SIMULATION OF SOLAR THERMAL POWER HEAT EXCHANGER

Lappeenranta–Lahti University of Technology LUT

Master’s Programme in Mechanical Engineering, Master’s thesis

2024

Ali Aslam

Examiners: Associate Professor (Tenure Track), D.Sc. (Tech.) Ville Leminen

D.Sc. (Tech.) Sami Matthews

ABSTRACT

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Keywords: Solar Thermal Power, Heat Exchanger Simulation, Renewable Energy Systems, Thermal Energy Storage, Concentrated Solar Power (CSP), Fluid Dynamics Modelling, Performance Optimization

The research project addresses the increasing demand for sustainable energy by optimizing heat exchanger efficiency in solar thermal power systems. By examining key variables like material selection, flow rates, configurations, and intake temperatures, the study fills gaps in the current literature. Using a detailed 3D model and simulations, it provides insights into heat exchanger operation. Emphasizing technical progress, energy efficiency, cost containment, and environmental sustainability, the solar energy trough collector methodology prioritizes durable and cost-effective materials. Practical considerations lead to the selection of mirror-coated aluminum over silver for reflecting surfaces and mild steel for structural components. Copper tubes are chosen for the collector's design due to advantageous mass flow rates and heat transfer properties. The completed parabolic trough collector design, incorporating a rotating mechanism for heat management, demonstrates practicality in both construction and functionality. The study extends to solar thermal energy storage systems, covering design standards, material selection, and emerging technologies. It explores three types of solar thermal storage materials, considering specific heat, fusion heat, and heat requirements in the design of a storage tank. ANSYS Workbench simulations and mathematical models are presented, concluding with discussions on the parabolic trough's length, heat calculations, and a recommendation for water-based coolant over ethylene glycol. The research suggests future exploration of fluid dynamics and heat transmission in parabolic collectors at varying temperatures.

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SYMBOLS AND ABBREVIATIONS

Roman characters

A	Cross-sectional area	m^2
Clp	Melted Potash Alum's Specific Heat	J/kg. k
c_p	Specific heat capacity	J/Kg. K
D	Diameter	m
d_i	Cylinder's inner diameter	m
d_o	Outside diameter	m
dx	Distance	m
I_B	Intensity of Radiation	$\frac{W}{m2}$
K	Thermal conductivity	w/m. k
L	Length	m
M	Mass of the fluid	g, Kg
N	Number of tubes	
P_r	Prandtl number	
Pι	Density of potassium alum in its melted liquid phase	kg/m^3
Q	Heat transfer	J, Cal
Re	Reynolds number	
r_i	Storage tank's inner radius	m
ΔT	Temperature difference	K
$\frac{dT}{dx}$	Temperature gradient	
V	Volume of potash alum	m^3

Greek Characters

η	Thermal efficiency	
ΔP	Pressure drops	Pa

Abbreviations

BBO	Biogeography-based optimisation
CFD	Computational Fluid Dynamics
GA	Genetic Algorithms
HEN	Heat exchanger network
I-ITHS	Improved Intelligent Tuned Harmony Search
MOWO	Multi objective wale optimisation
PCM	Phase change material
PSO	Particle Swarm Optimisation
SA	Simulated Annealing
SOFC-GT	Solid oxide fuel cell gas turbine

Table of contents

Figures

Tables

1 Introduction

This research optimises heat exchanger performance in solar thermal power systems, a major component of industrial energy systems. It responds to the worldwide trend for renewable energy. Heat exchangers must absorb and convey thermal energy efficiently to meet the growing need for greener, more efficient energy solutions. This work uses modelling and analysis to improve heat exchanger efficiency and effectiveness. This study is motivated by heat exchangers' industrial uses, notably in solar thermal power production. Solar thermal system efficiency is being improved by continuously developing and improving heat exchangers. The initial stage in thermal dynamics analysis is creating a cutting-edge three-dimensional heat exchanger model. The model is then added to a comprehensive simulation suite for testing in various operating settings. As digital laboratories for thermal study, these models provide vital information. The research covers several topics to improve energy efficiency, minimise operating costs, and promote environmental sustainability. Heat exchanger efficiency is examined by considering input temperatures, design, flow rates, material choices, and other factors. Advanced modelling approaches provide insights into heat exchanger dynamics and real-world implementation ideas, extending beyond academic exercises. The public and companies who use sustainable energy solutions may profit from this study's solar thermal system expertise.

To provide a more tailored preview of the upcoming chapters, it's crucial to highlight the connection of this work to research conducted at LUT (Lappeenranta-Lahti University of Technology) and address specific future needs in Finland. In the next chapters, will examine the literature, methods, and findings in more detail, with an emphasis on how this study contributes uniquely to addressing energy concerns on a global and regional scale.

1.1 Problem Statement

This project aims to improve the efficiency of heat exchangers in solar thermal power systems. The central question is: "How can enhance their efficiency?" By investigating key factors, material impacts, flow rates, configurations, and simulation insights, the goal is to reduce energy consumption, optimize performance, and align with broader sustainability objectives in solar thermal applications.

1.2 Research Objectives

- Investigate the primary factors influencing the efficiency of heat exchangers in solar thermal power systems.
- Assess the impact of material selection on the efficacy of heat exchangers within the context of solar thermal applications.
- Examine how different flow rates affect heat transmission within the heat exchanger.
- Analyse the influence of various heat exchanger configurations and layouts on overall efficiency.
- Explore the relationship between intake temperatures and the effectiveness of the heat exchanger.
- Utilize simulation results to gain insights into the temperature distribution, thermal gradients, and heat transport rates within the heat exchanger.
- Based on simulation findings, propose design and operational enhancements to improve the efficiency of heat exchangers in real-world solar thermal applications.

1.3 Research Questions

1. How does the variation in flow rates impact the heat transmission within solar thermal power system heat exchangers, and what are the optimal flow conditions for maximizing efficiency?
2. In what ways do different heat exchanger configurations and layouts influence overall efficiency within solar thermal applications, and how can these configurations be optimized to enhance performance and energy transfer?

1.4 Scope of the Study

This research is specifically scoped to address the optimization of heat exchanger efficiency within the context of solar thermal power systems. The main focus is on heat exchanger performance factors. This includes the development of a comprehensive 3D model of the heat exchanger and subsequent simulation under diverse operating conditions. The heat exchanger's temperature distribution, thermal gradients, and heat transfer rates will be addressed.

While the study is tailored to the intricacies of solar thermal applications, the study acknowledges the potential implications for industrial operations that use efficient heat exchange methods. Importantly, the research does not aim to focus on critical variables that ultimately improve efficiency. A thorough research allows for practical and usable heat exchanger performance optimization recommendations in solar thermal power systems.

1.5 Significance of the Research

The significance of this study lies in its potential to catalyse technological and environmental advancements. Technologically, the research seeks to understand solar thermal power system heat exchanger efficiency parameters. It seeks practical and actionable ideas to optimize these important components. This could affect heat exchanger design and operation in solar thermal businesses. The study also addresses a sustainable energy practice need. Heat exchanger efficiency becomes crucial as enterprises globally migrate to cleaner, more efficient energy alternatives. Thus, this research contributes significantly to energy efficiency, operational cost reduction, and environmental footprint reduction. The potential benefits extend to economic and environmental domains. The study optimises heat exchanger performance to reduce energy usage, carbon emissions, and sustainability goals. In a world where renewable energy is essential, this research could help industry adopt cleaner, more efficient alternatives. The study aims to equip industries to make informed decisions and create a more resilient, efficient, and environmentally responsible industrial future by linking theoretical knowledge with practical implementation. This research has the potential to change how use solar thermal electricity, making it more sustainable and technologically advanced.

