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MODELLING AND ANALYSIS OF SAND BATTERY SYSTEM

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IN

THERMAL ENGINEERING

Submitted by:

NEERAJ RAWAT

(2K21/THE/12)

Under the supervision of

DR. PUSHPENDRA SINGH

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

MAY, 2023

DEPT. OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

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I, Neeraj Rawat (2K21/THE/12) student of M.Tech (Thermal Engineering), hereby declare that the Project Dissertation titled — "Modelling and Analysis of Sand Battery System" 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.

Place: New Delhi

Date: 31/05/2023

NEERAJ RAWAT

(2K21/THE/12)

DEPT. OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project titled "Modelling and Analysis of Sand Battery System" which is submitted by Neeraj Rawat (2K21/THE/12), for fulfillment of the requirements for awarding of the degree of Masterof Technology (M.Tech) is a record of the project work carried out by the student under myguidance & 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.

Place: New Delhi

Date: 31/5/2023

Dr. Pushpendra Singh

(SUPERVISOR)

Associate Professor

Department of Mechanical Engineering

Delhi Technological University

ABSTRACT

Keywords - Solar Energy, Renewable Energy, Thermal Energy Storage System (TES), Sand Battery.

Energy is a basic necessity shared by all living things on the planet, much like water, food, and shelter. The main source of producing usable kinds of energy is fossil fuels. In light of this, the main cause of ozone depletion and global-warming are the fossil fuels. The search for energy sources that are independent of fossil fuels and have a smaller impact on global warming has been reignited by the recent rise in awareness of it. Renewable-Energy Sources (RES) like wind and solar and hydropower are more accessible when compared to fossil fuel alternatives. It is appropriate to use thermal energy from the sun for both heating purpose and cooling purpose. Low temperature heating processes like household heating of water, household and industrial heating of areas and spaces, heating of swimming pool, ventilation operations, and some manufacturing processes and industrial processes are among the main applications for solar technologies.

This research aims to investigate the possibility of using Indian desert sand as a material for energy storage in a high-temperature TESs. Sand has the potential to be a novel and environmentally friendly storage medium with low maintenance and operating costs. The Thermal Energy Storage Element will store thermally charged sand. It will need to be stored for a particular amount of time after achieving the right temperature in the sand to assess its efficiency.

The remaining heat will then be released and absorbed by the oil, and it will employ a Peltier Element to produce electricity. The experiments are divided into three sections : Charging Phase, Storing Phase, and Discharging Phase, but the simulation has been performed only for the charging part. Certain design constraints are addressed, as well as several methods for improving system functionality for future optimization.

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The successful completion of any task is incomplete and meaningless without giving any due credit to the people who made it possible without which the project would not have been successful and would have existed in theory.

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Neeraj Rawat
(2K21/THE/12)

TABLE OF CONTENT

Candidate declaration **i**

Certificate **ii**

Abstract **iii**

Acknowledgment **iv**

Content **v**

List of table **vii**

List of Figure **viii**

List of Symbols/ Abbreviations **x**

CHAPTER 1- INTRODUCTION ………………………………………………....1

1.1 Overview……………………………………………………………………....1

1.2 Problem Statement…………………………………………………………….2

1.2.1 Solar Cell: Costs, Challenges, and Design……………………………….….4

1.2.2 Solar Panel Efficiency………………………………………………………..4

1.2.3 High initial setup and required maintenance cost…………………………....5

1.2.4 Land requirement……………………………………………………………..5

1.2.5 Required of skilled workers…………………………………………………..5

1.2.6 Intermittency and power quality issue………………………………………..5

1.2.7 Material requirement for PV cells…………………………………………....6

1.2.8 Environmental downside……………………………………………………..6

1.3 Objectives……………………………………………………………………...7

1.4 Motivation……………………………………………………………………..7

CHAPTER 2- LITERATURE REVIEW……………………………………………8

2.1 Introduction……………………………………………………………………8

2.2 Literature review………………………………………………………………8

2.3 Study Gap……………………………………………………………………10

CHAPTER 3- BACKGROUND…………………………………………………..…11

3.1 TES System…………………………………………………………….......11

3.2 Classification of TES…………………………………………………........12

3.3 Seasonal TESs……………………………………………………………....12

3.3.1 ATES………………………………………………………………………….13

3.3.2 BTES…………………………………………………………………………......14
3.3.3 TTES………………………………………………………………………………..15
CHAPTER 4 – SAND BATTERY…………………………………………………...16
4.1 Sand Battery……………………………………………………………………..16
4.2 Utilization of sand as a storage material……………………………………...16
4.3 Advantage of using sand as a storing Material…..……………………………..…16
4.4 Working of Sand Battery………………………………………………………..17
4.4.1 Charging Stage………………………………………………………………...17
4.4.2 Storing Stage…………………………………………………………......17
4.4.3 Discharging Stage……………………………………………………………..17
CHAPTER 5- RESEARCH METHODLOGY……………………………………..18
5.1 Criteria…………………………………………………………………………..18
5.2 Model Description……………………………………………………………19
5.3 Governing Equations…………………………………………………………21
5.4 Boundary Conditions…………………………………………………………22
CHAPTER 6- RESULTS AND DISCUSSION…………………………………….…24
6.1 Charging state…………………………………………………………………...24
6.2 Discharging state……………………………………………………………..28
CHAPER 7- CONCLUSION……………………………………………………...32
REFERENCES

LIST OF TABLE

Description	Page No
Table 1. PROPERTIES OF TES MATERIALS	11
Table 2. PROPERTIES OF SAND	19
Table 3. BOUNDARY CONDITIONS FOR CHARGING	22
Table 4. BOUNDARY CONDITIONS FOR DISCHARGING	23

LIST OF FIGURE

	Description	Page No.
Fig. 1.1	Capacity addition in Solar Power in India.	1
Fig. 1.2	Annual Mean Daily Solar Radiation in India.	3
Fig. 3.1	Classification of Thermal Energy Storage System	12
Fig. 3.2	Aquifer Thermal Energy Storage	13
Fig. 3.3	Borehole Thermal Energy Storage	14
Fig. 3.4	Tank Thermal Energy Storage	15
Fig. 4.1	Sand Battery	17
Fig. 5.1	Model of Sand Battery	19
Fig. 5.2	Design Modular	20
Fig. 5.3	Meshed geometry of Sand Battery	22
Fig. 6.1	Charging State Temperature Countours at 247 sec	24
Fig. 6.2	Charging State Temperature Countours at 500 sec	24
Fig. 6.3	Charging State Temperature Countours at 1000 sec	25
Fig. 6.4	Charging State Temperature Countours at 1500 sec	25
Fig. 6.5	Charging State Temperature Countours at 2000 sec	25
Fig. 6.6	Charging State Temperature Countours at 2500 sec	26
Fig. 6.7	Charging State Temperature Countours at 3000 sec	26
Fig. 6.8	Charging State Temperature Countours at 4000 sec	26
Fig. 6.9	Charging State Temperature Countours at 5000 sec	27
Fig. 6.10	Charging State Temperature Countours at 6000 sec	27
Fig. 6.11	Charging State Temperature Countours at 6389 sec	27
Fig. 6.12	Temperature Distribution for Charging State	27
Fig. 6.13	Charging State Graph	28
Fig. 6.14	Discharging State Temperature Countours at 10 sec	29
Fig. 6.15	Discharging State Temperature Countours at 500 sec	29
Fig. 6.16	Discharging State Temperature Countours at 2000 sec	29
Fig. 6.17	Discharging State Temperature Countours at 4000 sec	30
Fig. 6.18	Discharging State Temperature Countours at 5500 sec	30
Fig. 6.19	Discharging State Temperature Countours at 7100 sec	30

Fig. 6.20 Temperature Distribution for Discharging State	30
Fig. 6.23 Discharging State Graph	31

LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations /Symbols	Descriptions
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 (J/kg)
C_P	Specific heat at const. pressure (J/kgK)
t	Time (minutes)
T	Temperature (K)
T_M	Melting Temperature
P	Pressure (Pascal)
HTES	Heat Thermal energy system
HTR	Heat transfer rate
SHS	Sensible heat storage
THS	Thermochemical heat storage
LHS	Latent heat storage
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)

CHAPTER-1

INTRODUCTION

1.1 Overview

The provisional storage of the heat energy due to heat at lower and higher temp. is denoted as TES i.e. Thermal Energy Storage. These concepts are not modernistic, it had been advanced and used for eras because of its importance in energy preservation. Because the heat energy source is very intermittent, itsoperative use is reliant on the obtainability of competent and operative sensible and latent heat-energy storage methods. As a result, solar-thermal machineries would not be capable to reach their full capability for domestic space-heating and hot water applications in the households. Seasonal heat energy storage can significantly reduce the overall costing of heat energy systems from the sun that can deliver up to 100% of a building's energy needs. These systems are intended to gather energy from the sun in the summer season and store it for use in the winter.

