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PERFORMANCE ANALYSIS OF LATENT HEAT THERMAL ENERGY STORAGE SYSTEM USING FINS

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IN

THERMAL ENGINEERING

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CANDIDATE'S DECLARATION

I, Nitin kumar (2K21/THE/13) student of M.Tech (Thermal Engineering), hereby declare that the Project Dissertation titled — "Performance Analysis of Latent heat thermal Energy Storage System using fins" which is submitted by me to the Department of Mechanical Engineering, DTU, Delhi in fulfillment of the requirement for awarding of the Master of Technology degree, is not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project titled "Performance Analysis of Latent heat thermal Energy Storage System using fins" which is submitted by Nitin Kumar (2K21/THE/13) for fulfillment of the requirements for awarding of the degree of Master of Technology (M.Tech) is a record of the project work carried out by the student under my guidance & supervision. To the best of my knowledge, this work has not been submitted in any part or fulfillment for any Degree or Diploma to this University or Elsewhere.

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ABSTRACT

Keywords - PCM; LHTES; Trapezoidal storage unit; HTF tube with fins; HTR; Liquid fraction (LF); Charging and Discharging time.

The Purpose of the current work is to examine the performance of a PCM i.e. phase change material within a Trapezoidal shape unit to store heat energy. The Numerical simulation is done using ANSYS 22 software to simulate and analyze the results, focusing on temperature and time contours throughout melting part and solidification part of PCM. Storage unit features a square shape tube in which fins are attached to the tube to study the HTR. One main challenge encountered in PCM melting is the collection of solid material at the lowermost in a process of charging and LF rests at the uppermost during the process of discharging. The numerical simulation explains the temperature distribution across various ranges during the melting and solidification phases. The system's effectiveness and performance are enhanced by using this setup. The simulation's results show that throughout the melting process, the liquid percentage rapidly grows, reaching 78% during the first 250 minutes. This is because heat is transferred through convection and conduction. However, after then, heat is transferred primarily through conduction, which results in a decline in the rate of liquid fraction and a total melting time of 2390 minutes for the PCM. In a similar manner, following the first 250 minutes of discharge, the solid percentage increases more slowly, solidifying to about 34%. However, it takes 1660 minutes for the PCM to fully solidify. The study's finding show that using a trapezoidal form geometry and including fins may enhance the melting and solidification part for a TESs.

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I would also like to take this moment to show our thanks and gratitude to one and all, who indirectly or directly have given us their hand in this challenging task. I feel happy and joyful and content in expressing our vote of thanks to all those who have helped us and guided us in presenting this project work for our Major project. Last, but never least, I thank our well-wishers and parents for always being with us, in every sense and constantlysupporting us in every possible sense whenever possible.

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations /Symbols	**Descriptions**
LHTES	Latent heat Thermal energy system
HTR	Heat transfer rate
LF	Liquid Fraction
PCM	Phase change material
SHS	Sensible heat storage
THS	Thermochemical heat storage
LHS	Latent heat storage
K	Thermal conductivity (W/m K)
H	Total enthalpy (J/kg)
h	Specific sensible enthalpy (J/kg)
h_o	Specific enthalpy at refer temp (J/kg)
L	latent heat of phase transformation (J/kg)
C_P	Specific heat at constant pressure (J/kgK)
t	Time (minutes)
T	Temperature (K)
T_S	Solidus Temperature
T_L	Liquidus Temperature
T_M	Melting Temperature
P	Pressure (pascal)
g	Acceleration due to gravity (m/s^{2})
S_X	Momentum in X direction (Pascal/ m)
S_Y	Momentum in Y direction (Pascal/ m)
Sz	Momentum in Z direction (Pascal/ m)
u	linear velocity in the X direction (m/ s)
v	linear velocity in the Y direction (m/ s)
x, y	Cartesian coordinate system (m)
ρ	Density (kg/ m^3)
μ	Dynamic viscosity (kg /m. s)

β	Thermal expansion coefficient (1/ K
λ	liquid fraction of PCM

CHAPTER 1

INTRODUCTION

1.1 Overview

An Increase in demand of energy is one of the major concerns nowadays. There are several types of systems to store energy for renewable use. Energy obtained from sun is unique and the primary sources of heat energy but it is not available in continuous form there is a system required to save this energy for other application uses. There is a need to develop a storage system so that the surplus energy can be used for other purposes also. Not only solar energy, waste heat energy can also be used for another industrial application purposes. This waste heat energy can be used to store in a specific form and then utilize in a specific manner the major material for the storage of the energy is PCM for the latent heat storage application.

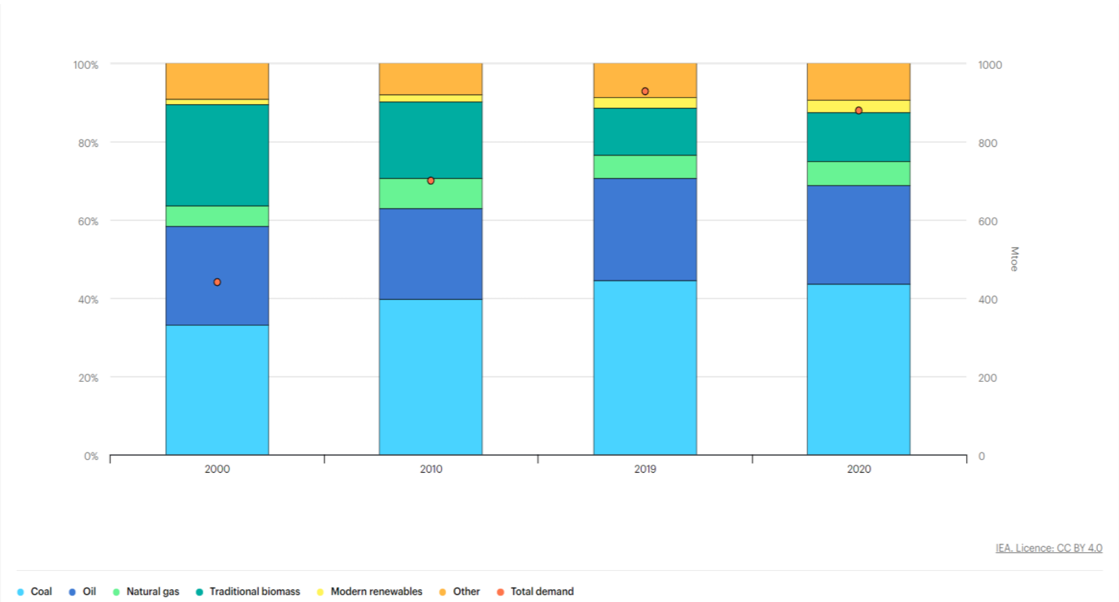

Fig. 1.1: Primary energy demand in India (Source: IEA, Total primary energy demand in India, 2000-2020, IEA, Paris) https://www.iea.org/data-and-statistics/charts/total-primary-energy-demand-in-india-2000-2020,

PCM has number of benefits for the thermal energy storage it includes the high density of energy and capability for effectively store at the constant temp condition with this addition PCM can also include into the present thermal energy system. PCM also can be used for number of the application with operating temperature range. One of the feature of PCM that they can help to reduce the size for the particular type of system this help to use the energy storage in the remote area with the limited space

PCM not only used in the solar fields but served in other fields also this include building cooling system, heating system, industrial process need and transport sector. One of the drawback of this system is to need a design parameter for process .with the care full design and optimization PCM- based system can be well designed and effective to store heat energy and reduce the dependence on the non-renewable source. At last the researcher are motivated to design the new method for the use this system so that the number of dependence of fossil fuel can be reduced and increase the potential for effective utilization of this energy.

1.2 Objectives

The reason of the current work is to examine the functioning of a PCM i.e. phase change material within a Trapezoidal shape unit to store heat energy. The study utilizes ANSYS 22 software to conduct simulations and analyze the results, with a specific focus on temperature and time contours during the solidification part and melting part of the Phase Changing Material. The storage unit in question comprises a square-shaped tube, and fins are incorporated to improve the HTR with in system.

1.3 Motivation

Phase change materials (PCMs) serve two main purposes: thermal energy storage and temperature control within a particular variety. The functioning principle of a Phase Changing Materials involves absorbing heat and changing to liquid phase from a solid phase as the temp. Increases to its melting point. Conversely, when the temp drops below the temperature of the melting point, the phase changing material discharges heat energy and returns to its solid phase.