2 Literature Review

The Literature Review chapter critically examines solar thermal power system heat exchanger studies. Focusing on significant research and their findings, this chapter will review the previous work. Heat exchanger efficiency is examined through material selection, flow rates, and designs. The review will also examine simulation studies' function in heat exchanger temperature distribution, thermal gradients, and heat transfer rates. Through critical literature review, strive to discover research gaps, problems, and untapped areas. This review sets the foundation for the research goals and advances solar thermal power system expertise.

The author did a comprehensive literature research using SpringerLink, IEEE Xplore, and ScienceDirect. Boolean operator searches focused on efficiency, heat exchangers, and solar thermal power. Examined IEA and NREL grey literature. The author focused on Finland, the EU, and the home countries to enhance the findings. This method allowed the author to cover the latest solar thermal system breakthroughs, improvements, and applications.

2.1 Background

In recent years, solar energy's potential as a renewable and sustainable electricity source has attracted a lot of attention in response to the pressing need for such solutions and mounting concerns about the state of the environment. A new and promising way to harness the sun's renewable and abundant energy is trough solar thermal power. The advancement in the field of solar energy utilization may be seen in the creation of solar thermal heat exchangers, which are designed to directly heat water without the use of conventional boilers (Habib et al., 2023).

The primary applications of solar thermal technologies have been in the generation of electricity and the heating of buildings. But new studies reveal that similar methods can also be employed to produce hot water. Despite this, there is a current push to improve solar thermal heat exchangers as a means of meeting the rising need for greener and more cost-effective methods of producing domestic and commercial hot water. The goal of these setups is to reduce energy waste by eliminating intermediary components like boilers and to maximize efficiency by converting solar radiation into thermal energy (Lundeto et al. 2023).

Improvements in fluid dynamics, heat transfer, and materials research have all led to the development of solar thermal heat exchangers. Scientists and engineers have spent countless hours improving solar collector efficiency. Researchers have tried flat-plate collectors, evacuated tube collectors, and concentrated collectors to collect and transfer more solar energy. To keep these systems running in all conditions, effective insulation and safety measures have been added. (Chaudhari & Selokar et al. 2020, pp 1587-1593.)

Solar thermal heat exchangers have great promise, but their efficacy, reliability, and cost-effectiveness have hindered their application. Heat loss, energy storage issues, and solar radiation fluctuations have hindered the adoption of this technology. Such devices' maintenance and short lifespan are other concerns. This emphasises the necessity for durable design solutions that reduce maintenance and repair. (Rostami et al., 2022, pp. 4519-4519.)

Innovative materials, superior design configurations, and sophisticated control mechanisms are being used to improve solar thermal heat exchanger performance and endurance. This is done to meet market norms. Research also values lifecycle evaluations and sustainability analyses, which assess the systems' environmental implications and long-term viability (Rüppel et al., 2018). A typical solar heat exchanger is shown in Figure 1.

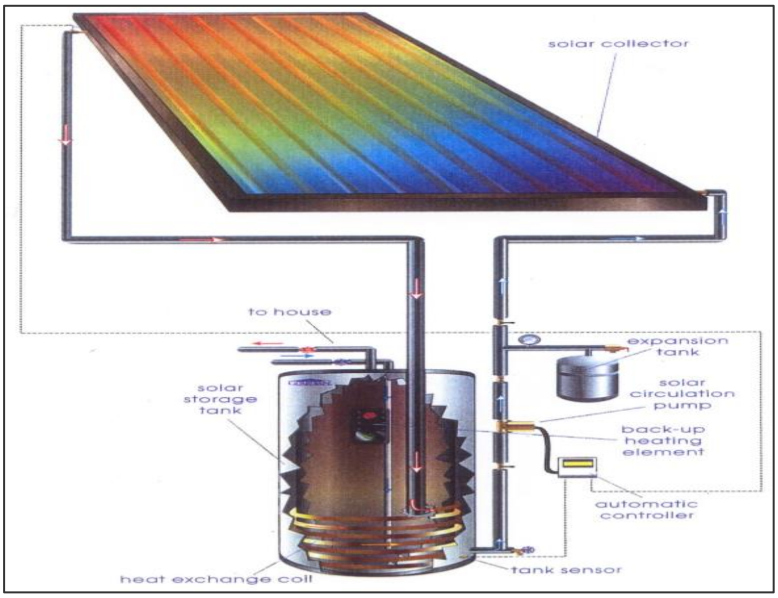

Figure 1. A typical solar heat exchanger (K. Ksenya et al., 2011).

Traditional heating systems emit more carbon dioxide emissions than solar thermal heat exchangers, which help achieve energy sustainability. This is due to the fact that solar thermal heat exchangers use the sun's heat to create usable energy. The goal of this research is to prove that solar thermal heat exchangers are a reliable and maintenance-free method of providing the world's ever-increasing demand for clean and renewable energy. This is achieved through fixing technology bottlenecks and discovering new approaches.

2.2 Theoretical Framework

In this section, the theoretical concepts related to solar collectors are presented.

2.2.1 Solar Collectors and Absorber Plates

Solar collectors absorb solar energy and include flat-plate, evacuated tube, and concentrated collectors. The collectors' absorber plates are designed to maximize solar energy absorption and transfer it to the heat transfer fluid. A typical A typical flat solar collector to collect the radiations from sun and convert it into usable electricity is shown in Figure 2.

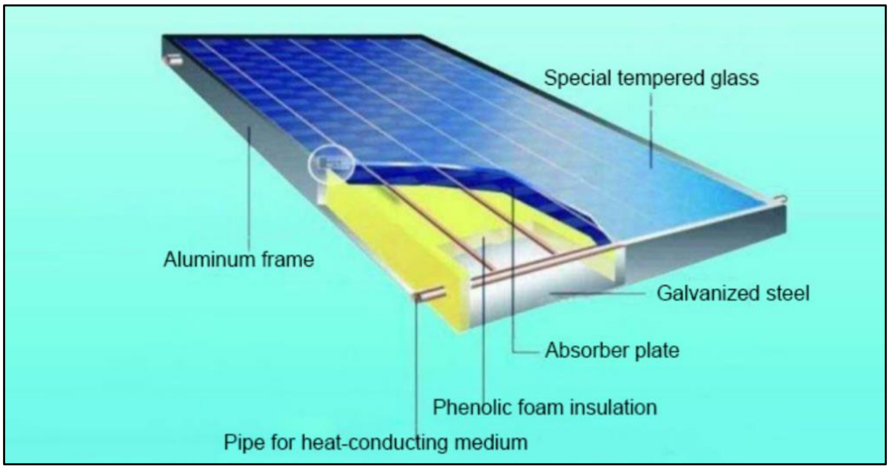

Figure 2. A typical flat solar collector to collect the radiations from sun and convert it into usable electricity (Xiamen et al.,2008).