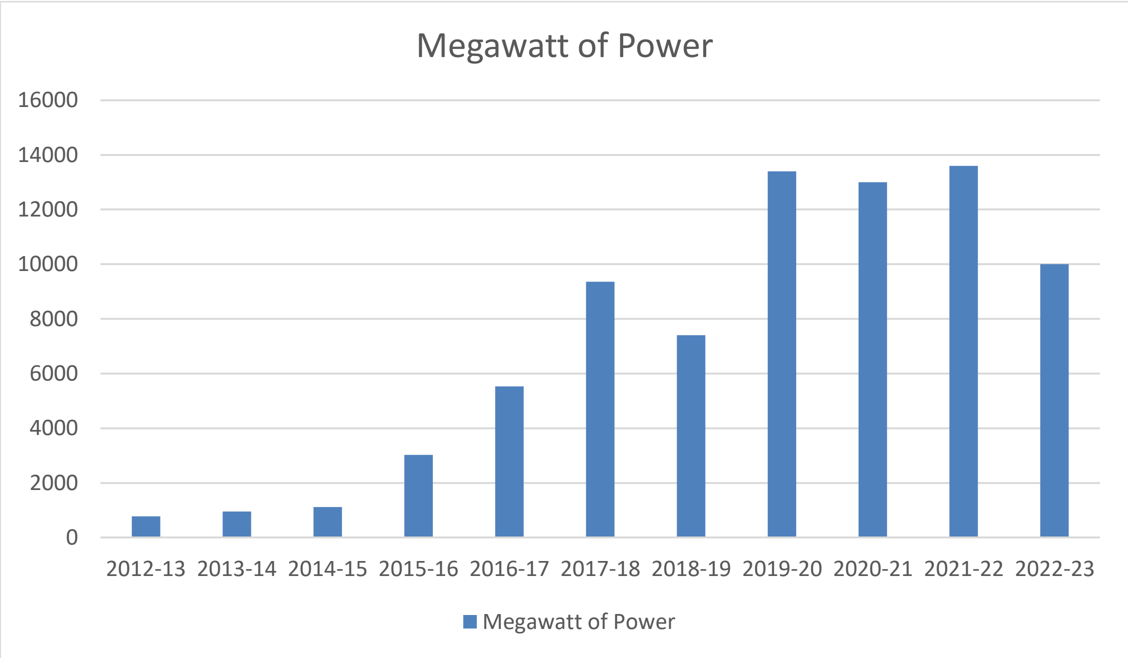

Fig. 1.1: Capacity addition in Solar Power in India.

Such type of systems has been developed and performed, it is hard to develop them in terms of cost effectiveness. Yearly storage on a public-wide domain could be designed in inexpensively justified projects, potentially lowering costs and improving the reliability of solar heating. Systems using renewable energy technologies, including solar energy systems, now heavily rely on the energy that can be stored. Thermal energy can be stored using heating or cooling method known as thermal energy storage (TES), which can then be utilized for power production, heating and cooling systems, and other things. Particularly in construction and industrial processes, TES systems are used. The use of Thermal Energy Storage in a heat energy system offers a number of advantages, including as a increase in overall thermal efficiency and storage security, but also it may boost economics due to cutting starting costs and running cost, lowering environmental pollutants, and reducing carbon dioxide (CO2) emissions. Contrary to photovoltaic systems with their waning efficiencies, solar thermal energy storage systems are technologically advanced and uses a significant portion of the solar thermal energy during the daytime. Though, it lacks significant thermal holdup to carry on working when there is very little or almost negligible solar radiation. Thermal Energy Storage system is developing increasingly significant for energy storage in grouping with concentrated solar power i.e. CSP facilities, because heat from sun is being stored and used whenever the sunlight is not present.

1.2 Problem Statement

Global energy demand is rising, and environmental worries about greenhouse gas emissions produced due to the use of natural fuels have prompted studies into the possibility of renewable-energy sources including solar, biofuel, hydrothermal energy, etc. Due to the ubiquitous accessibility of radiation from the sun and the advancements made in its overall efficiency, solar thermal energy is among them and is quickly becoming a highly desired type of renewable energy.

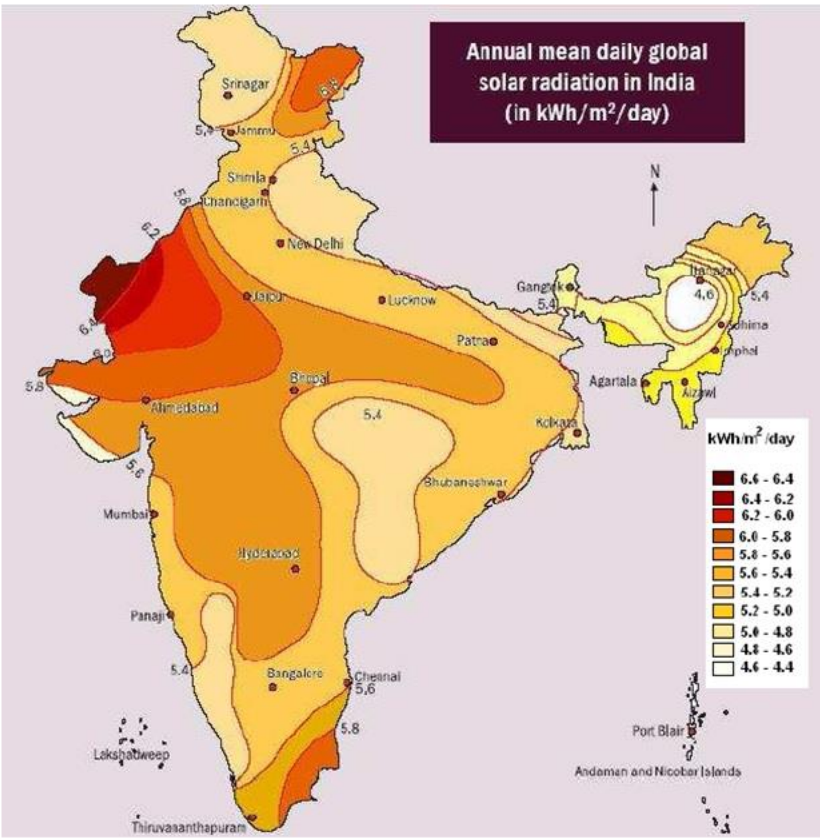

Fig. 1.2: Annual Mean Daily Solar Radiation in India.
(Source : https://www.eai.in/ref/ae/sol/rooftop/power_output)

There are several types of thermal storage, but so far reports have focused on Latent-heat storage i.e. LHS, Thermo-chemical storage i.e. TCS and Sensible-heat storage i.e. SHS. Studies in the literature have also been done that concentrate on the primary mechanical energy storage technologies. Additionally, batteries and other electrochemical energy storage systems are becoming more and more well-liked due to their extremely high energy conversion rates. Although they are still in the experimental stage, recently studied substances for numerous sunlight storage forms have enormous capability as upcoming storing materials as speculative limitations haven't still been achieved. Since earth receives daily solar energy that is over 200,000 times greater than the world's capacity for electricity production, solar energy offers a tremendous amount of potential. However, in spite of the fact that sunlight is available for free, many places still forbid its use owing to the high expenses of its collection, transformation, and storage facilities. Thermal or electrical energy may be produced from solar energy.

The quantity of energy from the sun that humans can consume is limited by a number of factors, including location, temporal fluctuation, covering of clouds, and the area of land that is approachable to us on Earth. The energy from the sun that is present near to the planet's surface is distinct from this potential solar energy. The Carbon Tracker Initiative estimates that in order to generate all of our energy from solar sources alone in 2021, 450,000 km^2 of land area (0.3% of the total land area of the planet) will be needed. Each second, the Sun sends energy into space equivalent to all the energy required by humans for 2 hours or more. Solar energy is a attractive source of energy because it is reasonable and renewable. Energy from the sun accounted for less than 2% of global energy consumption. Harvesting solar energy has always been costly and inefficient. The quantity of electricity generated from solar energy increased more than 300-fold globally between 2000 and 2019; however, even this small utilization of solar energy shows improvements over the preceding two decades. This rising dependence on solar energy has been propelled by the cost-saving impacts of new technology improvements over the past 20 years, and future technological developments are anticipated to support this usage by further decreasing prices and increasing solar efficiency.

1.2.1 Solar Cell: Costs, Challenges, and Design

• The solar panel efficiency

• High initial setup and required maintenance cost.

• Land requirement.

• Required of skilled workers

• Material Requirement for PV cells

• Environmental downside

1.2.2 Solar Panel Efficiency

The sun provides the world with (3.21 x 1020 J) of Energy/Hour, with the mean solar energy output on the Earth’s surface being 174.7 W/m^2. It is corresponding to 76,841 Mega-tons. In less than two hours, the sun generates more energy than the whole earth uses in one full year. Though, only little fraction of the energy can be transformed into solar power since solar cells have a lower efficiency. The several solar cells that make up a solar panel are joined together into the series connection or else in parallel connection to produce the solar-panel as a whole. Concentric Materials used in solar cells allow light energy to be absorbed and converted to electrical energy.

1.2.3 High initial setup and required maintenance cost

Although there are many long-term benefits to installing solar panels, the upfront expenses might be exorbitant. Solar panels require storage batteries and inverters to change direct current into alternating electricity in order to generate electricity. Other equipment installation is more expensive than solar panel installation.

1.2.4 Land requirement

The possibility that substantial degradation of the environment or the destruction of ecosystems for wildlife might result from the use of solar energy is another issue. Contrary to larger utility-scale PV systems, which may require a maximum of 3.5 to ten acres per megawatt of power, and CSP plants, which may require 4 to 16.5 acres per megawatt of power, solar PV systems may be attached to existing structures. Bigger utility-scale solar facilities may cause problems with loss of habitat and degraded land based on wherever they're being constructed. According to the method of production, the topography of the site, and the strength of the solar resource, different amounts of land may be needed. Solar installations are less inclined to coexist with agricultural utilization of the land than wind installations.