PCMs possess various properties that make them suitable for different applications. In the context of building envelopes, PCMs can be utilized due to their favorable chemical characteristics, thermal characteristics and physical characteristics. Sugar-alcohols, known as polyols are the bio-based materials that offer attractive PCM properties. Moreover, as byproducts of the food industries, sugar-alcohols are non-toxic, environmentally friendly and non-corrosive. They exhibit high volume-specific melting enthalpy and high mass specific enthalpy equated to other organic Phase Changing Materials, making them appropriate for numerous thermal energy storage system (TES) applications. Sugar alcohols typically have melting range temp between 90°C and 200°C, although little may not be stable at greater temperature range.

Among the sugar alcohols, Erythritol stands out as a assuring organic Phase Changing Materials for improving solar energy and the waste heat from the industries, especially at temp. upto a range of 160°C. Erythritol is gaining attention in the PCM field due to its appealing TES properties [10].

Overall, PCMs, including sugar alcohols like erythritol, offer exciting possibilities for thermal energy storage and temperature regulation applications, showcasing their potential in various industries.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Due to the reduction of fossil fuels & the requirement for reducing emissions, there has been an increase in the demand for renewable energy sources in recent years. To meet this demand, researchers have been exploring new technologies and apparatus that can store energy effectively and economically. PCMs have emerged as unique and single most of the promising material for TES due to their potential heat storage ability. The text discusses various research is connected to the usage of PCM for heat energy storage utilization. These substances are used for efficient energy storage as they are able to absorbed energy i.e. heat from the source and then change its phase into a liquid, known as the charging state. In the lack of a source of energy, they can discharge the stored energy, referred to as the discharging state. Several studies investigate the performance of different PCMs during the charging phase and discharging phase, material used for this are most of the organic and inorganic PCM. Erythritol is one of the promising PCM which can be used for the medium range application purpose. The purpose of the research is to advance heat i.e. thermal energy storage devices that are more effective and affordable and can use renewable energy sources.

2.2 Literature Review

For the storage of energy there is different studies based on the characteristics such as temp. at the starting inlet and the Heat Transfer Fluid flow rate, the Phase Changing Material unit's geometry, and the thermal-conductivity of the medium of storage. Solar cooker is the focus of modeling and numerical simulation research by [1]. Erythritol has the ability to reach the greatest temperature both during the charging period and at starting of 54 minutes of the discharging period, according to the study, which compares the functioning of different selected PCM in charging phase and discharging phase.

The solidification and melting behavior of Erythritol PCM were investigated in experimental investigation on phase change material with double spiral coil (PCM) by [2] According to the study, this technique considerably improved HT rate. As the rate of flow and entry temp of the Heat Transfer Fluid decrease, so does the amount of time needed to melt the PCM. The parameters related to heat of the discharging operation and charging operation of a constructed energy storage system of heat employing PCM were examined by [3]. The study discovered that paraffin wax, a latent heat storage medium, has far larger thermal energy storage densities than other materials allowing it to engross or relief huge amounts of energy while maintaining the steady temperature. The varied thermal energy storage techniques were investigated by [4] with a focus on cost reduction using various storage materials. Inorganic substances like salts of nitrates are the most commonly employed thermal energy storage substances in high-temperature zones, according to their study, whereas organic substances are used in lower and middle range temperatures applications.

The study shows improving the thermal-conductivity of TESs materials is main focus areas. [5] Found the importance of the geometry of the Phase Changing Materials container in storage of heat energy. They highlighted the usage of Phase Changing Material as an assuring technology for TES. [6] To reviewed recent research on new types of energy storage, advances, and improvements in energy storage. [7] To explain the substantial phenomenon of storage of heat energy/release in/from the solar water heater system, researchers developed a mathematical model and computational code. The study discovered that more load shifting is observed when the density and enthalpy of the PCM are increased. Overall, the literature suggests that PCM have the ability to be a assuring solution for the storage of heat energy because of their effective ability of energy storage. However, further research is needed to address the limitations of current PCM technology, including improving heat storing capacity and thermal conductivity, optimizing the geometry of PCM containers, and exploring new materials for thermal energy storage. [8] Study transient 2-D numerical research was established to investigate the melting behavior of a Phase Changing Materials within a trapezoidal cavity. The purpose of the research was to test how orientation affected Phase Changing Materials performance using paraffin wax inside the cavity. The study examined the transient heat transfer and phase change processes and added graphene nanoparticles to the pure Phase Changing Materials to evaluate the ability of nanofluid heat energy performance in reducing the effects of orientation, providing insights into optimizing PCM-based thermal energy storage systems. The research aimed to understand how geometric factors and nanofluid additives influence PCM melting efficiency and performance. [9] Study the geometrical design impact using vertical Shell- tube type LHTES. The mathematical representation is authenticated using investigational temperature data, emphasizing the effect of convection process on HT during the charging process and discharging process. Dimensions such as melting time, liquid-fraction, solidification time and stored energy liberated energy are analyzed to assess system functioning. The results demonstrate that the conical system exhibits faster storage of heat energy due to the dominance of natural convection, emphasizing the potential for optimizing shell & tube LHTES system design by leveraging natural convection process effects. In conclusion, research in PCM-based thermal energy storage systems has explored various aspects, including material selection, geometric considerations, and optimization of charging and discharging processes. These studies add to the enhancement of efficient and cost-effective energy storage technologies, which are vital for meeting the increasing energy demands in a sustainable using experimental temperature data, highlighting the consequence of usual convection on HT throughout the charging process and discharging process. Parameters such as melting time and liquid fraction, solidification time, and stored energy and released energy are analyzed to assess system functioning.

These studies contribute to the growth of cost-effective and convenient heat energy storage technologies, which are vital for meeting the increasing energy demands in a sustainable manner.

2.3 Research Gap

From the previous research work the study more focus on the geometry of the PCM Storage system there is study gap in trapezoidal storage unit equipped with fins the material used for the analysis is Erythritol. To know the behavior of the melting phase and solidification phase of the LHTES system. The temperature and liquid fraction with respect to the time is to be determined.

CHAPTER 3

THERMAL ENERGY STORAGE METHOD

3. TESs METHODS:-

There are 3 types of thermal energy storage which are in use and being currently under study. These are thermo-chemical heat storage, sensible -heat storage, Latent-heat storage.

3.1.1 Sensible-Heat Storage

$$q = \int_{Tm}^{Tf} mc_p \, dt$$

The 1st type, sensible-heat storage, deals with the increasing and decreasing temperature within the boundaries of materials' specific heat capacity. Equation.
The specific heat is represented by cp where 'm' is the 'mass' of 'storage medium'. The 'beginning' and 'final' temperatures of the medium are denoted by Tm and Tf, respt. Sensible-heat can be held in the solid, readily available, inexpensive substance like concrete and rocks. Long pipes are required for heat extraction and release from solid storage medium. In addition, not only do enormous tank capacities and a lot of heat transfer fluids need to be used to store excess heat. Heat storage in a liquid media has recently gained popularity as a SHS technique, particularly for solar applications. Fluids are used as a thermal energy storing medium and heat transporter, such as thermic oils or molten salts that are chosen based on their operating temperature. The SHS's energy Thermochemical Heat Storage (THS) Materials have a significantly reduced capacity to store latent heat.

3.1.2 Thermochemical heat storage (THS)

The least academically developed TES type is thermochemical heat-storage. It is founded on the idea that reversible-thermochemical processes can change reactants and products into one another. Endothermic and exothermic reactions store and release thermal energy, respectively. There are two key characteristics of thermochemical storage. The first is that, compared to other that is sensible heat storage due to specific heat and latent heat storage due to fusion enthalpy, reaction enthalpy promises to store considerably more thermal energy. Consequently, it delivers the same amount of energy from a smaller tank. On the other hand, heating is necessary to initiate the reaction and create an background for substances that speeds up the rate of reaction during charging and discharging Ammonia dissociation is a good example of THS, that works at ambient temp [10] (T amb = 25 ° C).

$$NH_3 + \Delta H \leftrightarrow \frac{1}{2} N_2 + 3/2\ H_2 \quad \Delta H = 66.5\ kJ/mol$$

3.1.3 Latent-Heat Storage

Latent heat-storage is a type of thermal-energy storage that relies on the phase transition of materials, such as to liquid from solid and from liquid to gas, using PCM. The solid-liquid phase conversion is the most practical LHS method, as it allows for the release heat and the storage of heat through melting and solidification. One benefit of Latent Heat Storage is that the fusion heat have a higher storage capacity per unit volume compared to specific heat [10]. Another benefit is that change of phase occurs at nearly const. temperature conditions, allowing for the extraction from the system at a const. temp. During the discharging processes and charging processes of LHS systems, the Phase Changing Materials stores heat in latent form while melting and releases it while solidifying. Despite its advantages, LHS still faces challenges such as limited heat transfer rates during charging and discharging processes, which require further research and development to improve its efficiency and effectiveness.