2.2.2 Heat Transfer Fluids

Water or specialized oils are used as heat transfer fluids to efficiently transmit heat throughout the system. To maximize energy transmission efficiency and avoid waste, fluid properties including specific heat capacity, viscosity, and thermal stability must be understood.

The Mathematical Model can be expressed as (Feilner, Werner, Rehmann, and Methner, et al. 2015).

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

Where (Q), represents the heat transfer, m is the mass of the fluid, (c_p) is the specific heat capacity, and (ΔT) is the temperature difference (Feilner, Werner, Rehmann, and Methner, et al. 2015).

2.2.3 Thermal Insulation

Insulation reduces heat losses and maintains heat transfer fluid temperature. Thermal insulation includes glass wool, polyurethane foam, and reflective coatings. The foundations of insulation installation and how they affect system function must be studied to maximize energy savings.

2.2.4 Required Specifications for Coating Material

Following are some specifications for coating material.

Low Absorption and Transitivity

- Minimize material absorption.
- Reduce transitivity for enhanced reflectivity.

Good Reflectivity

- Ensure high reflectivity for optimal performance.

Resistance to Corrosion

- Develop corrosion-resistant coating.

Ability to Endure High Temperatures

- Ensure stability under elevated temperatures.

2.2.5 Heat Transfer Mechanisms

Heat transfer systems are needed to convert solar energy into usable heat. Heat is transferred between molecules through solids or static fluids during conduction. The process of heat transmission caused by fluid motion is called "convection". "Natural convection," caused by density variations, or "forced convection," caused by mechanical means, are examples. Radiation radiates heat as electromagnetic waves. Release extra thermal energy into the environment with this procedure.

The Mathematical Model can be expressed as:

$$Q=-kA\frac{dT}{dx} \tag{2}$$

Where, Q is the heat transfer, k is the thermal conductivity, A is the cross-sectional area, ($\frac{dT}{dx}$) is the temperature gradient, and (dx) is the distance (Churchill and Holmstrom at al., 1998).

2.2.6 Fluid Dynamics and Flow Patterns

A precondition to optimizing the heat transfer fluid flow within the solar thermal heat exchanger system is a basic understanding of fluid dynamics. The efficiency of heat exchange is impacted by both laminar flow, which is defined by smooth, regular fluid motion, and turbulent flow, which is characterized by erratic, irregular fluid motion. The fluid's inherent resistance to flow diminishes pressure and energy transfer. Heat transfer coefficients affect fluid-environment heat transfer and system efficiency.

Mathematical model describes expression:

$$\Delta P = f\left(\frac{L}{D}, Re, Pr\right) \tag{3}$$

Where, (ΔP) represents pressure drops, ($\frac{L}{D}$) is the ratio of length to diameter, (Re) is the Reynolds number, and (Pr) is the Prandtl number (Lissandron, Sgarbossa, Santa, and Mattavelli, et al. 2015).

2.2.7 Thermal Efficiency and Loss Analysis

To estimate thermal efficiency, investigate the solar thermal heat exchanger system's build, parts, and operation. Form, thermal characteristics, and environment affect a heat exchanger's heat transfer efficiency. Energy loss detection and control are hallmarks of efficient systems. Insufficient fluid mobility, insulation, and buildings cause conduction losses.

Efficiency mathematical model:

$$\eta = \frac{\text{Useful Heat Output}}{\text{Solar Input}} \tag{4}$$

Where, (η) is thermal efficiency, emphasizing the importance of maximizing the ratio of useful heat output to solar input.

2.2.8 Control and Optimization Strategies

Solar thermal heat exchanger systems must be calibrated and run appropriately for maximum efficiency. Temperature and fluid flow rates are monitored and adjusted by automated control algorithms to keep the system operating within tolerances. Feedback systems use less energy and are more efficient because they adapt to changing conditions. For optimal outcomes, use these technologies to make sure the system is reliable and robust in all conditions.

The design-based goal function formula minimizes expenses as much as is practical

$$\min_{(\text{design variable})}\left(\text{Total Cost}=f(\text{Design Variables})\right) \qquad (5)$$

2.3 A review of literature

The significance of achieving ideal fluid dynamics, system performance, and heat transmission has been demonstrated by several research and studies on solar thermal heat exchangers. Based on these investigations, system longevity and performance can be significantly increased with improved control and optimization.

2.3.1 Search Terms

- Solar thermal tracking technologies
- Large-scale solar thermal applications
- High-efficiency solar thermal heat exchangers
- Simulation of solar thermal technologies
- Novel applications of solar thermal technologies

Table 1. Papers of literature

Paper Category	# of Papers	Papers
Tracking:	3	Sharma et al. (2013), Chen et al. (2019), Markowski et al. (2019)
Plant-sized Systems:	2	Turgut et al. (2014), Srinivasan et al. (2014)
Advanced Heat Exchanger Technologies for Solar Thermal Systems:	5	Ahmadi et al. (2015), Huijun Feng et al. (2019), Patel et al. (2010)
Modeling & Simulation:	4	Caputo et al. (2008), Buscher et al. (2019), Hadidi et al. (2013)
Emerging Applications and Analysis of Solar Thermal Technologies:	4	Rosti et al. (2019), Upadhyay (2016), Tanozzi et al. (2019), Anitha et al. (2019)