1.2.5 Required of skilled workers

The lack of qualified workers to complete the task is a significant barrier to installing solar panels. Understanding the complexities of these systems requires some training. Several different approaches are being taken to this issue. Some businesses are assembling and training specialized installation teams to work across vast areas. Travelling between job sites is inefficient under this arrangement, and any downtime is very expensive for businesses trying to keep devoted crews on the payroll.

1.2.6 Intermittency and Power Quality issue

One of the major problems with the use of solar power technology is that power can merely be generated when the sunlight is available. This suggests that on overcast days and at night, the supply might be disrupted. The deficit brought on by this interruption wouldn't be an issue if there were affordable means to store energy because highly bright times can result in excess capacity. As the demand for solar energy rises internationally, Japan and other nations who are pioneers in solar power technology are concentrating on creating adequate storage facilities to address this issue.

1.2.7 Material Requirement for PV cells

The silicon-based photovoltaic cells that now rule the global market have three major problems. The primary problem with silicon photovoltaic, or PV, cells is that they are made from a substance which doesn't occur frequently within the environment in the requisite unadulterated, elemental form. Some sand contains large amounts of silicon dioxide, but extracting the oxygen from it needs a lot of work. For some solar technologies, it is necessary to produce rare elements. CSP technology has less of a problem in this regard than does PV technology.

1.2.8 Environmental downside

Emissions of greenhouse gases have been linked to solar energy system construction and shipment. The fact that solar power uses a lot of the exact same hazardous materials as electronics is its only ecological drawback. The issue of disposing of dangerous materials gets more difficult with the expanding usage of solar power. Solar power will probably be a desired replacement for energy from fossil fuels in the not-too-distant future due to its fewer emissions of greenhouse gases, provided the issue of suitable dumping is resolved. Freshwater might be necessary for particular solar power installations for cooling turbine engines or wash the collectors and concentrators. Cleansing collectors in certain arid regions having plenty of surface or groundwater might have an impact on the natural environments that are dependent on these water sources. In addition, a solar power tower's focused sunlight beam may kill insects and birds that fly into it. However, solar energy generates a lot less pollution than other alternative energy sources.

1.3 OBJECTIVES

This investigation aims to analyses the thermal modelling of the TES system: Sand-Battery and also to find a more ecologically friendly and economical solution to the thermal storage than current methodologies can provide. It can also provide this form of energy security in an eco-friendly manner.

It is beneficial to employ molten salt in contemporary Thermal Energy Storage (TES) systems. As a storage catalyst, this substance can only be used at temperatures up to 600 °C and is prohibitively costly. At 1000 °C, or around 400 °C higher than molten salt, concentrated solar power (CSP) technologies are able to retain thermal energy.

Sand is also easily accessible throughout the nation, and its environmental friendliness makes it a deserving storage medium to pave the way for a new wave of thermal energy storage technologies. In order to lower prices, improve availability, and lessen the environmental effect of current TES system models, this research aims to develop a Thermal Energy Storage system that use sand as an heat energy storing media. To do this, crucial storage features including charging, storing, and discharging are employed.

1.4 MOTIVATION

The development of energy storage technologies that are both economical and energy-efficient is crucial to making use of solar energy-based projects. But in order to properly create power on demand that is not reliant on solar intermittencies, the usage of TES technology becomes essential. The TES system may greatly improve energy efficiency and system dependability by reducing the temporal or cost variation between demand of the energy and the supply of the energy. A TES system would increase power plants' functioning through load leveling, leading to energy saving and economic effectiveness. To fulfill India's rising energy needs while upholding its interest in clean and renewable sources, creative and ecologically responsible solutions must be created and put into the actual practice for example the solar power Sand battery.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Previous investigation proved that the use of molten salt as the storage media is the only option available for thermal energy storage at the moment. Desert sand from India has been shown to beaffordable & upkeep-free option for high-temp. sensible thermal (SHS) energy storage.

2.2 Literature Review

In an experimental study [1], it was discovered that the sand needed 56 minutes tocharge up to 150°C. Under insulated settings, the temperature of the sand reduced to 91°Cafter 5 hours of storage, suggesting a high storing efficiency of 88.9 percent. 0.535 Voltage was then produced by the thermo-electric generator after the heat transfer fluid had recuperated the heat energy from the sand in 7 minutes with a discharge efficiency of 61 percent. Another investigation focus particularly on, Large-scale thermal storages such borehole thermal storage, aquifer thermal storages, pit and tank thermal energy storages are the subject of thisreview study on thermal energy storage methods. The investigations in this paper's studies show that every storage has both advantages and disadvantages of its own [2].

The main disadvantage of subcritical solar thermal plants is thermal energy storage, which results in lower efficiency and a higher cost per MWh is study. Water evaporation uses more than 50% of the heat energy required in CSP solar plants. As a consequence, the development of dependable and cost efficient and cost effective latent heat storage systems may aid in the widespread deployment of these types of CSP systems. [3].

The study investigated that the energy storage options canbe divided into sensible, latent, and thermochemical heat stores depending on the energy storage substance. For residential and building applications, liquid thermal storage is typically used as a separate unit, like water storage and solar pounds, whereas solid thermalstorage can be used as both a separate storage unit, like packed bed storage, as well as anintegral part of the building, like an envelope integrated energy storage system .

The Thermal Energy Storage System and types of TES are the study focuses on TES innovations that allow buildings to use less energy while still utilizing solar heat. The discussion also includes thermo-chemical storage and latent heat storing system linked to PCM for application in solar powered building heating operations and cooling operations, heat-pump systems, solar based water heating system, and concentrating CSP power plants. Finally, a quick review of cool thermal energy storage is provided. Relevant data on the effectiveness and expenses of TES systemsare also presented [5].

For lowering the price of the substances used forstorage, a key area of study is increasing the thermal conductivity of thermal energy storage materials. The technologies are quite developed and commercialized for latent heat storage materials and sensible heat storage materials. However, thermo-chemical compounds are also in the experimental phase. Due to their largest volumetric energy storage capacity, thermochemical materials have a lot of capability as TES materials in the future [6].

[7] Investigated the prime important considerations for analyzingtypes of TES that are presently storage efficient and the cost of materials and operations. Sensible-Heat storage is the most commonly used type of thermal energystorage due to its reliability, low price, ease of application, and large no. of experimental outcomes. Latent-Heat energy storage is ideal for storing excess heat energy when the consumption is low. The highest energy storage capacity by volume is provided by thermo-chemical heat storage, which includes storing heat energy in chemical-bonds.

The fine grained gravel and silica sand are excellent thermal energy storage materials. Within sand grain beds with a diameter of 0.2 to 0.5 mm, air can transfer heat. These beds have been evaluated up to a 550 °C storage capacity. The fineness of the sand affects the packing density. Greater packing density can be found in finer sand. The grains in gravel are 0.4 millimeter in diameter. Basalt gravels could be utilized directly for solar power systems as solar thermal heat energy storage options [8].

The batteries are the most usual method for storing solar energy. The main focus areas in thermal energy storage right now are storage material cost reduction, operation cost reduction, and energy storage efficiency improvement. On the high temperature side, inorganic materials such as nitrate salts are the most commonly used thermal energy storage materials. On the low and medium temperature side, organic materials such as commercial paraffin are the most commonly used [9].

Although the temperature of the fluid used for heat transfer in a CSP plant can reach 1000 C, most modern power plants run between 220 C to 565 C due to the breakdown of the molten salts at high temperatures. This study discovered that although concrete temperature rises as you increase the mass flow rate, the tendency becomes less pronounced after the mass flow rate exceeds 6 kg/s. During the charging phase, there is a negative correlation between the borehole dia. and the mean concrete temperature, and the opposite is true throughout the discharging process. Efficiency levels for energy and exergy ranged from 0.2% to 98.1% and 0.1% to 77.9%, respectively [10].

The various types of storage units are discussed in this investigation with a focus on TES units using PCM.This paper describes numerous types of PCMs and their properties, but it also describesa new type of PCM known as composite PCMs. In comparing to single PCMs such as Paraffin-wax, Composite PCMs have improved properties such as heat of fusion, melting point, thermal conductivity and density. Latent heat thermal energy storage devices are more affordable because they can store five to fourteen times the thermal energy than sensible heat thermal energy storage materials.

2.3 Study Gap

According to a literature study [1], the use of molten salt improves current Thermal Energy Storage (TES) systems. This substance could only be utilized as heat energy storage at temperatures up to 600 °C, and it is quite expensive. With the use of Concentrated Solar Power (CSP) technology, desert sand may be utilized to store thermal energy up to 1000 °C, which is about 400 °C higher than molten salt [4]. Sand also serves as an attractive heat strong media to lead a fresh generation of heat energy storing technologies due to its availability within the country and eco-friendliness. Coal and petrol are the main sources of energy in India [8]. The demand for electrical energy is expected to quadruple by 2025, according to current projections.

Chapter 3

BACKGROUND

3.1 Thermal Energy Storage System (TES)

Over the past few decades, a no. of heat energy storage devices has been researched and created. While others are made to store massive quantity of heat energy, while some are made to store thermal energy at medium and small scales. In recent decades, many heat energy storage devices had been researched and developed. The increased use of renewable energy sources over the last two decades has increased the importance of energy storage system researchand development. Solar energy, wind energy, and tide energy didn't always generate energy at the samerate that it is consumed in cities. This transition from traditional fossil fuel-based energy systems to systems with high renewable energy penetration introduces supply and demand variations in the load. The fact that heat accounts for 50% of all final energy use globally highlights the significance of TES in future energy systems with significant volumes of intermittent renewable energy sources. It has possibilities for using heat pumps or electric boilers to integrate intermittent sources of renewable energy, such solar power, and wind power, into the heating or cooling sector since thermal energy storage is far less expensive than electrical storage. By lowering peak thermal demands, boosting system effectiveness, and incorporating additional heat sources like industrial waste heat or saltwater, TES enhances heating and cooling networks.