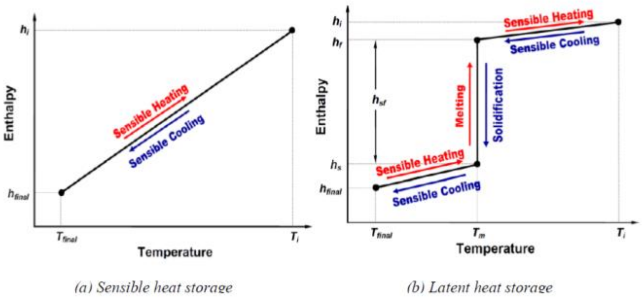

Fig 3.1.3: Sensible and latent heat storage method [10]

(Source: İsmail Gürkan DEMİRKIRAN, 2020)

3.2 Basics of Phase Changing Materials

The role of Phase Changing Materials, being used as storage substance in Thermal Energy Storage applications, has mentioned above. From energy storage types, Phase Changing Materials has another deployment arena for example thermal management of Photo Voltaic panels, passive cooling of electronic-equipment and battery, drugs & food delivery devices.

The selection of Phase Changing Materials and to conclude proper working-conditions is an important issue for any functions. The selected Phase changing Materials has to fulfill chemical, thermal requirements, physical and financial requirements.

Table 3.2: Property and Desirable criteria [11]
(Source: L. SOCACIU, A. PLEŞA, P. UNGUREŞAN and O. GIURGIU, 2014)

Property	Desirable Criteria
Melting point	Operating temperature range
latent heat of fusion per unit mass	High
specific heat	High
thermal conductivity	High
volume changes during phase transition	Small
Chemical stability	No chemical decomposition and corrosion resistance

3.2.1 Classification of PCM:-

PCM are commonly categorized into 3 groups: organics, inorganics & eutectics. When selecting a PCM, it is important to consider the advantages and disadvantages associated with each material.

Organic Phase Changing Materials can be further divided into 2 subgroups i.e. Paraffins and Non-Paraffin's. Paraffin's are basic hydrocarbon compounds that are derived from petroleum through distillation [10]. The melting temperature of a paraffin inc. as the no. of carbon atoms and hydrogen atoms in its structure Inc. (C_nH_{2n+2}).

Non-paraffin organic PCMs include sugar-alcohols, fatty-acids, and esters, which are acquired from food oriented sources. In the subsequent section, the focus will be on sugar alcohols and specifically on Erythritol.

Organic PCMs generally exhibit good thermal-stability and have low-corrosive & toxic-effects. However, they do have certain drawbacks, such as low fusion enthalpy i.e. the amt. of heat released or absorbed during the phase changing process and poor thermal conductivity.

It's important to consider these characteristics when selecting a PCM for a specific application. While organic PCMs have their advantages, their limitations in terms of fusion enthalpy and thermal-conductivity should be considered to ensure optimal performance in TESs

CHAPTER 4

ERYTHRITOL AS A PROMISING PCM

Low molecular weight members of the family of carbohydrates are sugar alcohols derived from organic PCMs. The food and pharmaceutical industries are general utilization domains for the TES function. They are frequently created through carbohydrate reduction processes, while they are naturally present in some fruits and vegetables. Sugar alcohols have exceptional qualities. As shown in Table 4.1, sugar-alcohols have a latent-heat capacity that is two to three times more than that of paraffins operating in the same temperature range. Additionally, they are non- toxic, non-corrosive, inflammable. The most frequently investigated ones include adonitol, xylitol, d-mannitol, l- arabitol, and erythritol, which have melting temperatures between 95 and 167°C and latent heat capacities between 250 and 340 kJ/kg, respectively [10]. Despite the fact that organic PCMs are preferable to salt hydrates due to higher enthalpy of fusion of inorganic PCMs Because of these thermo-physical characteristics, sugar alcohols are typically competitive.

4.1 Thermodynamic Property of Erythritol PCM

Erythritol (C4H14O4), the sugar alcohol with the maximum enthalpy of fusion (L Erythritol have 339 kJ/kg) [12], is a very promising PCM. In earlier work, it happened in applications for waste heat from diesel engines and solar box cookers. Solar-powered ORC and residential hot water applications are interested in Erythritol because of its 117 ° C melting point.

Fig. 4.1: Erythritol PCM
(Source: https://pl.wiktionary.org/wiki/erytrol)

In numerous applications involving thermal energy storage systems, PCM can be used. Basically, melting point, phase change enthalpy, and density are taken into consideration when choosing PCM. In this study, we may use erythritol as a Phase Changing Materials with a melting point of 117°C. In this temperature range, erythritol have a higher latent-heat of fusion that is 340 kJ/kg, making it the ideal choice for applications requiring medium range of temperature. The comparison property of the various pcm is shown in the table below [1].

Table 4.1: Comparison of different PCM [1]
(Source: D. Tarwidi, 2015)

Properties	$C_4H_{10}O_4$	$Mg(NO_3)_2 \cdot 6H_2O$	RT100	$MgCl_2 \cdot 6H_2O$
Density (kg/m^3)	1480	1636	940	1570
Specific heat (kJ/kg °C)				
Solid	1.38	1.84	1.8	2.25
Liquid	2.76	2.51	2.4	2.61
Thermal conductivity (kJ/m s °C)				
Solid	$0.733 \cdot 10^{-3}$	$0.611 \cdot 10^{-3}$	$0.200 \cdot 10^{-3}$	$0.704 \cdot 10^{-3}$
Liquid	$0.326 \cdot 10^{-3}$	$0.490 \cdot 10^{-3}$	$0.200 \cdot 10^{-3}$	$0.570 \cdot 10^{-3}$
Melting temperature (°C)	118	89	99	116.7
Lantent heat of fusion (kJ/kg)	339.8	162.8	168	168.6

4.2 Heat Transfer Enhancement using different geometry.

Geometry plays a significant role in latent heat storage systems by influencing their overall performance and efficiency. Latent heat storage systems are designed to store and release thermal energy by utilizing PCM, which release or absorbs large amounts of heat-energy in the process of changing their phase there are several methods to inc. the heat transfer rate. Most of the methods involved using different geometry. The most common method is the shell-tube type system this geometry is generally used for the storing of heat for LHTES another is square shape geometry with shell type channel tube conical shape geometry and cylindrical shape is also the most common to analyze the behaviour of the of melting and solidification phase of the latent-heat storage-system. Most of the study is optimize the geometry for the effective use of the number of ways that have been discovered depending on an operating parameter. The trapezoidal shape geometry is one of the geometry which can also use for finding the behaviour of the LHTES system and to increase of heat transfer rate of the system can equip with fins for effective use By attaching fins to a surface the effective surface area is increased, promoting higher heat transfer rates. Fins can be straight, curved, or even pin-shaped. They improve convective heat transfer by increasing the contact area with the surrounding fluid and promoting better heat transfer.

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CHAPTER 5
MODEL AND GEOMETRY

5.1 MODEL AND DESCRIPTION

The physical model of the LHTES in a Trapezoidal shape unit is demonstrated in figure 5.1. Square shape tube attached with fins are used. Fins are made of Aluminum in order to save cost and effectively use of material for the model part. The bond contact part with the fins are the thermal wall and outside wall is considered as adiabatic condition.

The trapezoidal unit is filled with the Erythritol PCM. Fins are in rectangular shape 50x10mm are attached with square shape tube of 50 x 50 mm dimension. The base of trapezoidal shape energy storage unit is 140 mm with inclination angle of 75°. The height from the base is 250 m. The fins are above and below the shape geometry. The 3D Model is demonstrated in figure 5.1.