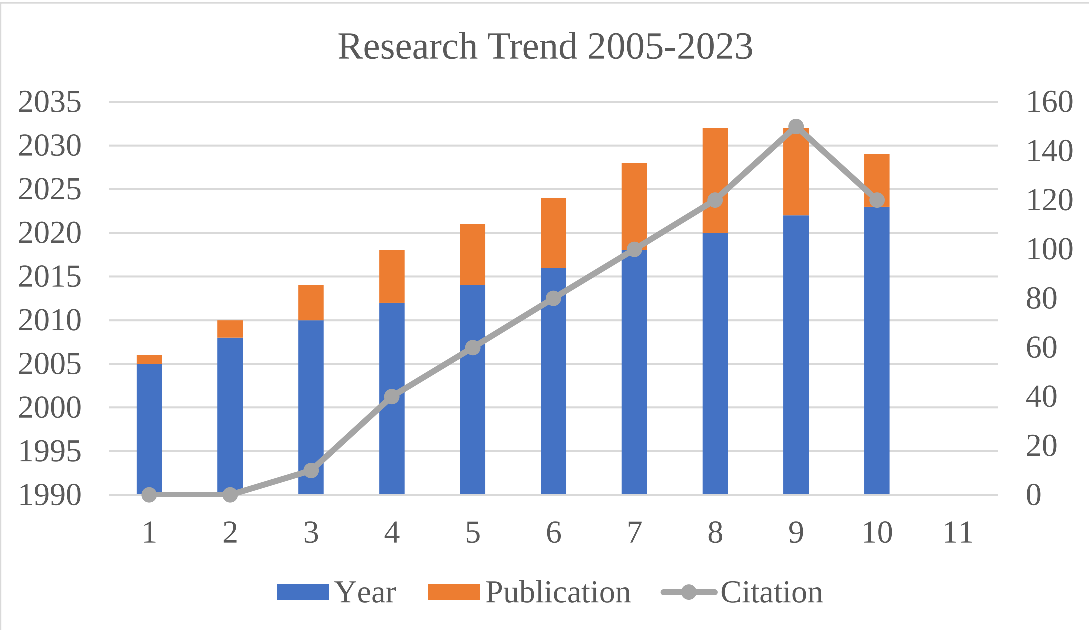

Figure 3. Research Trend over the years on Solar thermal heat exchangers

The graph in Figure 3 clearly shows that the solar thermal heat exchangers are gaining popularity day by day that's why more and more researchers are doing research on them every year. Researchers have examined the intricate connections between these components to develop more environmentally friendly, high-efficiency solar thermal systems that may be installed in residences and commercial buildings. In fact, an unlimited way to arrange the design variables, and no single objective function can be adequately described in terms of these variables alone. In the most recent decades, a substantial amount of work has been put towards improving their efficiency in order to reduce their energy consumption and make their processes more profitable. Due to the depletion of fossil fuel reserves, it is necessary to ensure that heat exchangers are designed and operated in the most efficient manner possible. The design of a heat exchanger can be improved in such a way as to provide considerable benefits, such as reducing the quantity of external utilities that are required to run the process, which in turn would lower operating costs and enhance profits, in addition to reducing the overall impact that the process has on the environment. Because the tube diameter, tube length, shell types, and so on are all standardized and are only available in certain sizes and geometries, the design of a heat exchanger typically involves a process of trial and error in which the heat transfer area is calculated for a particular combination of the design variables, and then another combination of the design variables is tried to see if there is any possibility of reducing the heat transfer area. The designer requires an effective method to quickly discover the design configuration that results in the lowest cost for the heat exchanger because there are multiple discrete combinations of the design configurations that are feasible. Therefore, the task of achieving the best possible heat exchanger design can be characterised as a large-scale, discrete, combinatorial optimization challenge. A generalized thermal design technique for heat exchangers was established by Avdhesh Sharma et al. (2013). This methodology takes into account a given heat duty. They created an objective function in terms of the costs of materials and operations. Optimisation was done using Simulated Annealing and realistic restrictions. Shell diameter, baffle space, and outside tube diameter were limits. Cost should determine shell and tube building materials, according to the findings.

$$F(\mathbf{x}) = \sum_{i=1}^{n} c_i x_i \tag{6}$$

The mathematical model represents an objective function incorporating design variables (x_i) and coefficients (c_i).

Chen et al. (2019) created a serpentine coil molten salt-to-air heat exchanger with salt on the tube and air on the shell. After testing the code, they demonstrated the heat exchanger's performance. They predicted tube and shell side outlet temperatures and heat transfer rates using experimental data and found them within the error range. Heat exchangers were optimised by Ahmadi et al. (2015) using particle swarm optimisation. They calculated heat exchanger costs using six design parameters. These criteria included shell inner diameter, tube diameter, baffle spacing, cut, passes, and layouts. The findings showed that PSO optimised heat exchanger design better than Feng et al. (2019) studied disc-shaped heat exchanger fabrication. The first order Double Shell and Tube Heat Exchanger (DHSE)'s thermal efficiency drops first when the number of tubes is held constant, and the best tube angle yields the highest thermal efficiency. Patel et al. (2010) showed that the Particle swarm optimization (PSO) technique can be used to build an economically efficient heat exchanger. PSO's ability to converge to the ideal objective function value in a few generations showed its importance for heat exchanger optimisation. The sensitivity of cost parameters can be compared using parametric analysis. Markowski et al. (2019) sought optimum heat recovery in their mathematical model for online regulation of a heat exchanger network (HEN). They regulated the procedure so HEN branches received various crude oil volumes. They created a complicated mathematical model of a blocked heat exchanger using industry data. CFD studies by Garrett W. Mann et al. (2019) revealed the best fin height and helix angle modifications to improve heat transport and reduce friction. This helped them choose the best option.

A mathematical representation of Max design variables is:

$$\max_{(\text{design variables})}\left(f_1(\mathbf{x}), f_2(\mathbf{x})\right) \tag{7}$$

The optimisation model aims to maximise both objectives (f_1) and (f_2) simultaneously for design variables (x).

The historical data shows that low enhancement levels can improve heat transmission and friction with little helix angle and fin height changes. Caputo et al. (2008) proposed an optimum shell-and-tube heat exchanger design approach. This evolutionary algorithm reduces equipment expenditures like initial investment and yearly pumping energy costs. They used evolutionary algorithms to improve shell-and-tube heat exchangers. Et al. (2019) simulated flow pattern transitions and validated their model using experimental data. A cross-corrugated channel with idealised features was tested for flow. A new model predicted the minimum kinetic energy for bubble rupture and accounted for flow pattern alteration at increasing void percentages, explaining gas accumulation during slow downflow. Both models described gas buildup. Using an algorithm known as Improved Intelligent Tuned Harmony Search (I-ITHS), Turgut et al. (2014) developed a thermal design for shell and tube heat exchangers. They minimised the total cost of the heat exchanger by using design variables such as baffle spacing, shell diameter, tube outer diameter, and the number of tube passes. The total cost includes the capital investment as well as the sum of discounted annual energy expenditures related to pumping and heat exchanger area (Núñez, Gracia and Castillo et al., 2022).

The $\min_{(\text{design variables})}$ is given by:

$$\min_{(\text{design variables})}\left(C_1 f_1(\mathbf{x}) + C_2 f_2(\mathbf{x})\right) \tag{8}$$

The multi-objective optimization model minimizes a weighted combination of objective functions (f_1) and (f_2),with factors(C_1) and (C_2).

Seyyed Ali Farshad and colleagues (2019) demonstrated a comparative simulation of the decline in exergy and the enhancement of heat transfer caused by the insertion of multi-channel twisted tape. They ran simulations with different values for the number of channels, dimensionless diameter, Reynolds number, and the number of rotations. They talked about the effects that significant parameters have on the exergy lost and the efficiency of the second law. The authors Costa et al. (2008) published a study about the design optimisation of shell-and-tube heat exchangers and defined the solution for a problem consisting of the minimization of the thermal surface area for a specific service that involved discrete decision variables. In addition, the authors of this study discussed the design optimisation of shell-and-tube heat exchangers. The outcomes showed that the proposed technique could lead optimisation efforts towards more effective designs. Dinesh et al. (2019) proposed maximising plate heat exchanger heat transmission while limiting pressure loss. Multi objective wale optimisation (MOWO) improved plate heat exchanger hydraulic and thermal restrictions. This increased heat exchanger sensitivity. They found that heat transfer is proportional to the horizontal port centre distance and pressure drop is inversely linked.

The mathematical model is given by:

$$\max_{\text{Design Variables}}(\text{Heat Transfer Rate-Pressure Loss}) \tag{9}$$

This model optimises plate heat exchanger performance by maximising heat transfer rate minus pressure loss.