Table 1. Properties of TES Materials

Material	Density (kg/m^3)	Heat Stored (kJ/kg)	Type
Sand-Rock	1600	130	Solid
Concrete	2200	85	Solid
Sodium Chloride	2160	85	Solid
Synthetic Oil	900	230	Liquid
Cast Iron	7200	56	Solid

3.2 Classification of TES

When the demand for heat is greater than the supply, thermal energy storage is necessary. On the other hand, heat energy storage application for conservation of energy allow for the development of much more efficient and effective, integrated energy systems. TES enables waste cold recovery as well as hot recovery for space heating and cooling as well as more effective use of new renewable energy sources. Various TES technologies are shown in Fig. 3.1 according to the temperature and amount of stored thermal energy. thermal energy.

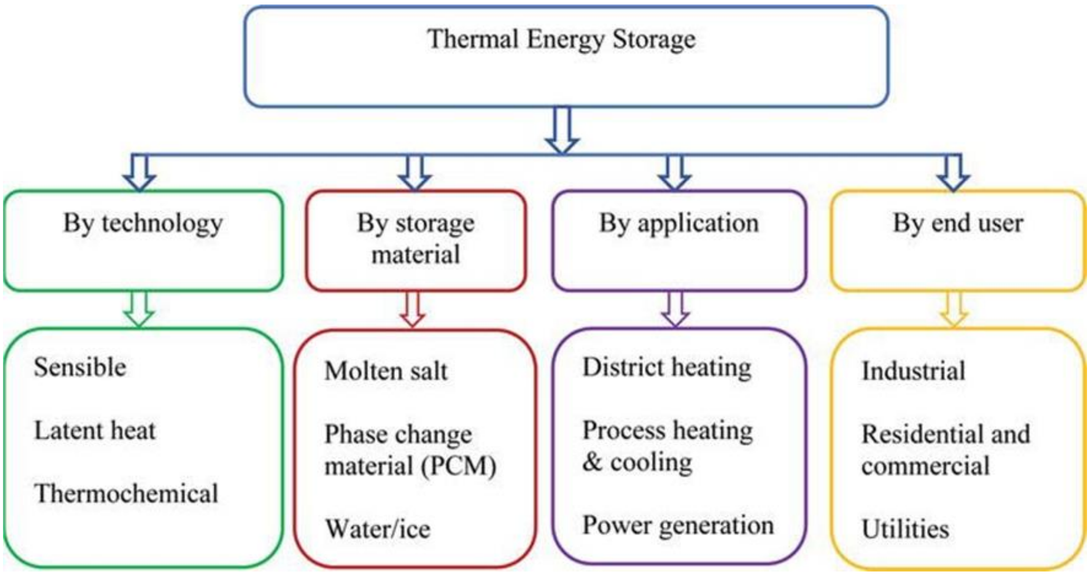

Fig. 3.1: Classification of Thermal Energy Storage System
(Source: https://www.intechopen.com/chapters/63027)

3.3. Various Seasonal Thermal Energy Storage System

The globe has a variety of firm important and seasonal thermal energy storages.

a.) Aquifer Thermal Energy Storage (ATES)

b.) Tank Thermal Energy Storage (TTES)

c.) Borehole Thermal Energy Storage (BTES)

d.) Pit Thermal Energy Storage (PTES)

3.3.1 ATES - Aquifer Thermal Energy Storage

ATES is a geothermal technology that is based on a cold/warm groundwater aquifer and is considered an innovative open-loop seasonal storage system. The subterranean system is the main storage location. Water is combined with very hydraulically conductive layers of sand, gravel, sandstone, or limestone. Though effective ATES systems used for space heating and cooling cannot be categorized as renewable technology. To provide electrical power to operate the mechanical parts of ATES, it is frequently combined with wind turbine or solar panel which are renewable energy sources.

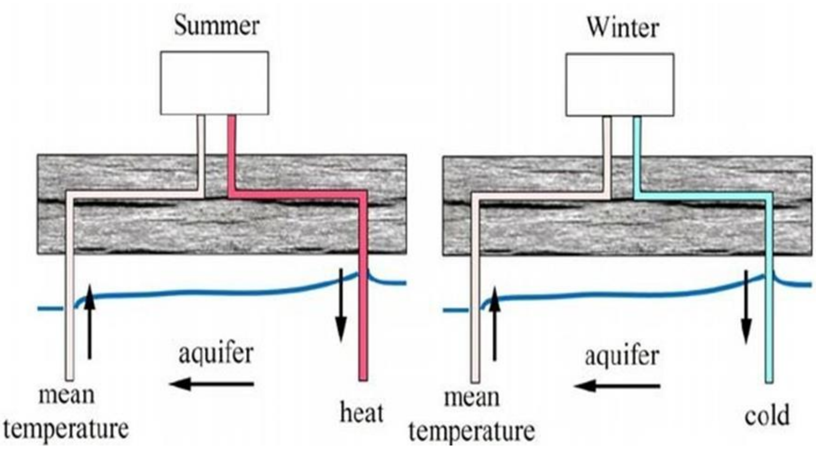

Fig. 3.2: Aquifer Thermal Energy Storage
(Source: Lavinia Gabriela Socaciu, 2012)

The wells drilled into the earth, the ends of which reach an aquifer, are the major parts of the ATES system. At least two wells are needed, out of which one for withdrawing water from the aquifer and the other for pumping it again back to well. For instance, cold water is released from the cold well and utilized for cooling if the user demands it. After then, the heated well recharges the aquifer with hotter water. In large-scale ATE storage system, a number of hot and cold wells are required. In addition to wells, other key elements of ATES include heat exchangers, tubes for conveyance, control systems and mechanical system for integrating it with building cooling systems as well as heating systems.

3.3.2 BTES - Borehole Thermal Energy Storage

The more feasible borehole thermal energy storage i.e. BTES may be implemented anywhere save in areas with high-pressure geysers, empty and big caverns under underground rocks. BTES contains a variety of materials underground, including unconsolidated material and rock that may not include groundwater. Depending on the amount of underground water present, subsurface layers can be both saturated or unsaturated. The major part of a BTES is a vertical heat exchanger i.e. BHE, sometimes called a Bore-hole heat exchanger. Flowing heat carrier fluid through BHE, which is primarily composed of solid-state materials with conduction as the dominant heat transport mechanism, can transmit thermal energy between BHE and subsurface layers. There are several varieties of BHE due to geological factors.

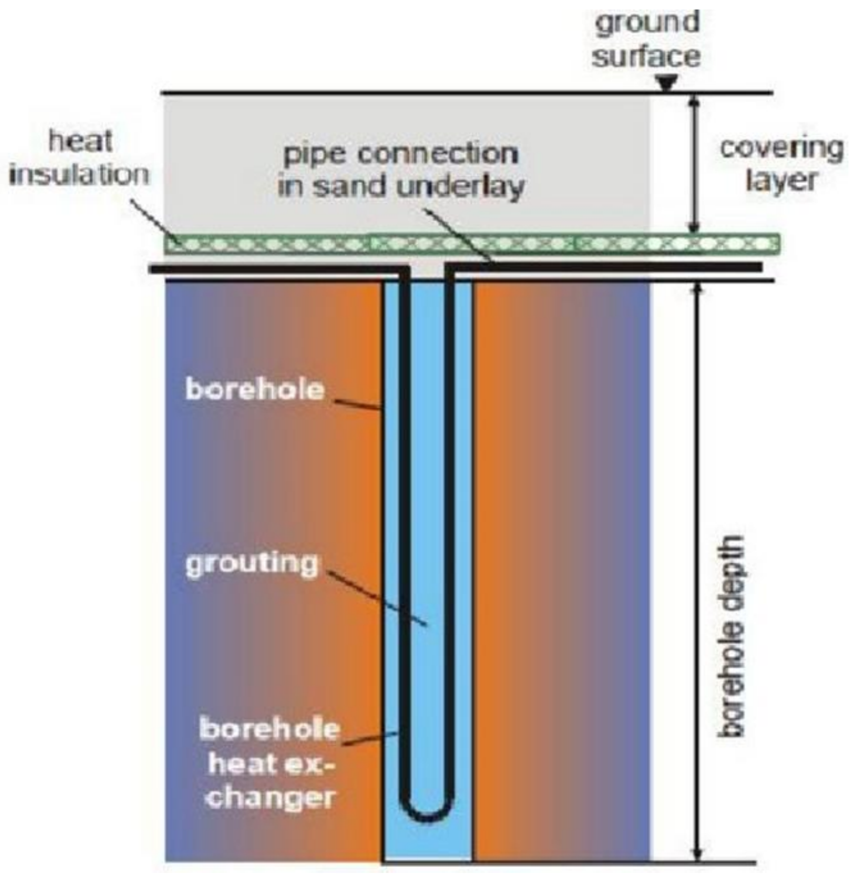

Fig. 3.3: Borehole Thermal Energy Storage
(Source: Lavinia Gabriela Socaciu, 2012)

3.3.3 TTES - Tank Thermal Energy Storage

As buffer storage for single-family homes, the majority of small tank storage is coupled to solar collectors. There are occasional instances of tank storage, however, being utilized for seasonal storage. Reinforced concrete seasonal tank storage is partially submerged in the earth. The construction of this kind of storage is essentially independent of geological situations. Its top and vertical sides are thermally insulated.