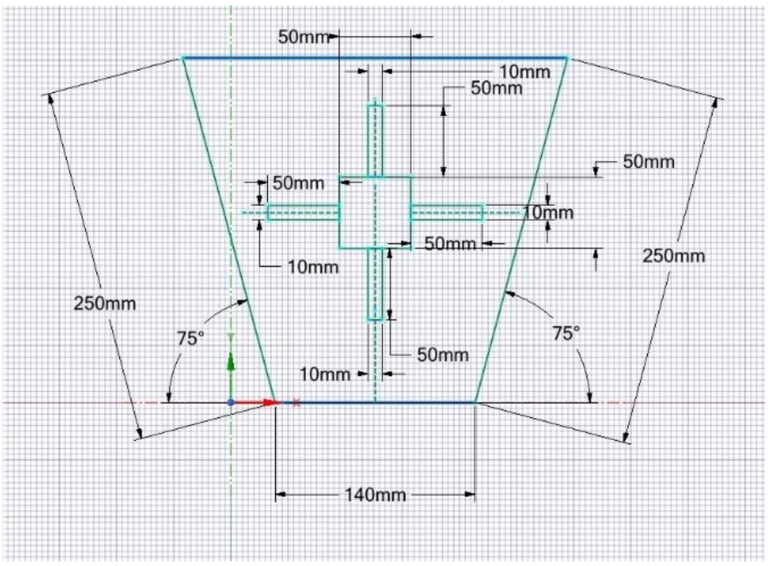

Fig. 5.1.: Dimension of geometry

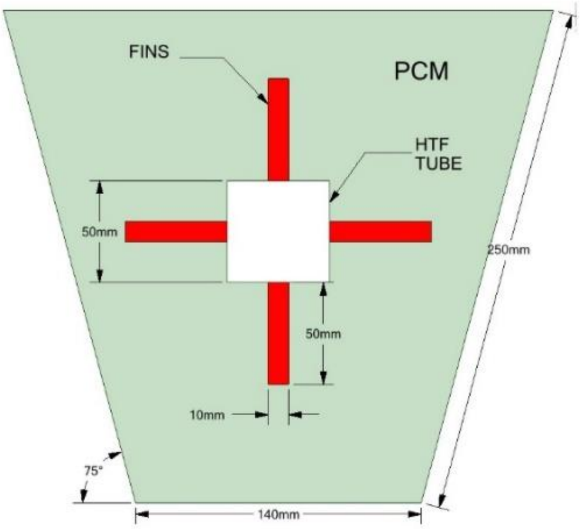

Fig. 5.2: Pictorial view

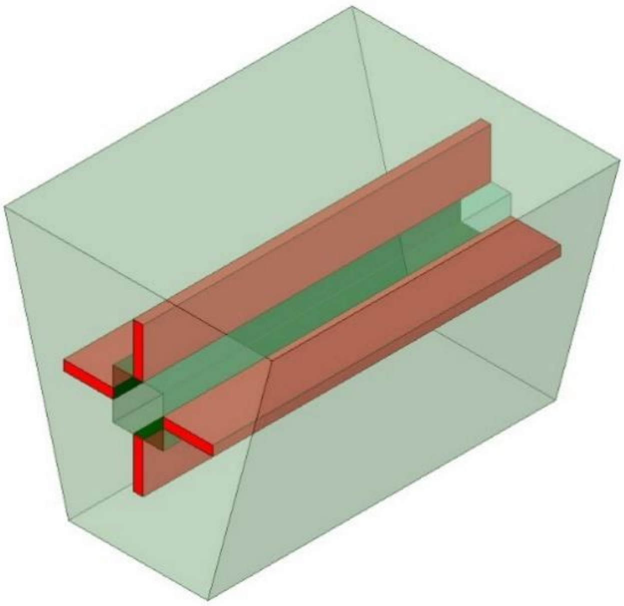

Fig. 5.3: 3D Model View

CHAPTER 6

MESH GENERATION

6.1 Meshing Overview

The meshing of model first completed in with geometry in geometric modular as shown in fig 6.1 the geometric modular is done in ANSYS R2 2022 version after specifying it dimensions and name the section of the part geometry is imported to mesh editor. The preferences has been set for the mesh type setting.

The model is in 2D transient stage condition so the setting for 2d axisymmetric condition is used for the model type system the when the meshing is complete number of elements size and grain growth default setting and the number of nodes are shown mesh quality depicts these parameters. Setting is default for the physics preferences CFD and solver preference is fluent with the element order of linear type. Contact bonding is given to respective section part. This explains the region of the respective wall type with in the geometry.

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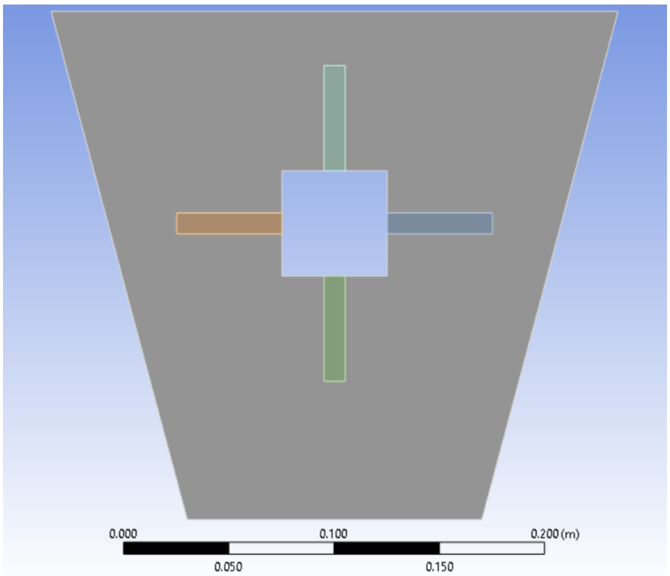

Fig. 6.1: Design Modular

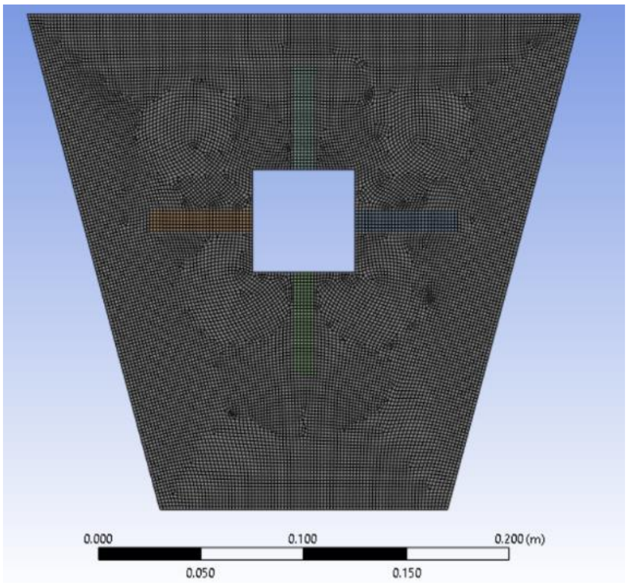

Fig. 6.2: Mesh Generation

The element size is 1.6e-003m. The statics depicts the meshing no of nodes and elements with 18828 and 18225. The name section provided to the generated part are the fluid domains adiabatic wall, fin and thermo-wall the mesh completion is shown in fig.6.2.

CHAPTER 7

METHODOLOGY

7.1 Numerical Model

According to the existing literature, there is a research gap in the area of geometric design for thermal-energy storage systems using erythritol as the phase PCM. Previous studies have revealed that Erythritol has a lower heat storage capacity compared to other PCMs, which restricts its application in energy storage systems.

To address this gap, future research endeavours could concentrate on investigating novel designs of thermal energy storage-systems using erythritol as the PCM. This research could involve performing thermodynamic and performance analyses on various geometric designs.

In conclusion, the research gap pertaining to erythritol-based thermal energy storage systems presents an opportunity for further exploration and optimization. This exploration has the potential to facilitate the development of more efficient as well as effective energy-storage technologies.

The heat-transfer within the cavity involves both conduction & convection effects, operating in the solid phase & liquid phases of the phase change material (PCM), respt. The melting process in the Phase Changing Material is assumed to follow the Newtonian-behavior and be in-compressible. The flow resulting from the melting is considered to be laminar, and any viscous dissipation, thermal radiation, and 3-dimensional effects are assumed to be insignificant. Additionally, it is taken that the base Phase Changing Materials, if present, are in thermodynamic-equilibrium and flow at the equal velocity. These assumptions help simplify the analysis and modeling of the heat transfer phenomena within the cavity.