Srinivasan et al. (2014) showed a small furnace manufacturer piloting Six Sigma DMAIC phases to improve shell and tube heat exchanger efficiency. The most essential goal was to improve furnace quality utilising DMAIC phases. They learned from consumer feedback that heat exchanger efficacy was the key to quality. Wenzhu et al. (2019) improved a novel heat exchanger with latent heat thermal energy storage. They concluded that a phase change material composite (PCM) may yield the best optimisation results. Energy storage and working power increased significantly with the enhanced heat exchanger. They investigated if a new heat exchanger might be integrated into multi-working fluid energy storage systems. Hadidi et al. (2013) developed a biogeography-based optimisation (BBO) algorithm for heat exchanger design optimisation. BBO achieves its goals through migration and mutation. The given algorithms are compared to previously reported optimisation results from different methods. This comparison showed that the proposed heat exchanger design method is accurate, fast, and cost-effective. Behnam Rosti et al. (2019) used time lag and decrement factor theory to solve the transient heat conduction equation for multi-layered wall configurations to determine the best thermal insulation configuration for an earth-air heat exchanger building.

The time lag is given by

$$\text{Time Lag}=\int_{t_1}^{t_2} \frac{T_1-T_2}{q}\, dt \tag{10}$$

Heat transport dynamics can be understood by computing the time lag as the integral of temperature differences over time.

They found that buildings with a wall with a single layer of insulation on the exterior and two layers on the middle and outside performed best. Upadhyay et al. (2016) worked. The Simulated Annealing (SA) technique optimises by considering limits such the tube outer diameter, shell diameter, and baffle space. The generalised optimisation approach he described for STHEx must account for baffle cut's effect on the shell side heat transfer coefficient and friction factor to improve predictions. The studies showed that shell and tube building materials affect cost. Federico Tanozzi et al. (2019) proposed a hybrid vehicle heat exchanger network (HEN) for a solid oxide fuel cell gas turbine (SOFC-GT) system. They used HEN synthesis to balance hot and cold streams, entrance and outflow temperatures, and heat loads. HEAT exchanger space was optimised. Space optimisation allows studying many HEN setups by reducing space. S. Anitha et al. (2019) obtained unstable, three-dimensional heat exchanger flow equations for an incompressible viscous hybrid nanofluid. They assumed no exchanger inner wall slip.

Recent years have seen a surge in solar thermal heat exchanger simulation. This trend is driven by the demand for renewable energy and green energy solutions. Researchers have been developing unique simulation methods to optimise solar thermal system design and operation to improve energy efficiency and reduce dependence on traditional energy sources. Several studies have examined solar thermal heat exchangers in this field. These qualities include device designs, performance, and solar energy capture efficiency.

Sharma et al. (2013) developed a generalised solar thermal heat exchanger thermal design method. The writers emphasised material and operating cost-based objectives. They optimised with Simulated Annealing and limited outer tube, shell, and baffle space. Utilising Simulated Annealing, Upadhyay et al. (2016) optimised tube and shell size and material cost.

Researchers are developing solar thermal heat exchangers. To verify the code and demonstrate performance, Chen et al. (2019) built and tested a serpentine coil molten salt-to-air heat exchanger. By comparing predicted values to experimental data, scientists verified their findings within an error. In disc-shaped heat exchangers, tube number and angle affect thermal efficiency, according to Feng et al. (2019). Huijun Feng and colleagues found tube quantity and angle affect thermal efficiency.

PSO has also been frequently employed to improve solar thermal heat exchanger efficiency. Ahmadi et al. (2015) proved that PSO optimises heat exchangers better than GA. Their total cost function formula considered baffle spacing, shell inner diameter, and tube diameter.

Researchers have also simulated solar thermal heat exchangers, highlighting the need for better control and modelling tools. Markowski et al. (2019) created a mathematical model for online heat exchanger network control to maximise heat recovery. Industrial measurements and precise process control under different operating conditions were their approach.

Overall, the research focuses on efficient and cost-effective solar thermal heat exchangers using modern modelling and optimisation approaches. Advanced control systems, design configurations, and optimisation algorithms can boost solar thermal energy system performance and sustainability. Sustainable and eco-friendly energy may result.

2.4 Research Gap

Improving solar thermal power plants' heat exchanger efficiency is an area where the current literature is severely lacking. There are still a lot of important questions that need answering, but the overarching goal is to improve system performance while decreasing energy usage. First, a complete understanding of the main elements affecting solar thermal power system heat exchanger efficacy is inadequate, hampering targeted improvement measures. A vacuum in knowledge exists because material selection's subtle effect on heat exchanger efficiency has not been studied. Existing studies do not adequately address the dynamic link between flow rates and heat transmission in heat exchangers. Additionally, the efficiency effects of heat exchanger types and layouts are poorly understood. Finally, intake temperatures and heat exchanger efficiency need further study. The research addresses these gaps by providing extensive analysis and actionable recommendations for solar thermal power system applications.

3 Methodology

In this chapter the design and methodology of the solar trough collector will be explained in detailed. Several elements were found that are both cost-effective and attractive based on throughout the research into materials with good thermal, mechanical, and chemical capabilities for the many components of the solar collector. The reflecting material's optical efficiency ranges from 70% to 85%, which led to its decision to be coated with mirror aluminum. Aluminum with a mirror coating has a long lifespan and less corrosion, which is an additional perk. It avoids distortion due to wind loading as well. Compression should be less of a problem than tension for the building material. The material should be resistant to corrosion, have a high strength, and be able to withstand fatigue loading. For this reason, mild steel is the material of choice. It is ideal for the material used to construct the pipe section to have low emissivity, good absorption and conductance, and to be a good heat conductor. Additionally, it should be able to retain its properties at sufficiently high temperatures. The ability to withstand corrosion is essential. Regular water is used as the working fluid on the inside, which might cause rust and calcification. A protective system should also be in place for the exterior surface that is exposed to the atmosphere. The movement of mass rates and heat transfer characteristics of 30 mm diameter copper tubes make them the material of choice. The design methodology for this system is going to be based on VDI 2221. VDI 2221 is a German engineering standard that provides a systematic methodology for the design process. It guides the development, analysis, optimization, and validation of designs. Choosing VDI 2221 as the basis for system's design methodology signifies a commitment to a structured and efficient approach in engineering design.

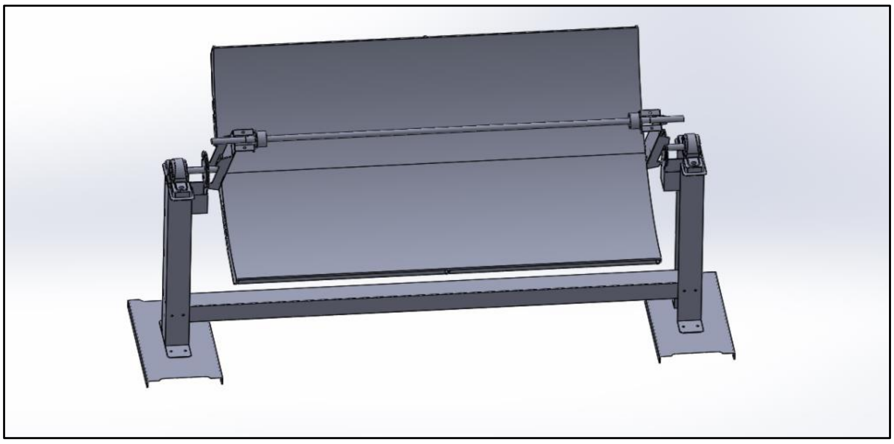

Figure 4. SOLIDWORKS Design of setup for simulation

3.1 Materials

Solar thermal storage materials are primarily grouped into three types based on their storage mechanisms. Although there are many inexpensive materials for sensible heat storage and the technology is well-developed (Zalba et al. (2003)), the system size is much increased due to its limited storage capacity. Even though latent heat storage can store substantially more energy, it typically comes with poor heat transfer unless heat transfer enhancement is used. Unfortunately, chemical storage isn't very practical due to its low long-term durability (reversibility), chemical stability, and the complexity of the reactors required for individual chemical processes.