Germany created one of the earliest tank storage facilities in 1995. Water was the storage substance employed in the 600 m3 pilot heat store. The shop had a cylindrical form and was partially submerged in the earth. Insulation and stainless steel liners were applied to the top and sides.

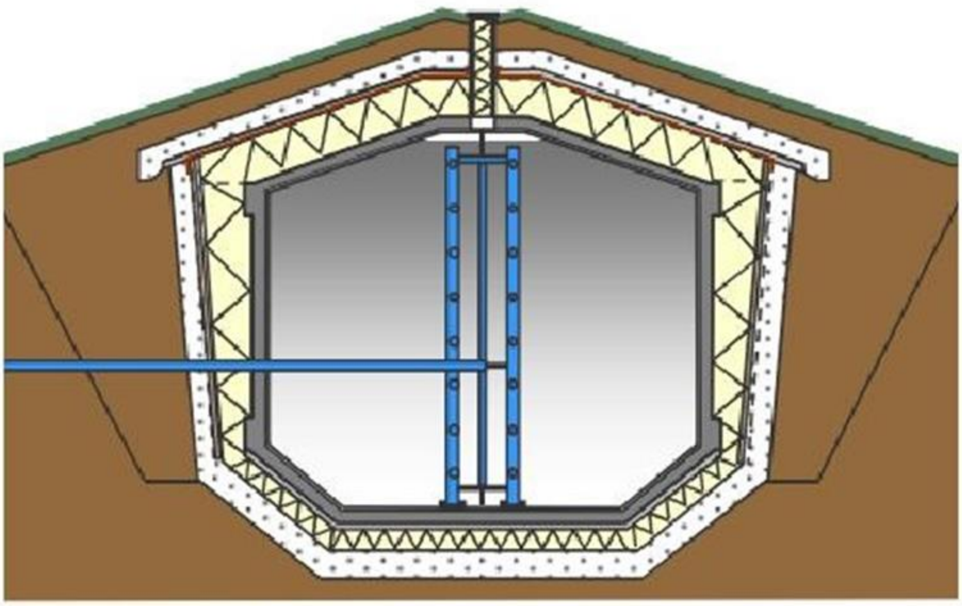

Fig. 3.4: Tank Thermal Energy Storage
(Source: Lavinia Gabriela Socaciu, 2012)

Chapter 4

SAND BATTERY

4.1 Sand Battery

A very high-temperature thermal energy storage system known as a "sand battery" employs sand or substances that resemble sand as the storage medium. In the form of heat, sand retains energy. Its main job is to store extra from the sun and wind in a high-capacity, high-power reservoir. Heat is the form in which the energy is stored, and heat may be utilized to heat buildings or to supply hot steam and high-temperature process heat to companies that commonly rely on fossil fuels. As the globe swings towards an ever-increasing proportion of renewable energy in power production, the short-term availability of these energy sources presents difficulties for energy networks.

4.2 Utilization of Sand as a Storing material

Innovative and sustainable solutions must be created and put into practice in order to meet India's growing energy needs while upholding its interest in clean and renewable sources. A heat exchanger and the storage medium (sand) are both included in the one storage tank that makes up the Sand Battery, a high-temperature sensible thermal energy storage device. An electric heater is selected as the heat input for the valuation of the thermal properties of the sand.

4.3 Advantage of using Sand as a Storing Material

To provide an energy management solution with a low-cost platform and environmental imprint, sensible TES systems are being tested and optimized. If properly optimized, such applications can offer a valuable and urgently required breakthrough in the field of TES systems technology. building a system for storing thermal energy with sand as the storage material. Even in its early phases, such a design has shown a lot of promise in terms of its prospective capacity to came across the globe's projected demands of energy. For instance, molten salt, the most popular storage medium, causes plugging-related problems if it is not kept above a certain temperature (260 °C). In this scenario, the system has to be heated from outside to bring the molten salt back to its liquid condition. Systems based on molten salt are quite costly. In particular, 28,000 tons of molten salt nitrate are required for 7.5 hours of heat storage.

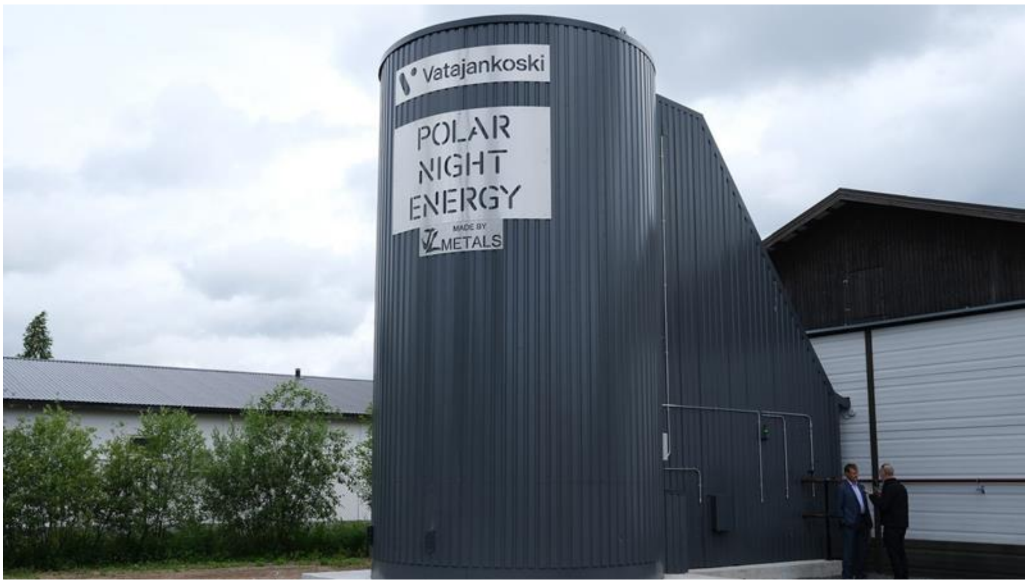

Fig. 4.1: Sand Battery
(Source : https://polarnightenergy.fi/sand-battery)

4.4 Working of Sand Battery

The working of the sand battery can be explained in the three sections: charging, storing and discharging stage .

4.4.1 Charging stage

The primary stage of the system which determines the actual time that is required to reach the given temperature by the sand.

4.4.2 Storing stage

The second stage of the system determines the storing capacity of the sand battery in other words the capacity of loss of heat after the certain period of the time.

4.4.3 Discharge Phase

The final stage of the system which determines the actual time that is required to reaches to the initial time of the system.

CHAPTER- 5

RESEARCH METHODOLOGY

In this study, a Sand Battery TES system is considered for CSP applications. The conceptual representation of TES, the heat exchanger inside the well-insulated storage unit is made up of two charging tubes, consisting of a pair of straight pipes connected with the fins at each side. The heat transfer fluid is recharged again into the pipes continuously. The working fluid inside the heat exchanger system is assumed to be mineral oil. This storage system can be retrofitted with existing CSP plants. The whole process is divided in two stages: charging and discharging. Further the thermal energy can be extracted from the system whenever needed in form of heat energy as a final outcome or electricity as the desired output.

Thermal Modelling is to be done of the system i.e. Sand Battery which involves following steps:

1.) Problem specification and geometry

2.) Governing equations

3.) Boundary conditions and material properties

4.) Mesh generation

5.) Result Optimization

5.1 Criteria

Sun's heat energy i.e. solar energy is used as a source of heat and sand is used as a medium of heat storage by the TES investigated in this work. Some of the TES norms are described in Table 1, while others, like capacity of heat storage i.e. Charging period and then Discharging Period that can be determined from the modelling and simulation that is the focus of this investigation.

There are many different criteria, including feasibility, methodological, ecological, financial, sizing, and time duration of storage that can be used to evaluate TES and applications 2.

Table 2. Properties of sand

PROPERTY	VALUE	UNIT
Density	1600	kg/m^3
Specific Heat Capacity	830	J/kg K
Thermal Conductivity	0.25	W/ m K
Viscosity	1.5×10^{-8}	Kg/m s
Thermal Expansion Coefficient	1.657×10^{-5}	K^{-1}

5.2 Model Description

The layout of the storage unit is shown in Fig. below. It consists of a bed that is a cuboidal with charging tubes built into it. The heat exchanger, represented by the charging tubes including the fin, absorbs and liberate heat energy by allowing cold and hot Heat Transfer Fluid (HTF) to pass inside it. Square shape fins are enclosed to the charging tubes to increase the rate of heat transfer from heat transfer fluid to Sand. The material of the fins that are used in the geometry is copper. The hot heat transfer fluid enters the sand battery from the one end and leaves from the other by exchanging energy i.e. heat through convection mode of heat transfer with the tube wall, which then conducts the heat to the sand battery. The unit's exterior is well-insulated to restrict loss of heat energy to the ambient. The storage model is filled with the sand.

The cross section of cuboidal shape energy storage unit is 90 mm with 60 mm height.

The Fins are in rectangular shape 8x2mm are attached with cylindrical shape tube of 20 mm diameter. Four fins are attached to single charging tube i.e. total 8 fins are used in the above geometry. The 3D Model is demonstrated in Fig. 5.1.