7.2 GOVERNING EQUATION

The governing equations used in the 2D transient Numerical simulation of charging and discharging process involve mass conservation equations. In this study model used is the enthalpy-porosity method which is extensivley applied for the simulation and modelling of the PCM melting phase and solidification phase

1. **Numerical model**
   The governing equations in the above described conditions are elaborated below .

- Mass conservation equations:

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

- conservation equation - (X–momentum):

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

- conservation equation - (Y-momentum) :

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\partial p}{\partial y} + S_y + \rho g\beta(T - T_m) \quad (3)$$

- Conservation equation for energy :

$$\rho\left(\frac{\partial H}{\partial t} + \frac{\partial(uH)}{\partial x} + \frac{\partial(vH)}{\partial y}\right) = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \quad (4)$$

H is used in both sensible enthalpy (h) and latent heat of phase transformation (Δh)

$H = h + \Delta h$ Specific enthalpy is shown as: (5)

$$h = h_0 + \int_{T_0}^{T_m} C_p dT \quad (6)$$

& latent heat for phase transition of PCM is

$$\Delta h = \lambda L \quad (7)$$

The LF can be represented with the temperature of PCM, explains as below

$$\lambda = \begin{Bmatrix} 0 \quad if\ T < T_S \\ \frac{T-T_S}{T_L-T_S} \quad if\ T_S < T < T_L \\ 1 \quad if\ T > T_S \end{Bmatrix} \tag{8}$$

The specific heat capacity of the PCM and the thermal conductivity are expressed by the initials k and C_P, respectively. Enthalpy h is the enthalpy of the PCM at various states, as described by Eq. (6), where Tm is the base temperature and enthalpy at this temperature is zero. H is the latent heat of fusion. The temperatures at which phase change begins and ends are T_L and T_S, respectively.

Table 7.2: The Properties of Erythritol PCM [12]

(Source: R. Ranjan and A. C. Tiwari, 2019)

Property	Value	UNITS
Melting Point	118 ° C	K
Density	1480	(kg/m^3)
Latent Heat Capacity	339800	(J/kg)
Specific Heat Capacity (solid)	1380	(J/kg K)
Specific Heat Capacity (liquid)	2760	(J/kg K)
Thermal Conductivity (solid)	0.733	(W/mk)
Thermal Conductivity (liquid)	0.326	(W/mk)
Thermal Expansion Coefficient	0.001014	(1/K)
Dynamic Viscosity µ	0.01	(kg/ms)

Table 7.3: Boundary conditions During Charging Process

Description	Boundary Conditions
Heating Temperature (Inner Tube Wall)	421.5 K
PCM Melting Temperature	391 K
Initial Fins Temperature	380 K
Initial PCM Temperature	380 K
All Remaining wall	Adiabatic wall

The simulations and modelling were completed in a 2D transient state with a time step of 0.02 s during charging part and discharging Part. The mass melting fraction and temp. Distribution are analyzed during the flow of heat transfer through the PCM. Natural convection and Conduction are the modes of heat transfer. In this study rate of Heat transfer is further advances with the help of fins. The boundary conditions are provided to perform the simulation

To enhance the rate of heat transfer, fins are often employed in the system. Fins act as extended surfaces that increase the surface area available for heat transfer. By utilizing fins, the heat transfer area is augmented, resulting in improved efficiency and performance of the thermal energy storage system.

To simulate and analyze the system, appropriate boundary conditions are provided. These boundary conditions define the constraints and parameters under which the simulation is conducted. By specifying boundary conditions, such as temperature, heat flux, or velocity, the behavior and heat transfer characteristics of the PCM and the entire system can be accurately predicted and studied.

Overall, the analysis of heat transfer in PCM-based thermal energy storage systems involves considering melt fraction and temperature contours, utilizing conduction and natural convection modes, and incorporating fins to enhance heat transfer. This, in combination with well-defined boundary conditions, allows for comprehensive simulation and analysis of the system's performance.

Table 7.4: Boundary conditions During Discharging Process

Description	Boundary Conditions
Cooling Temperature (Inner Tube Wall)	349.5 K
PCM Melting Temperature	391 K
Initial Fins Temperature	394 K
Initial PCM Temperature	394 K
All Remaining wall	Adiabatic wall

CHAPTER 8

RESULT AND DISCUSSION

The 2d transient ansys fluid fluent investigation of melting phase of PCM in a trapezoidal storage geometry followed by the square shape tube is completed. The findings of modelling and simulation were notice at a ongoing period of time for the full melting cycle of 2390 min. The complete discharging cycle take place in 1660 min. the simulation model for the energy unit help to evaluate the transfer of conduction and convection heat phenomenon which helps to increase the HTR. The report are presented by the representation of as contours of mass fraction temperature and Temperature contours. The temperature distribution ranges from 380 K to 417.9 for the charging phase of the storage system. The fins which are close to the adiabatic wall increase the heat transfer rate which helps in charging phase of the system.

The Charging phase: The contours of temp and liquid fraction in a storage in Figures 8.1 to 8.6 illustrate the unit in the axial direction of the unit in modelling and simulation at different points during the charging procedures. The PCM's inlet conditions is at 380 K with the fins temperature at 380 K Further the fins heated to the 417.9 K the amount of liquid fraction generated in 370 min is 81.8%. Geometry than in the upper part in figures 8.3 and 8.4. However, the uppermost part has greater average temp than the lowermost. As the temp of tube is over the melting temperature, Phase Changing Material has begun to melt close to aluminum fins. The Conduction was the primary route for transfer of heat at first since the entire PCM was initially in solid phase. The upper part of the square tube was close to where the PCM had completely melted. When the temperature remains the same during the sensible heating, significant temperature changes can be observed if the HTF tube temp is not uniform across the aluminum tube's circumference. While the phase transition, return to the constant value. This explains why the top part's average temperature is higher than the bottom part's Performance Analysis of LHTES using fins.

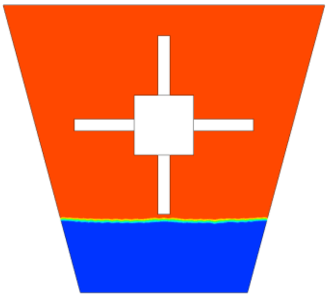

Fig. 8.1: 250 min

Fig. 8.2: 500 min

Fig. 8.3: 1000 min

Fig. 8.4 : 1500 min

Fig. 8.5: 2000 min

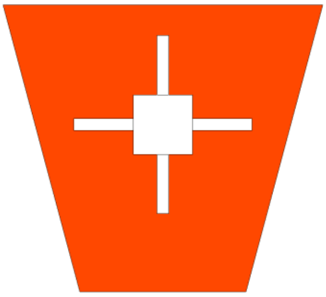

Fig. 8.6: 2390 min

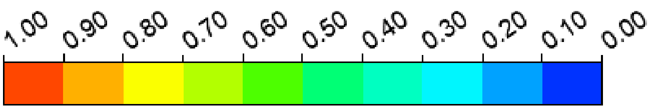

Fig. 8.7 : Liquid Fraction

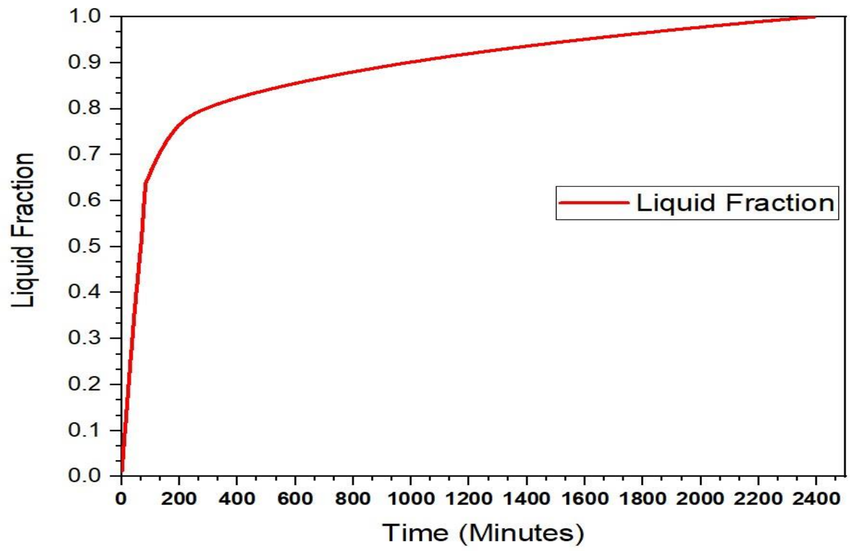

Fig. 8.8: Liquid fraction vs. time (minutes)

Temperature Contours: The contours of temp and the difference in temp over time are shown in Fig.8.9 to 8.14 the maxi. Temp reached in the starting stage of the melting phase is 400 K, and it reaches 417.9 K during the later phases low temperature distribution zone are observed in the blue color, the green color represent mid temperature range This zone's shape is similar to the solid Phase Changing Material in the PCM boundaries, as shown in figure. After 250 min, a red zone starts to form in the PCM domain closer to the heat tube's surface, and it steadily gets bigger. This is due to the impact of liquid PCM turbulence. After melting part is complete, all the development of temperature distributions zones can be clearly seen in remaining min. because towards after the process of melting concludes, all of the Phase Changing Materials is in the liquid phase and its properties.