3.1.1 Storage materials for Sensible heat

Thermal storage media, whether can be solid or liquid, can be heated or cooled to store thermal energy in sensible heat storage. Materials such as sand-rock elements and ferro-alloys are among the most popular solid-state thermal storage options, and their primary properties are displayed in Table 2 (Gil et al. (2010)). These materials can withstand temperatures ranging from 200C to 1200C. The one drawback is that their heat capacities aren't very high, usually between 0.56 and 1.3 kJ/(kg ^{o}C), so can lead to an inflated storage unit size. Oils, liquid sodium, and an inorganic molten salt are among the compounds listed in Table 4 (Zha et al. (2011)) that may store thermal energy in a liquid state. Because they necessitate an airtight system, oils pose significant safety risks due to their relatively high vapour pressure (Kenisarin et al. (2007)). The thermal conductivity of liquid sodium can reach 71.0 W/(m K); but, due to its extremely unstable chemical reactivity, it necessitates the adoption of additional safety precautions, which significantly increases the cost. To make unfreezing the system much easier, (Oró et al. (2012)) published a series of new ternary salt compositions with ultra-low temperature of melting of 76C, 78C, and 80C, all of which are below 100C. Compared to synthetic oil and commercial molten salts, the viscosities of their salt combinations of KNO3, LiNO3, and Ca(NO3)2 were over 80% lower. Additionally, their salt combinations exhibited excellent chemical stability up to 500 °C. More recently, Kenisarin et al. (2010) have reported the presence of such metallic salts with melting points lower than 100 °C. With a melting point as low as 99 degrees Celsius, they discovered a new quaternary eutectic salt. In comparison to latent heat storage, which typically costs between 4.28 and 334.00 US$/kg, sensible heat store is more cost-effective, with prices ranging from 0.05 to 5.00 US$/kg (Gil et al. (2010)).

Table 2. Storage material for sensible heat (Gil et al. (2010)).

Storage materials	Working Temprature[°C]	Density [kg/m^3]	Thermal Conductivity [W/(mK)]	Specific Heat [KJ/(kg°C)]	Specific Heat [kWh/(m^{3}°C)]	Cost per kWh$_t$ (US$/kWh$_)$
Sand-rock minerals	200-300	1700	1.0	1.3	0.61	4.2
Reinforced concrete	200-400	2200	1.5	0.85	0.52	1.0
Cast iron	200-400	7200	37	0.56	1.12	32
Sodium Chloride(NaCl)	200-500	2160	7.0	0.85	0.51	1.5
Cast steel	200-700	7800	40	0.6	1.3	60
Silica fire bricks	200-700	1820	1.5	1.0	0.51	7.0
Magnesia fire bricks	200-1200	3000	5.0	1.15	0.96	6.0

3.1.2 Storage materials for Latent heat

When phase structures reconstruct during melting, solidification, gasification, or liquefaction, phase-change materials, also called PC can store or release a lot of heat. Latent heat storage offers a significantly higher storage density compared to sensible heat storage due to the significantly higher phase-transition enthalpies of PCMs (100-200 times, as indicated in Table 3 & 4). Several marketed PCMs, inorganic salts, and eutectics have their thermal-physical properties listed in Table 3 (Pilkington et al. (2000)). The phase transition temperatures and latent heats of the materials shown in Table 4 are 100 897 °C and 124–560 kJ/kg, respectively. Latent heat storage makes use of the phase change process to function in a nearly isothermal fashion, as opposed to sensible heat storage, which causes materials to undergo a significant temperature increase or decrease when storing or releasing thermal energy. For this reason, applications requiring very specific operating temperatures benefit from latent heat storage. Nevertheless, relative heat transfer augmentation strategies must be utilized due to latent heat storage's poor thermal conductivities, which typically range from 0.2 W/(m K) to 0.7 W/(m K) (Zha et al. (2011)).

Table 3. Storage material for Latent heat (Pilkington et al. (2000)).

Storage materials	Phase change temprature [°C]	Density [kg/m^3]	Thermal Conductivity [W/(mK)]	Specific Heat [KJ/(kgK)]	Latent Heat [kJ/kg]	Latent Heat (MJ/m^3)
RT100 (Paraffin)	100	880	0.20	N.A	124	N.A
RT110 (Paraffin)	112	N.A	N.A	N.A	213	N.A
EI 17 (Inorganic)	117	1450	0.70	2.61	169	245
A164 (Organic)	164	1500	N.A	N.A	306	459
$NaNO_3$	307	2260	0.5	N.A	172	389
KNO_3	333	2110	0.5	N.A	226	477
KOH	380	2044	0.5	N.A	149.7	306
$AlSi_{12}$	576	2700	1.6	1.04	560	1512

Table 4. Storage material for Latent heat (Zha et al. (2011)).

Storage materials	Phase change temprature [°C]	Density [kg/m^3]	Thermal Conductivity [W/(mK)]	Specific Heat [KJ/(kgK)]	Latent Heat [kJ/kg]	Latent Heat (MJ/m^3)
$MgCl_2$	714	2140	N.A	N.A	452	967
NaCl	800	2160	5	N.A	492	1063
LiF	850	N.A	N.A	N.A	N.A	1800
Na_2CO_3	854	2533	2	N.A	275.7	698
K_2CO_3	897	2290	2	N.A	235.8	540
48%$CaCO_3$-45%KNO_3-7%$NaNO_3$	130	N.A	N.A	N.A	N.A	N.A
KNO_3-$NaNO_2$-$NaNO_3$	141	N.A	N.A	N.A	275	N.A
$LiNO_3$-$NaNO_3$	195	N.A	N.A	N.A	252	N.A
$MgCl_2$-KCl-NaCl	380	2044	0.5	N.A	149.7	306

3.1.3 Storage materials for Chemical heat

Chemical heat storage materials can be either organic or inorganic, but they must be able to absorb or release a significant quantity of heat in reversible chemical reactions. Simple responses (reactions can't be too hard to be realized), high chemical reversibility, and a big shift in chemical enthalpy are the three fundamental requirements for any chemical storage system design. Many of the materials listed in Table 5 (Thomas et al. (2000)) exhibit an enthalpy change between 3.6 and 4.4 GJ/m3, making them ideal candidates for chemical heat storage. Table 3 and Table show that the storage densities of latent heat and chemical heat are on the request of MJ/m3 and GJ/m3, respectively, whereas the former is significantly higher. But there hasn't been a tonne of study into chemical storage, and the following issues limit its use: complex reactors that are required for particular chemical reactions, chemical stability, and limited long-term durability (reversibility).