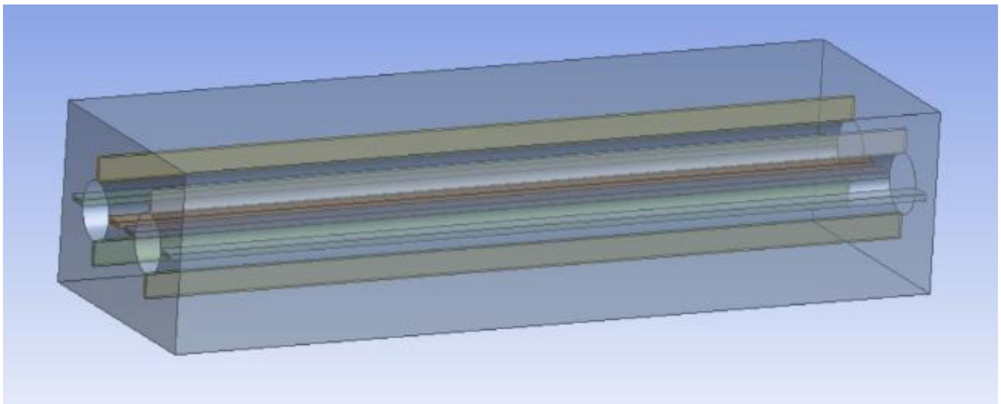

Fig. 5.1: 3D Model of Sand Battey

Fig.5.2 displays the 2D transient model research domain that was taken into consideration for this investigation.

The meshing of model first completed in with geometry in geometric modular as shown in fig 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 have been set for the mesh type setting.

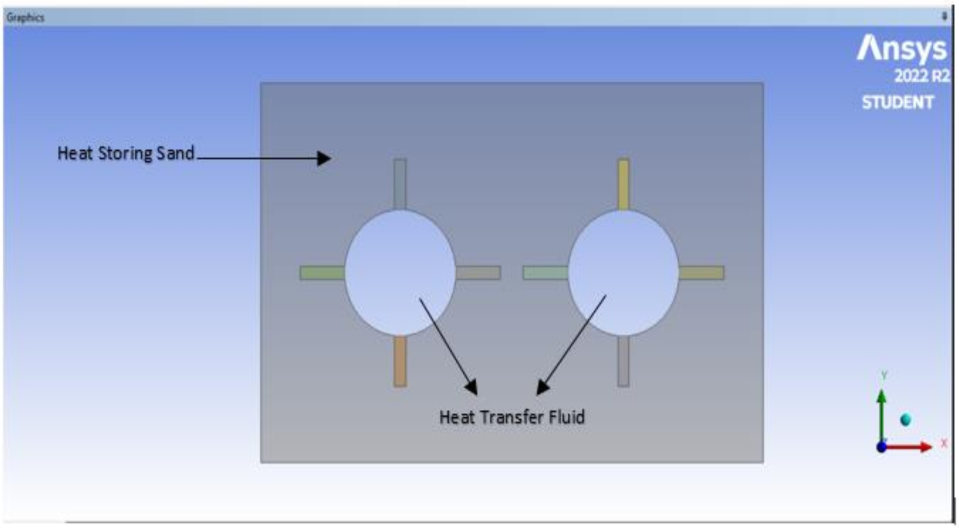

Fig. 5.2: Design Modular

5.3 Governing Equations

The material Cp i.e. Specific Heat Capacity is the factor that determines the quantity of energy which is being stored as heat by the storage material using the concept of sensible heat. The thermal energy which is being stored as sensible heat is represented by the following equation:

$$Q = mC_p\Delta T \tag{1}$$

Here, 'm' stands for 'mass' in 'kg', 'C_p' for the 'Specific Heat Capacity' of material in 'J/kg K', and 'ΔT' for the 'Change in Temperature' in 'K'. In this storing approach, the material does not go through a phase shift but instead experiences temperature upsurge when it absorbs the heat from the charging process. The 'Density', 'Volume', 'Specific Heat' C_p, and 'Change in temperature' of the material being utilized as a storage medium all directly relate to the substance's ability to store heat energy.

Heat transfer through the sand is exclusively accomplished through conduction in order to simulate and analyze the thermal behavior of the storage medium, following equation is used as the heat conduction equation:

$$k_s \nabla^2 T = \rho \; Cp \frac{\delta T}{\delta t} \tag{2}$$

Where,

k_s = Heat Transfer Coefficient

$\nabla^2 T$ = Transient Temperature Gradient

ρ = Density of Sand

Cp = Sp. Heat at const. Pressure of Sand

$\frac{\delta T}{\delta t}$ = Temp Gradient

5.4 Boundary Conditions and Mesh Generation

The research domain has a constant T ini temperature at initial time (t = 0).Taking the intial sand temperature as 300 K and initial fins temperature as 380 K. The outer wall of the sand battery geometry is taken to an adiabatic wall for better simulation results.
The boundary circumstances are shown in fig below. Geometry has been simplified using a free triangular mesh.

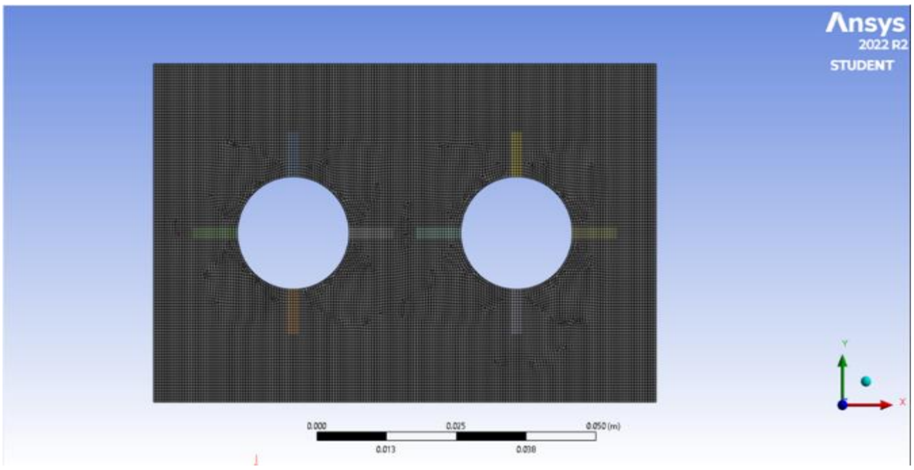

Fig. 5.3: Meshed geometry of Sand Battery

Table 3. Boundary conditions for charging

Description	Boundary Conditions	Initial Conditions
Initial Temperature	Fins	380 K
Final Temperature	Fins	1073 K
Initial Temperature	Sand	380 K
Final Temperature	Sand	1070 K
Outer Wall	Wall	Adiabatic Wall
Inner Wall (Copper)	Wall	Thermo Wall

Table 4. Boundary conditions for discharging

Description	Boundary Conditions	Initial Conditions
Initial Temperature	Fins	900 K
Final Temperature	Fins	401 K
Initial Temperature	Sand	900 K
Final Temperature	Sand	401 K
Outer Wall	Wall	Adiabatic Wall
Inner Wall (Copper)	Wall	Thermo Wall

CHAPTER- 6

RESULT AND DISCUSSION

6.1 Charging State

This project involves the modelling and analysis of a sand battery system. For the whole 6389-second cycle, the simulation results were recorded at regular intervals. The sand battery can charge up to a temperature of 1070 K. The contours of temperature are recorded at various intervals, as shown in the Fig’s below, to help understand the heat-gaining behaviour of the sand battery. Charging was quite rapid in the central area of the geometry, as there were two fins in the middle part of the geometry due to two charging tubes. It can be observed that the entire storage volume's temperature is constant and equal to T ini at time t = 0 s. As time passes, the area of the substance and the surrounding storage material in direct contact with the tube wall and the fins of the tubes begin to heat.