Fig. 8.9: 250 min

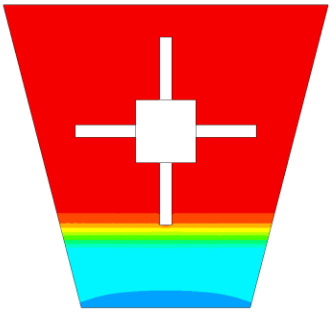

Fig. 8.10: 500 min

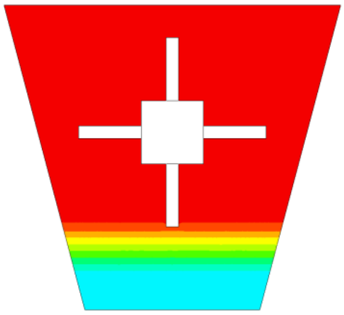

Fig. 8.11: 1000 min

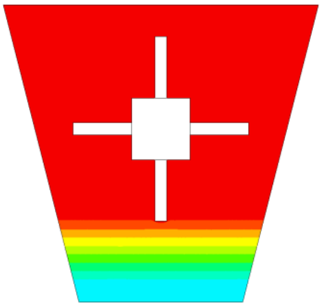

Fig. 8.12: 1500 min

Fig. 8.13: 2000 min

Fig. 8.14: 2390 min

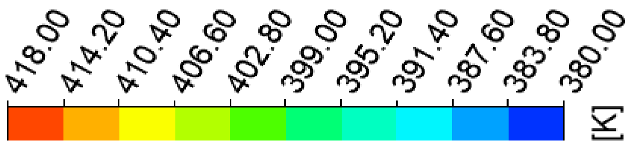

Fig. 8.15 : Temperature contours

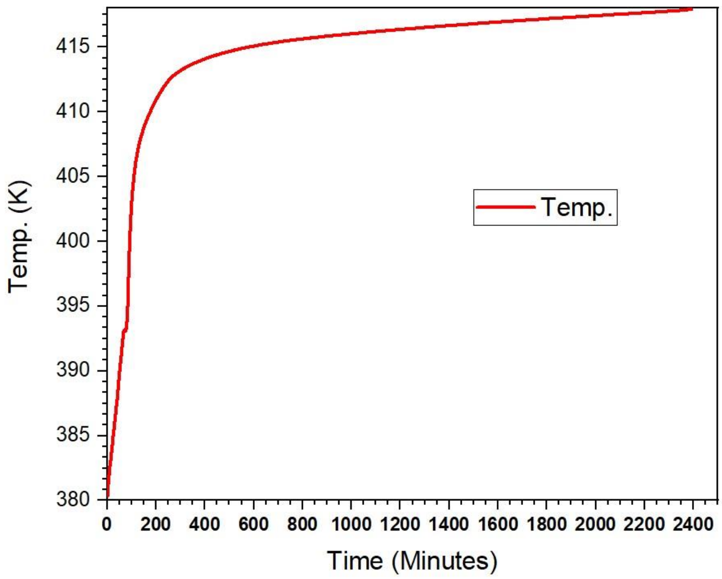

Fig. 8.16: Temperature vs Time (Minutes)

Velocity Profile: The velocity profile of the corresponding phase is described in fig 8.17 to 8.22 for this velocity vector of in pcm turbulence is explained the pcm flow through the various regions in range of the maximum of 0.00 m/s to 0.008 m/s the PCM unit in which tubbed fin are attached the flow rate of the material in various regions at the part geoimtery. The charging portion of the system, which is located in materials close to the firewall and a wall, exhibits a higher convection rate of heat than the system's father portion. The velocity vector demonstrates the direction that heat is flowing in each component.

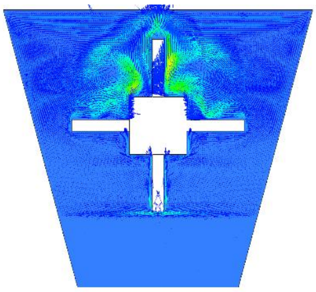

Fig. 8.17: 250 min

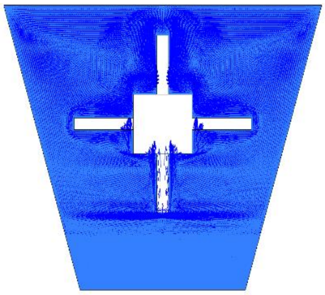

Fig. 8.18: 500 min

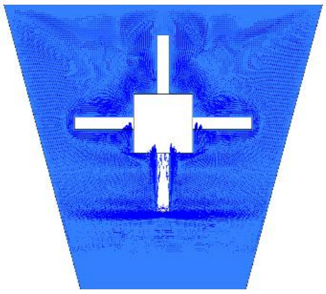

Fig. 8.19: 1000 min

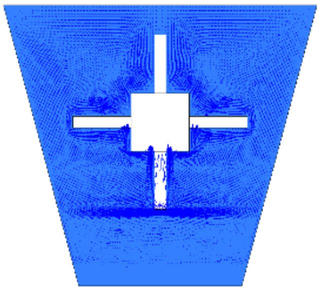

Fig. 8.20: 1500 min

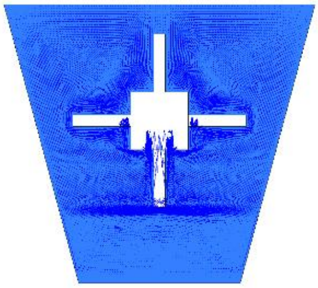

Fig. 8.21: 2000 min

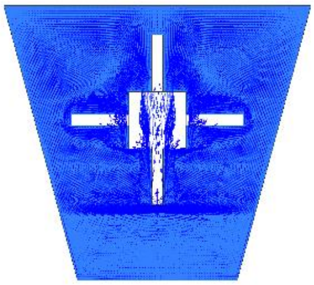

Fig. 8.22: 2390 min

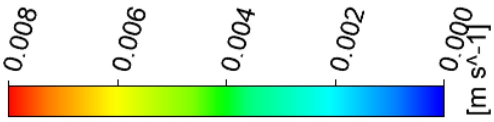

Fig. 8.23: Velocity Vector

Discharging: The contours of liquid fraction and temp. during the discharging of an energy storage unit can be observed in the provided fig 8.24 to 8.29. The simulation shows various time points when focussing on the geometry's longitudinal direction. The phase change material's (PCM) inlet temperature is 394 K, while the fins' temperature forms part of the initial conditions. The temperature rises to 394 K during the discharging phase while the fins are cooled to 360 K. The amount of liquid generated around 250 minutes is 54%, and at the end of 500 minutes, it decreased to 34% Interestingly, the figure reveals that the lower half of the square tube exhibits a minimum average temperature compared to the upper half, despite the upper half have a high overall temp. This discrepancy can be credited to the solidification of the PCM. Initially, heat transfer occurs predominantly through conduction and convection since the entire PCM in a liquid phase. As temperature rises, PCM begins to solidify near the aluminum fins, which are cooler. During the sensible heating phase, variations in temperature become noticeable if the temperature across the circumference of the aluminum tube is uneven. However, during the phase transition, the temperature stabilizes and remains constant. At 1000 minutes into the discharging process, the amount of liquid fraction present is 11.1%. As the cooling progresses, the HTR decreases, particularly Because of decrease in the transfer of heat from the PCM to the fins. This slow rate of heat transfer is primarily attributed to the phenomenon of pure convection.At this stage of the process, the complete solidification of the PCM takes approximately 1660 minutes, indicating that it requires more time for the PCM to transition from the liquid phase to the solid phase.

