 340 KJ/kg
Thermal Conductivity	: 0.733 w/m
Density	: 1480 Kg/m3
Specific Heat	: 1.383KJ/kg^{0}c

Number of PCM balls:

- Number of balls inside the storage tank can be arranged by triclinic method, which is best method that can accommodate more no. of balls.
- Storage tank with more number of balls will have more thermal Conductivity.
- For calculating the total balls that can be accommodated in the tank, initially it was drafted in AutoCAD.
- An excel sheet has been generated for calculating the total no. of balls and attached below for reference.
- For analyzing the charging and discharging process, void fraction plays a vital role. The same can be calculated by using the below sheet.

Triclinic arrangement

Diameter of cylinder	= 1000 mm
Diameter of ball inscribed in cylinder	= 20 mm
Radius of cylinder	= 500 mm
Radius of ball inscribed in cylinder	= 10 mm
Height of cylinder	=1500 mm
Distance b/w chords in horizontal plane	= tan60°
Radius of ball	= 17.32 mm
No. of Chords (1st Quadrant) in horizontal plane	= 28
No. of chords in vertical plane	= 86
Total spacing b/w chords (1st Quadrant) or Distance from the centre of outer circle to the last chord	= 484.97
No. of balls in vertical line joining the quadrants	= 25*2 = 50
No. of balls in horizontal line joining the quadrants	=14*2 = 28

5. Results and Discussions

Introduction

This chapter is dedicated to display and discuss the currently obtained results of the work carried out to investigate the simulation and validation of Solar Air Conditioning system integrated with phase change material using latent heat& sensible heat storage.
The results of the storage system can be driven from the

- Numerical calculation of the storage Tank
- Flow Analysis in Fluent

5.1 Numerical Calculation of the Storage Tank

Total no. of balls inscribed in cylinder (Tri-clinic arrangement) - 187652 Balls
Volume of the cylinder - 1.18 m^3
Volume of the balls filled inside the cylinder - 0.79 m^3
Void space/Unfilled volume - 0.39 m^3
% of void space/unfilled volume - 33%
Q pcm sensible heat = 48266.3 KJ/hr
Q pcm latent heat = 395530.2KJ/hr
Q water in voids = 49234.89 KJ/hr
Q total =493031.4 KJ/hr
Hence total amount of heat energy stored in the system is 345121.98 KJ/hr

5.2 Flow Analysis in Fluent

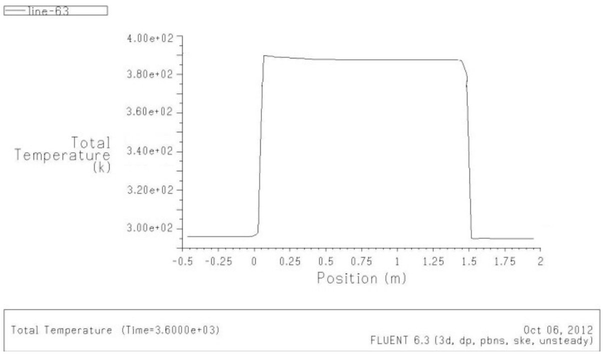

Figure 7. Charging Temperature Vs Position

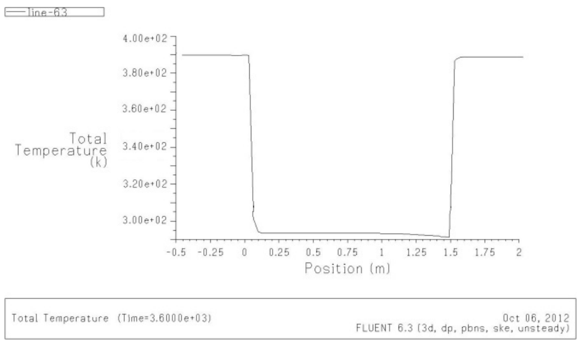

Figure 8. Discharging Temperature Vs Position.

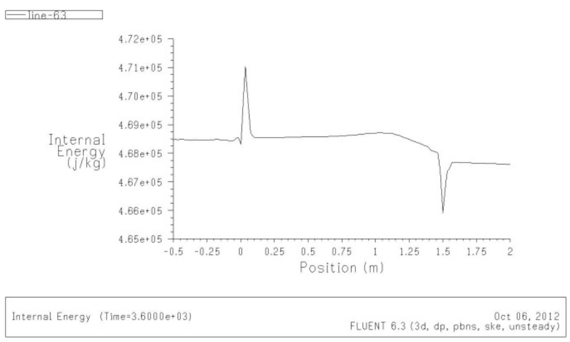

Figure 9. Internal Energy Vs Position.

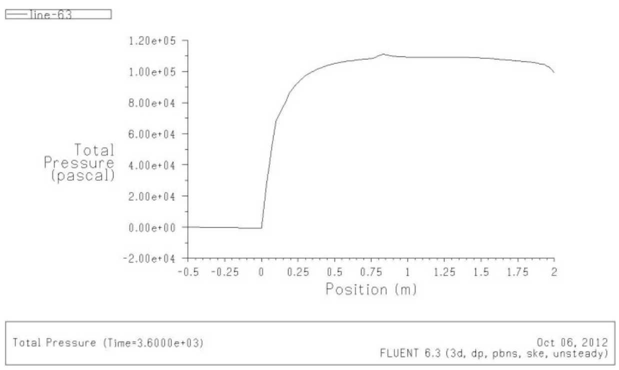

Figure 10. Total Pressure Vs Position.

6. Summary and Conclusion

6.1 Summary

Nowadays consumption rate of all types of energies are high and the available resources are very less. Hence in this project try to utilize the energy that is renewable and conventional. In this current study Numerical calculation and analysis in Fluent are done for a storage tank packed with PCM.

In this work the analysis and investigation is stimulated, in future experimental model of the system is done and verified.

6.2 Conclusion

A model for a packed bed latent heat thermal energy storage using sphere-shaped container is developed in the present work to forecast the thermal behavior of the system. This study investigates the effects of heat transfer fluid inlet temperature, mass flow rate, Phase change temperature range and the radius of the capsule on the dynamic response of a packed bed latent heat thermal energy storage system using spherical capsules for both charging and discharging modes. The following conclusions can be drawn:

1. The complete solidification time is too longer compared to the melting time. This is due to the very low heat transfer coefficient during solidification.
2. Higher inlet heat transfer fluid temperature the shorter is the time for complete charging. Similarly for higher the mass flow rate of heat transfer fluid shorter is the time for complete charging.
3. The charging and discharging rate are significantly higher for the capsule of smaller radius compared those of larger radius.

7. Acknowledgement

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