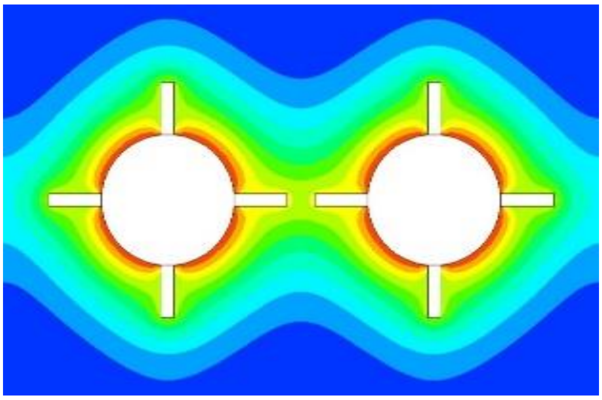

Fig. 6.1 : t = 247 sec

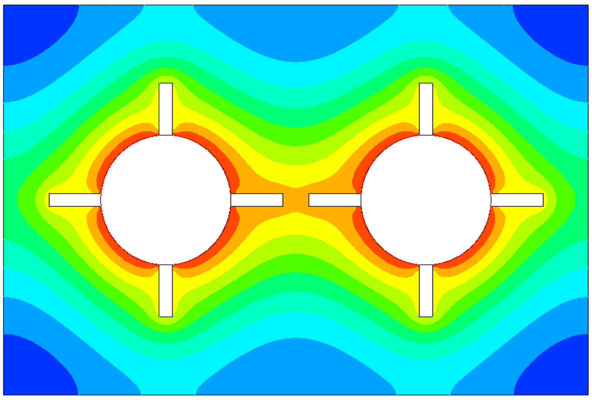

Fig. 6.2 : t = 500 sec

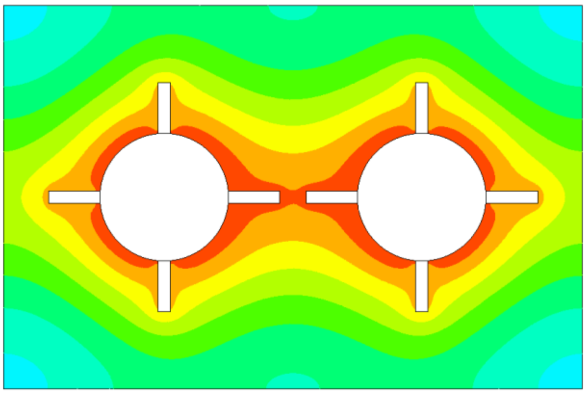

Fig. 6.3 : t = 1000 sec

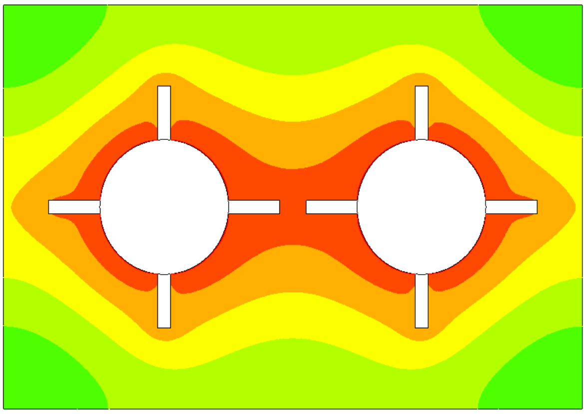

Fig. 6.4 : t = 1500 sec

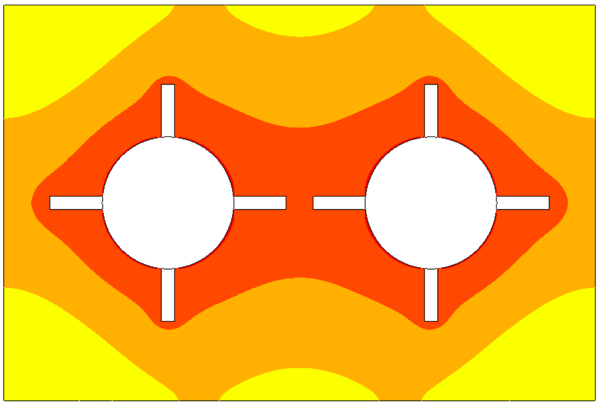

Fig. 6.5 : t = 2000 sec

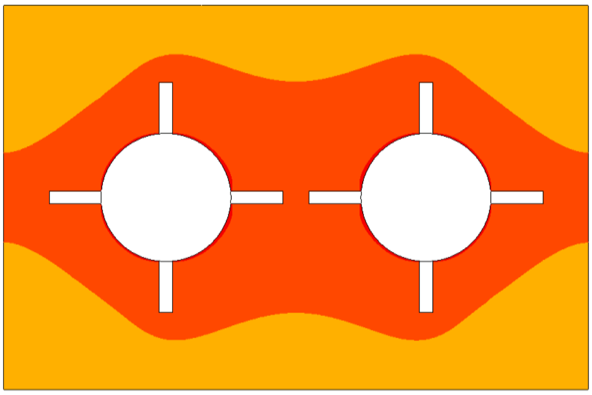

Fig. 6.6 : t = 2500 sec

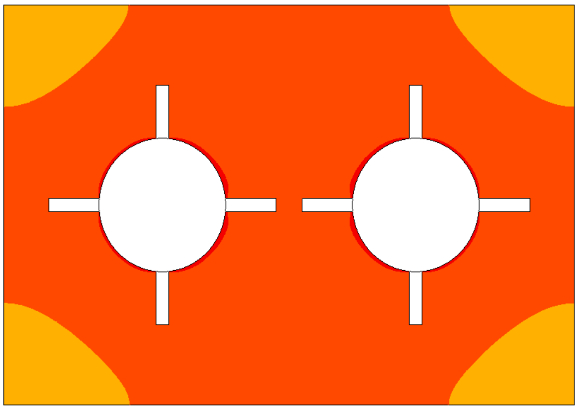

Fig. 6.7 : t = 3000 sec

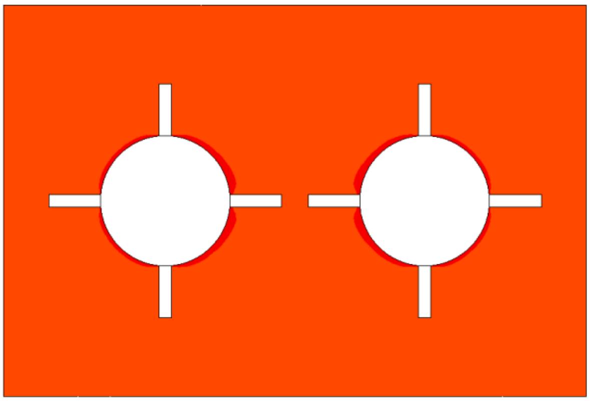

Fig. 6.8 : t = 4000 sec

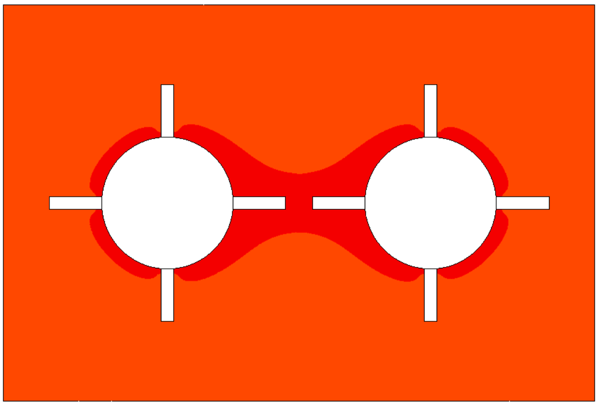

Fig. 6.9 : t = 5000 sec

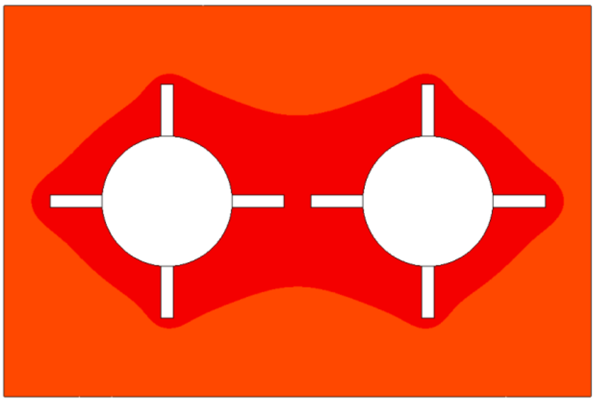

Fig. 6.10 : t = 6000 sec

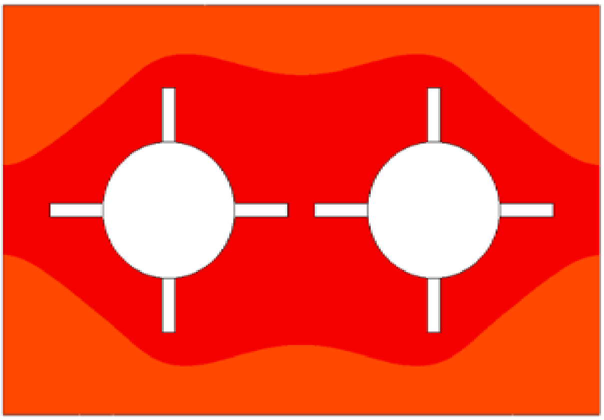

Fig. 6.11 : t = 6389 sec

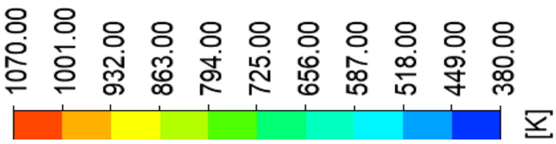

Fig. 6.12: Temperature Distribution

The time versus temperature graph during the charging of the sand battery is shown in the following curve, which indicates that the charging initially starts from the boundary of the tubes and gradually increases through the fins of the tubes. The use of fins in the current geometry indicated a greater heat transfer rate.

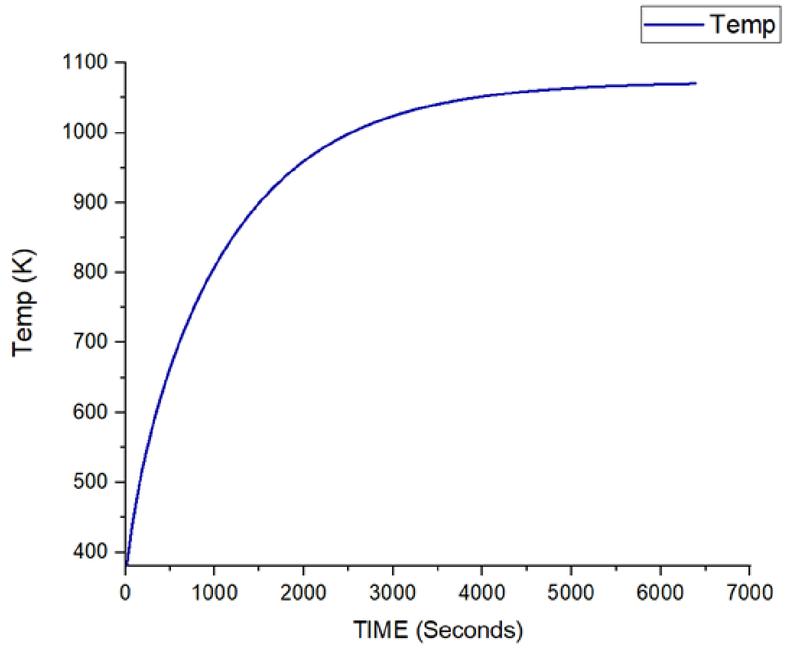

Fig. 6.13 : Charging State

6.2 Discharging State

Now, after the charging state, the sand battery is simulated for discharging state. The result of the simulation was observed and the graph was also plotted for the same.The conditions for discharging were taken initially at t=0 sec for discharging phase the Temperature was T= 900K. Now for the cycle time of 7100 sec, the simulation results were recorded at regular intervals of time. The sand battery started discharging up to 401 K. The temperature contours were recorded at various intervals and to understand the heat-releasing behavior of the sand battery the Fig.s are shown below.