Fig. 8.24: 250 min

Fig. 8.25: 500 min

Fig. 8.26: 1000 min

Fig. 8.27: 1250 min

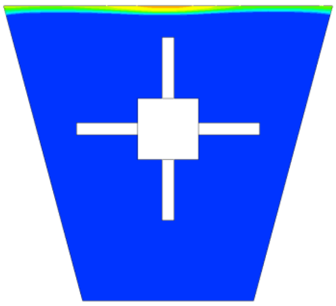

Fig. 8.28: 1500 min

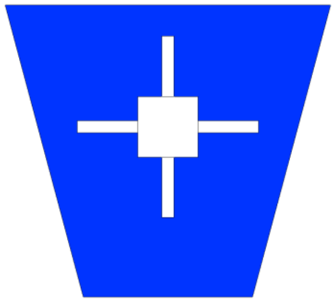

Fig 8.29: 1660 min

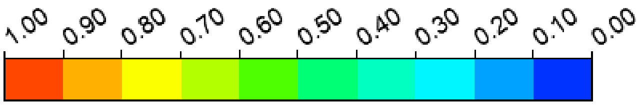

Fig. 8.30: Liquid Fraction

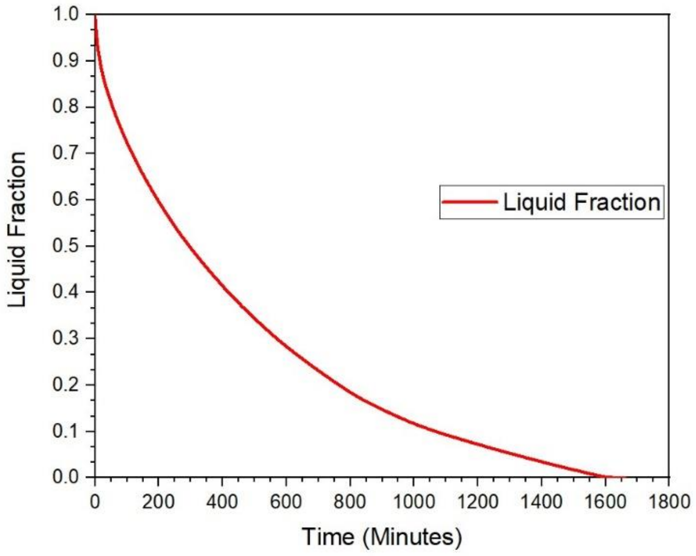

Fig. 8.31: Liquid Fraction vs Time Minute

Temperature Contours: The contours of temp. and the difference in temp. over time are shown in Fig 8.32 to 8.37. The max temp reached while the starting part of the melting phase is 394 K, and it reaches 360 K during the later phases. The low temp distribution is represented by the blue color the green color represent mid temperature range this zone's shape is similar to the solid Phase Changing Materials in the PCM boundaries, as shown in fig.8.35. After 250 min, a red zone starts decrease in the PCM domain closer to the heat tube's surface, and it steadily gets bigger. This is due to the impact of the liquid PCM's turbulence. After the solidification process is complete, all the development of constant temperature zones can be obviously observed in figure. for time 1500 min. because towards the conclusion of the discharging phase, all the Phase Changing Materials is in solid phase and its conditions become stable there is uneven distribution of temperature that can seen in fig 8.35 low turbulence effect of pcm is one of the reason behind this the temperature profile helps to find the where the maximum temperature reach in the system. fig 8.39 explains the graph between the temp and time in minutes

Fig. 8.32: 250 min

Fig. 8.33:500 min

Fig. 8.34: 1000 min

Fig. 8.35: 1250 min

Fig. 8.36: 1500 min

Fig. 8.37: 1660 min

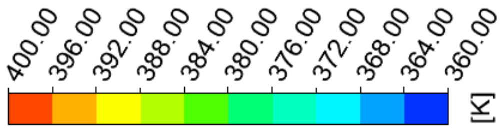

Fig. 8.38: Temperature contours

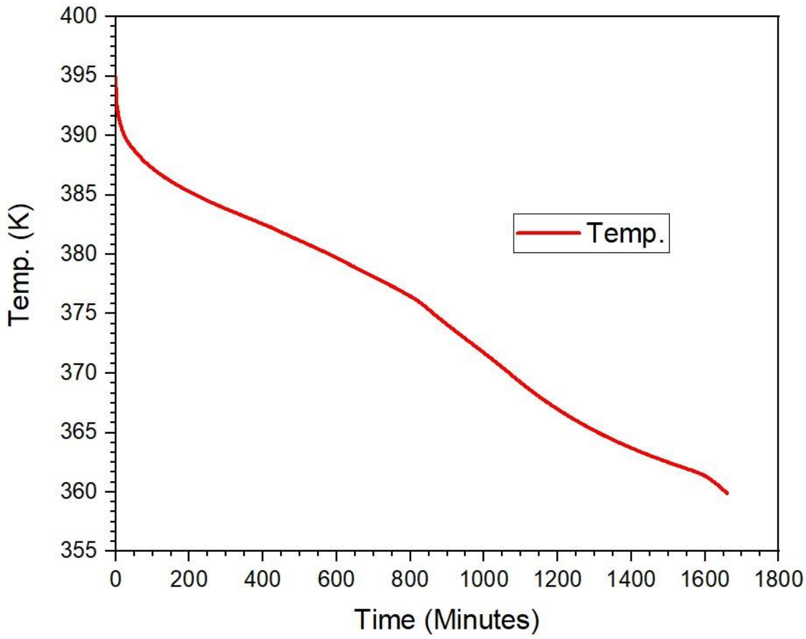

Fig. 8.39: Temperature vs Time

Velocity Profile: The velocity profile of the corresponding phase is described in Fig 8.40 to 8.45 this velocity vector of pcm turbulence is explained the pcm flow through the various regions in the range of the maximum of 0.00 m/s to 0.008 m/s the PCM unit in which tubbed fin are attached to the flow rate of the material in various regions at the part geometry. The Discharging portion of the system, which is located in materials close to the firewall and a wall, exhibits a higher convection rate of heat than the system's father portion. The velocity vector demonstrates the direction that heat is flowing in each component.

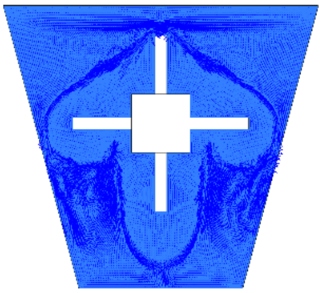

Fig. 8.40: 250 min

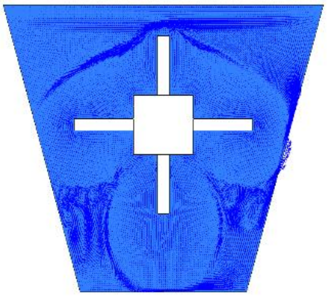

Fig. 8.41: 500 min

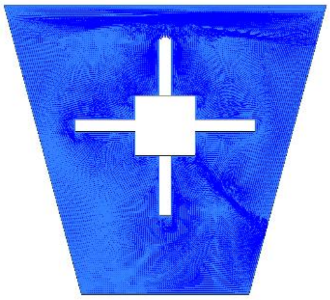

Fig.8.42: 1000 min

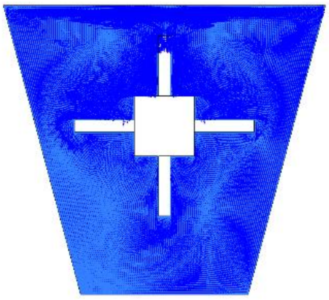

Fig. 8.43: 1250 min

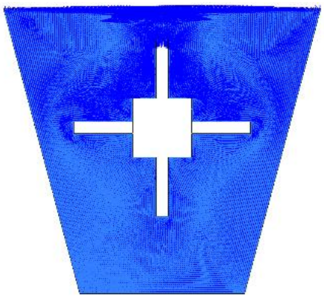

Fig. 8.44: 1500 min

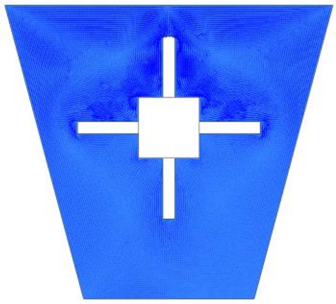

Fig. 8.45: 1660 min

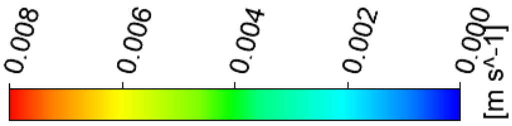

Fig. 8.46: Velocity vector

CHAPTER 9

CONCLUSIONS

In this study, 2D transient state simulations model were investigated to determine the charging part and discharging part of a PCM Storage System. The following conclusion can be drawn from the given thermal analysis:-