Table 5. Storage materials for Chemical heat (Thomas et al. (2000)).

Materials	Temperature range [°C]	Enthalpy change during chemical reaction	Chemical reaction
Iron carbonate	180	2.6 GJ/m^3	$FeCO_3 \leftrightarrow FeO+CO_2$
Methanolation demethanolation	200-250	N.A	$CH_3OH \leftrightarrow CO+2H_2$
Metal hydrides	200-300	4 GJ/m^3	(Metal xH_2) $\leftrightarrow$Metal $yH_2+(x-y)H_2$
Ammonia	400-500	67 KJ/mol	$NH_3+\Delta H \leftrightarrow 1/2N_2+3/2H_2$
Hydroxides	500	3 GJ/m^3	$Ca(OH)_2 \leftrightarrow CaO+H_2O$
Methane/Water	500-1000	N.A	$CH_4+H_2O \leftrightarrow CO+3H_2$
Calcium carbonate	800-900	4.4 GJ/m^3	$CaCO_3 \leftrightarrow CaO+CO_2$
Metal oxides(Zn and Fe)	2000-2500	N.A	2-Step water splitting using Fe_3O_4/FeO re-dox system
Aluminium ore alumina	2100-2300	N.A	N.A

3.2 Calculations

In this chapter, design calculations are shown including the dimension of the tank and the volume flow rate.

3.2.1 Design of storage tank

The thermal plant's heat requirement is Q, which equals 3400 kJ.

The potash alum (PCM) fusion heat is 184 kJ/kg.

Therefore, $M_{pcm}= Q_r / h_m$ is the mass of PCMs needed to store 3,400 kJ of energy.

At 18.4 kg, M_{pcm}.

The total mass of the PCM is thus 18.4 kg.

Melted Potash Alum's Specific Heat (Cl_p) = 2.76 kJ kg.k

Potash alum's specific heat in the liquid phase is 1.38 kJ/KgK abbreviated as Csp.

Am = 1 is the melted fraction.

Tm= 92°C, Ti= 10°C, and Tf= 140°C are the melting points of potash alum.

For the specific instance of solid-liquid transformation involving sensible heat, the overall storage capacity of an LHS system may be calculated using the following equation:

$$Q_{pcm} = m_{pcm}[a_m \times h_m] + [\text{The } Csp \times (Tm - Ti) + (Clp \times (Tf - Tm)] \quad (11)$$

The potential energy is 4591 kJ or Q_{pcm}.

The sensible heat term, denoted as C_{sp} *(Tm -Ti)+Clp *(Tf -Tm), is responsible for this energy gain. Since perceptible heat is lost so rapidly, have determined the necessary PCM mass solely from latent energy. This implies that are only treating the latent energy from the PCM as useful energy. It follows that selected PCM material can store the necessary quantity to heat (3400 kJ). Losses can absorb the remaining energy from sensible heat.

Pι = 1300 is the density of potassium alum in its melted liquid phase.

The equation V=m/pl yields V=0.0079 m^3, which is the volume of potash alum that is needed.

Cylinder d_o have an outside diameter of 0.201 m.

The cylinder's inner diameter, d_i, is 0.2 m.

N= 89 is the number of tubes.

The tubes have an inner diameter of 0.0254 m.

The following information can be derived from the PCM volume: the number of tubes, their inner diameter, the volume of the storage tank, and the number of tubes. Considering that the length of the storage tank will be somewhat longer (3 cm) than the length of the PCM tube

Vacuum x 4 times the product of n times n times du^2 is the formula for the PCM tube length. Two, the PCM tube is 0.74 meters long.

The storage tank's length is 0.77 meters.

The storage tank's inner radius is rii=0.00635 m.

inside entrance The formula for area, A, is 3.14 times ri^2, which equals 0.000125 ma^2.

q = 1.256×10^4 m^2 is the volume flow rate. S is the mass flow rate, which is equal to 0.013 kg, where m is the product of PHTEX and q. "S" speed At the entrance of the HTF, the values of u and Ai are equal to 0.1 m S.

At 20 degrees Celsius, the viscosity of HTF is 2.1671×10^{-3} Pa.s.

Using the formula Re= PHTF HE X2 X HHTF, can find the Reynolds number from the velocity, which is 605.

The flow is laminar because the Reynolds number is 605, which is lower than the crucial Reynolds number for internal flow (2000).

Therefore, need a pump that can provide a 2.5 x 105 m^3/s volume flow rate.

4 Results

In this chapter the results of the research are introduced.

4.1 Design

The finalized design of the parabolic trough collector is shown in the image below. It is designed to be readily rotated when not in use, which is useful in case the battery is already full and there is excessive heat so that’s why it is important to rotate it to avoid the heat. Figure 5 shows the parabolic trough collector.

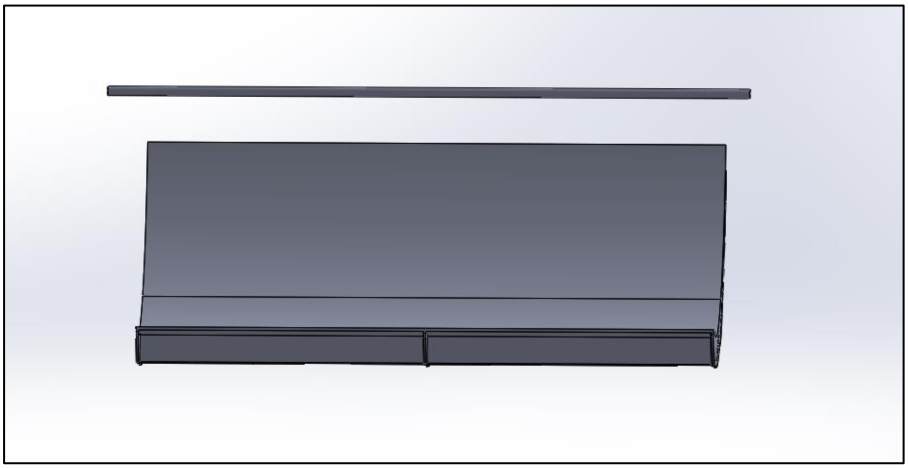

Figure 5. Parabolic trough collector

The Figure 6 showcase the PTC from every angle: front, top, and side.

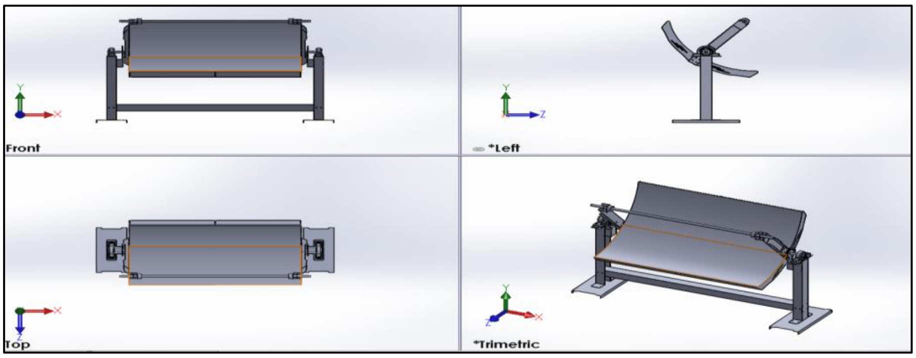

Figure 6. Different views of Design

4.1.1 Solar thermal energy storage

An effective means of storing the thermal energy that has been captured by the parabolic solar collector is required for its subsequent release. Consequently, developing a reliable energy storage system is a top priority. Solar the storage of thermal energy is the subject of the current part of the thesis, which delves into its design requirements, ideal materials, and new technology for improving heat transfer.