As observed in the charging, the discharging phase was also initiated at the middle part of the geometry due to the fin orientation at the centre, further proceeded toward the other area starting from the middle of the sand batter

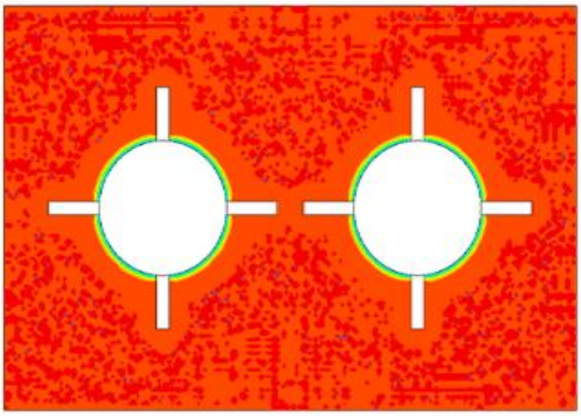

Fig. 6.14 : t = 10 sec

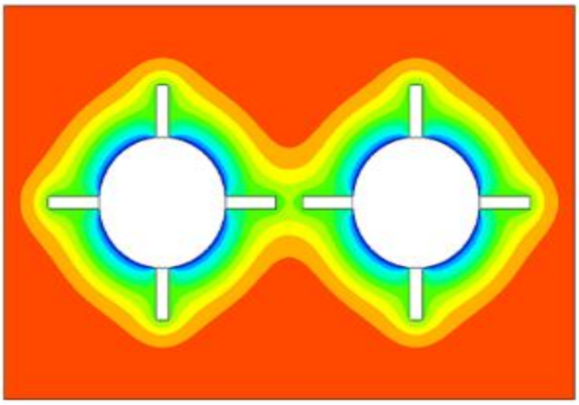

Fig. 6.15 : t = 500 sec

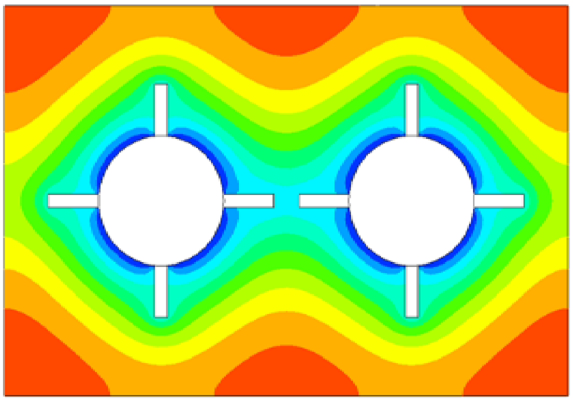

Fig. 6.16 : t = 2000 sec

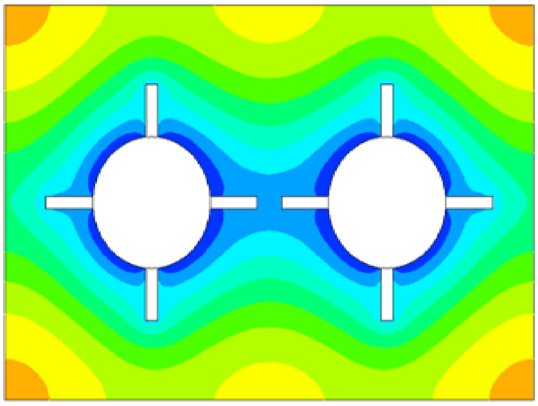

Fig. 6.17 : t = 4000 sec

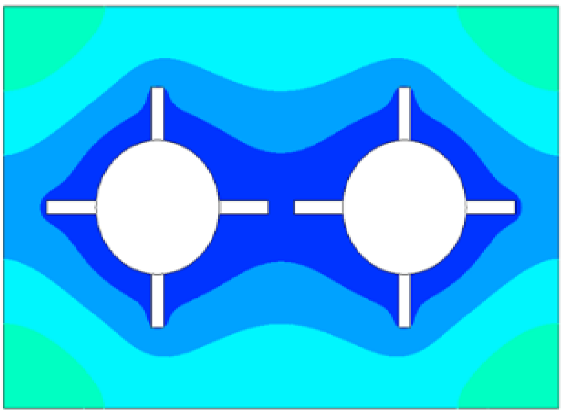

Fig. 6.18 : t = 5500 sec

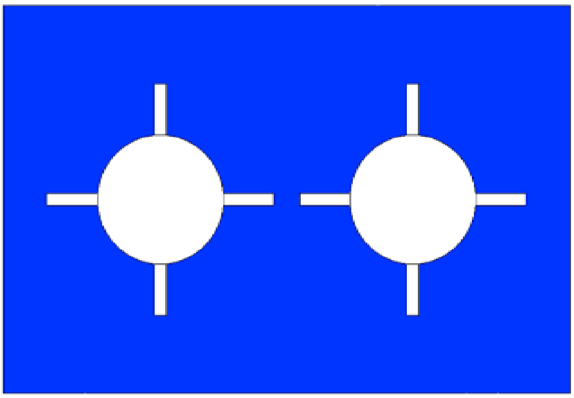

Fig. 6.19 : t = 7100 sec

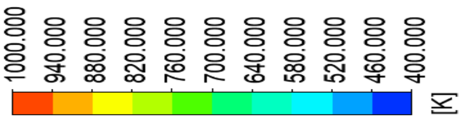

Fig. 6.20: Temperature Distribution

The time vs temperature graph of the discharging is also plotted and shown in fig.8.20

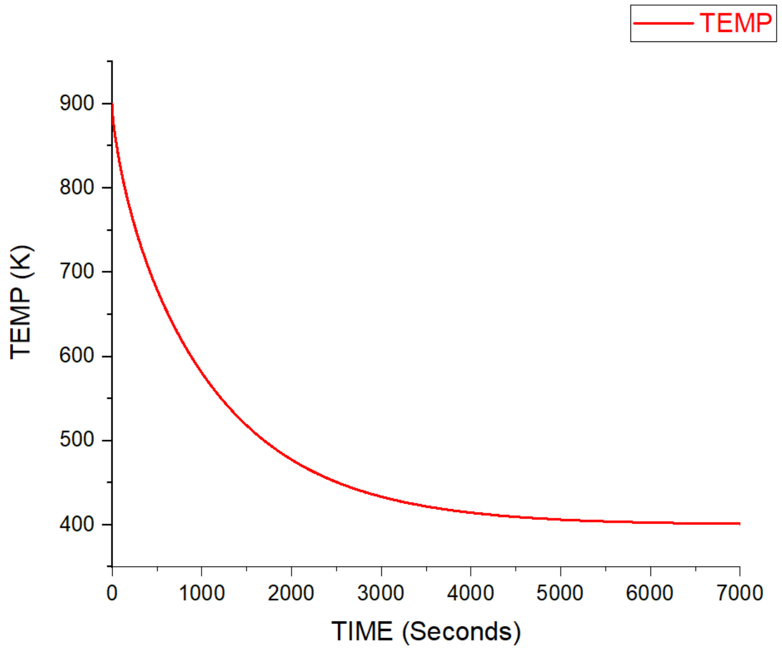

Fig. 6.21: Discharging State

CHAPTER- 7

CONCLUSION

In this investigation, 2D transient state modelling and simulations were done to determine the charging behaviour and discharging behaviour of the sand battery system. The following conclusions can be drawn from the given thermal analysis: -

- It can be seen that the sand bed charges in roughly 6389 seconds up to 1070 K with the initial condition taken as fins temperature 380 K and initial sand temperature also taken as 300 K.
- The discharging time of the sand bed is around 7100 seconds and can discharge up to 401 K and the initial conditions taken on the discharging process is fins at 900K.
- The distribution of temperature in the sand battery results in greater efficiency of energy. These findings demonstrate the demand for sand battery as a heat storage medium for solar energy and encourage us to develop the storage container.
- The use of fins increases the rate of heat transfer and allows bed to charge at a faster rate which can easily be concluded from the graph so plotted for charging and similarly for the discharging state. A parametric investigation experiment is anticipated.
- Current thermal energy storage methods are limited to the use of molten salt as the storage medium. Because of their maintenance requirements, molten salts face high fixed and marginal costs. Desert sand is much more cost-effective and maintenance-free option for high-temperature sensible thermal energy storage. Its properties have proven to be very promising, especially at high temperatures, with a specific heat capacity comparable to that of water.

CHAPTER- 8

FUTURE SCOPE

- The purpose of this project is to develop a TES system using sand as an energy storage medium in order to reduce costs, increase availability, and reduce environmental impact of presently used TES system models. To accomplish this, important storage characteristics such as charging, storing, and discharging are evaluated.
- Thermal energy batteries show immense potential and will definitely play a vital role in the future of renewable energy.
- The potential of Lithium Ion batteries are less than that of the thermal energy storage technologies, so working in the advancement of the thermal energy storage devices will have a great research imitative of the future energy storage technologies.
- The future holds many mysteries and in the coming years we will see many remarkable advancements in battery and energy storing technologies.

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