- Results of the simulation indicate that throughout the melting process, liquid fraction increases rapidly, reaching 78% within the initial 250 minutes this because the heat is transfer due to convection and conduction However, thereafter, the heat transfer occurs predominantly through conduction, leading to a decrease in the rate of liquid-fraction the overall melting of the pcm occurs in 2390 mins.
- Similarly, throughout the discharging process, the solid fraction increases at a slower rate after the initial 250 minutes, with approximately 46% solidification. However the full solidification of the pcm occurs in the 1660 mins.
- The temperature contours with respect to the time (minutes) is also studied in order to find how much temp reached by the material in the given storage unit for charging part the temp of 400 K is constant around the all wall temperature in 2390 min. Similarly the temperature contours with respect to time is constant at some region at the end of discharging part.
- Further the geometry helps to Analysis the performances characteristics of the LHTES system using fins. The performance characteristics of the system is substantially influenced by the transfer of heat between the PCM temperature and fins, with quicker charging rates shown for some systems. The results of the current simulations can be utilised to improve the design of a system for storing latent thermal energy.

CHAPTER 10

FUTURE SCOPE

The heat transfer between the PCM temperature and fins has a significant impact on the system's performance characteristics, with certain systems showing faster charging rates. A system for storing latent thermal energy can be designed better using the findings of the current simulations.

The simulation used in this study based on its geometrical model and its PCM material , further study can used to increase the number of fins in order to analysis the system performance based on its heat transfer phenomenon.

The orientation of a storage unit plays a significant role in the heat transfer and overall effectiveness of a latent heat thermal energy storage (TES) system. The orientation determines how heat is transferred between the storage medium and its surroundings, as well as the distribution of temperature within the storage unit.

References

[1] D. Tarwidi, "Modeling and Numerical Simulation of Solar Cooker with PCM as Thermal Energy Storage," in *3rd International Conference on Information and Communication Technology (ICoICT*, Indonesia, 2015.

[2] A. R, V. Mariappan and S. Suresh, "Experimental investigation on melting and solidification behaviour oferythritol in a vertical double spiral coil thermal energy storage system," *Sustainable Cities and Society,*, Vols. Volume 44,, no. ISSN 2210-6707,, pp. Pages 253-264, 2019,.

[3] Dr.B.Kanimozhi, K. Harish, B. S. Tarun, P. Reddy and P. S. Sujeeth, "Charging and Discharging Processes of Thermal Energy Storage System Using Phase change materials," in *IOP Conf. Series: Materials Science and Engineering*, Chennai-119, 2017.

[4] G. Alva, L. Liu, X. Huang and G. Fang, "Thermal energy storage materials and systems for solar energy applications," *Renewable and Sustainable Energy Reviews,* Vols. Volume 68, Part 1,, no. ISSN 1364-0321,, pp. Pages 693-706,, 2017.

[5] A. Elsayed, A. Amer and V. Lebedev, "Thermal Energy Storage by Using Latent Heat Storage Materials," *International Journal of Scientific & Engineering Research,* vol. Volume 9, no. , Issue 5,, 2018.

[6] S. Koohi-Fayegh and M. Rosen, "A review of energy storage types, applications and recent developments,," *Journal of Energy Storage,* Vols. Volume 27,, no. ISSN 2352-152X,, p. 101047, 2020.

[7] S. Mellouli, T. Alqahtani and S. Algarni, "Parametric Analysis of a Solar Water Heater Integrated with PCM for Load Shifting," *energies,* vol. 15, p. 8741, 2022.

[8] F. Iachachene, Z. Haddad, H. F. Oztop and E. Abu-Nada, "Melting of phase change materials in a trapezoidal cavity: Orientation and nanoparticles effects," *Journal of Molecular Liquids,* vol. Volume 292, no. ISSN 0167-7322,, p. 110592, 2019.

[9] S. Seddegh, S. S. M. Tehrani, X. Wang, F. Cao and R. A. Taylor, "Comparison of heat transfer between cylindrical and conical vertical shell-and-tube latent heat thermal energy storage systems," *Applied Thermal Engineering,* vol. Volume 130, no. ISSN 1359-4311, pp. Pages 1349-1362, 2018,.

[10] Demirkıran and İ. G., "Computational fluid dynamics (CFD) analysis of latent heat storage in heat exchangers by using phase change materials (PCM).," İzmir Institute of Technology, İzmir, Turkey, 2020.

[11] L. SOCACIU, A. PLEŞA, P. UNGUREŞAN and O. GIURGIU, "Review on phase change materials for building applications," *Leonardo Electronic Journal of Practices and Technologies,* no. issue 25, pp. 179-194, 2014.

[12] R. Ranjan and A. C. Tiwari, "CFD Analysis of Latent Thermal Energy Storage for Erythritol Phase Change Material," *INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN TECHNOLOGY,* vol. Volume 7, no. Issue 11, 2021.

[13] Z. Andrássy and Z. Szantho, "Modelling of latent thermal energy storage systems," *International Review of Applied Sciences and Engineering,* vol. 8., pp. 51-56., 2017.

[14] G. Manu, R. Agrawal, M. Singh, K. P. Singh and R. Yadav, "Numerical Investigation of Thermal Energy Storage System with Helical Coil using PhaseChange Material," *International Journal of Engineering Research & Technology,* vol. Vol. 10, no. Issue 08, August-2021.

[15] M. Mahfuz, M. Anisur, M. Kibria, R. Saidur and I.H.S.C. Metselaar, "Performance investigation of thermal energy storage system with Phase Change Material (PCM) for solar water heating application," *International Communications in Heat and Mass Transfer,,* vol. Volume 57, no. ISSN 0735-1933, pp. Pages 132-139,, 2014.

[16] A. Vijayan and D. J. Hussain, "Experimental Analysis of Thermal Storage Systems using Phase Change Materials," *International Journal of Engineering Research & Technology,* vol. vol 5, no. issue 06, 2016.

[17] H. Zhang, J. Baeyens, G. Cáceres, J. Degrève and Y. Lv, "Thermal energy storage: Recent developments and practical aspects," *Progress in Energy and Combustion Science,* vol. Volume 53, no. ISSN 0360-1285, pp. Pages 1-40, 2016.

[18] B. Akhmetov, A. G. Georgiev, A. Kaltayev, A. Dzhomartov, R. Popov and M. S.Tungatarova, "Thermal energy storage systems – review," *Bulgarian Chemical Communications,* vol. Volume 48, no. Special Issue E , pp. pp. 31 - 40, 2016.

[19] M. Kazemi, M. J. Hosseini, A. A. R. and R. Bahrampoury, "Improvement of Longitudinal Fins Configuration in Latent Heat Storage Systems," *Renewable Energy,* no. doi :10.1016/j.renene.2017.10.006, 2017.

[20] U. C. Pawar and P. V. Honguntikar, "CFD Analysis of Erythritol Melting Process in a Closed Cylindrical Container," *International Research Journal of Engineering and Technology,* vol. Volume: 06, no. Issue: 01, 2019.

[21] P. K. Shuklaa and P. A. Kishan, "CFD Analysis of Latent Heat Energy Storage System with Different Geometric Configurations and Flow Conditions," in *Heat and Mass Transfer Conference (IHMTC-2019)*, Roorkee, India, 2019.

[22] J. Kumar, P. Singh and R. Kumar, "Performance enhancement of latent heat storage unit by the multiple chambers," *Energy storage,* no. doi.org/10.1002/est2.446, p. est2.446, 2023.

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