4.1.2 Criteria for design

While planning a solar stored thermal energy system, it is essential to think about its technical characteristics, how much it will cost, and what kind of effect it will have on the environment. To guarantee a solar warm energy storage system's technical feasibility, excellent technical qualities are crucial. To begin, maximising efficiency while decreasing system volume requires a thermal storage capacity that is high. This thermal storage capacity can be in the form of sensible heat, latent heat, or chemical energy. Secondly, for the necessary rate of heat absorption or release, it is essential that the heat storage materials and heat transfer fluid maintain an adequate heat transfer rate. Thirdly, after a particular amount of temperature cycles, the storage material shouldn't degrade chemically or mechanically, therefore it should have good stability. An investment's payback duration is directly related to how cost-effective it is. Storage material, heat exchanger, and land cost make up the bulk of the solar thermal electricity storage system's total cost (De Winter, F. (1991)). Due to the fact that a small system with a high thermal storage capacity and great heat transmission performance can be very cost-effective, the aforementioned technical features are often associated with one another. Table following lists other parameters to be examined alongside technical properties along with expense effectiveness. These include operating policy and integration to a particular power plant. Table 6 shows the criteria for design.

Table 6. Criteria for design (Cabeza & Oró, 2016).

Criteria	Influencing factors
Technical Criteria	• High thermal energy storage capacity (the most important). • Efficient heat transfer rate between HTF and storage material. • Good mechanical and chemical stability of storage material. • Compatibility between HTF, heat exchanger and/ or storage material. • Complete reversibility of a large number of charging and and discharging cycles. • Low thermal losses and ease of control.
Cost-effectivness criteria	• The cost of thermal energy storage materials. • The cost of the heat exchanger. • The cost of the space and/ or enclosure for the thermal energy storage.
Environmental criteria	• Operation strategy. • Maximum load. • Nominal temperature and specific enthalpy drop in load. • Integration to the power plant

4.2 For ANSYS

Utilize the following design in Ansys for simulations since importing the previous design causes the mesh to be very time-consuming and error-prone, and because geometry is not useful for analysis in Ansys.

4.2.1 Boundary conditions and assumptions

Three analysis was conducted with a mass flow rate of 0.5 kg/hr.

Temp of inlet water =300 k.

Following assumptions are made in the analysis

- Water is a continuous medium and incompressible.
- The flow is steady and laminar flow characteristics.
- Assume that there is no convection or heat transfer from the copper tube.
- Collector is semi transparent.
- Mass flow rate remain same throughout the pipe.
- Inlet temperature remains same at 25°C.
- Pressure remains same throughout the pipe.
- The thermal physical properties of absorber plate, is independent of temperature.

4.3 Simulation

To simulate the Earth's Parabolic Though Collector in this study. This is accomplished by creating a PTC model in the ANSYS Workbench 19.2 program. Parabolic solar collectors, as depicted in the figure, consist of a lengthy reflecting surface and a long tube positioned at the focus. The aluminum reflector is 1.3 meters in width and 1.5 meters in width, and it is represented in the Ansys workbench program. A 1.3-meter-long, 1-millimeter-thick copper tube serves as the receiver. Using a 30 cm focal length and a 30:1 concentration ratio, the receiver tube is positioned at the parabolic trough collector's focus. Figure 7 shows this simulation results.

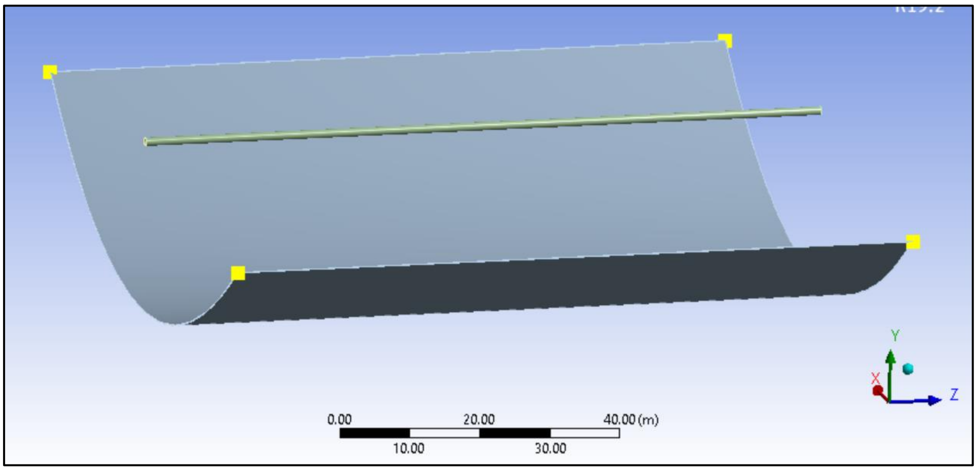

Figure 7. Simulation after applying boundary conditions

4.4 Solar load

When the sun's rays enter a computational domain, ANSYS FLUENT offers a model that may be used to calculate the radiation impacts. Model steady and chaotic flows with the help of the solar calculator tool, which takes in the time of day, date, and where it places the sun and uses that information in creating its position in the sky. Over the course of a day, it's possible to simulate solar loading effects and calculate the solar transfer through all glazed surfaces. Typical parameters include starting time and date, and grid orientation, global position (latitude, longitude, and time zone), solar irradiation method, sunshine factor, and grid orientation. Using the typical solar irradiation approach as fair weather conditions, the grid orientation is given in the North (from negative Z axis) and East (whether it's X axis) direction component in the CFD grid. Sun direction vector, ground reflective (diffuse) solar energy for vertical surfaces, diffuse solar irradiation for horizontal and vertical surfaces, and direct normal solar energy at Earth's surface are the values that are computed. Figure 8 shows the Solar Load, and Figure 9 shows the solar load collector values.

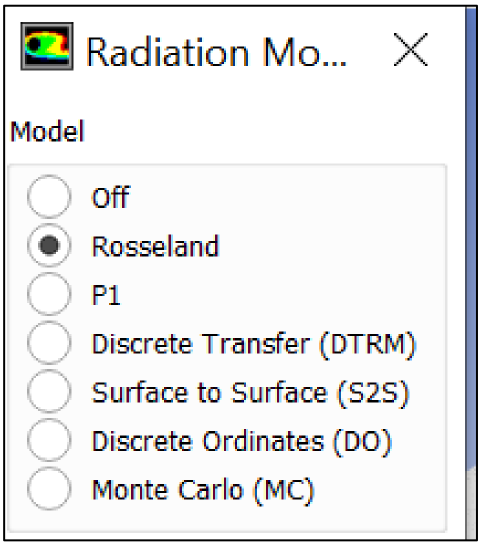

Figure 8. Solar Load type chosen for simulation

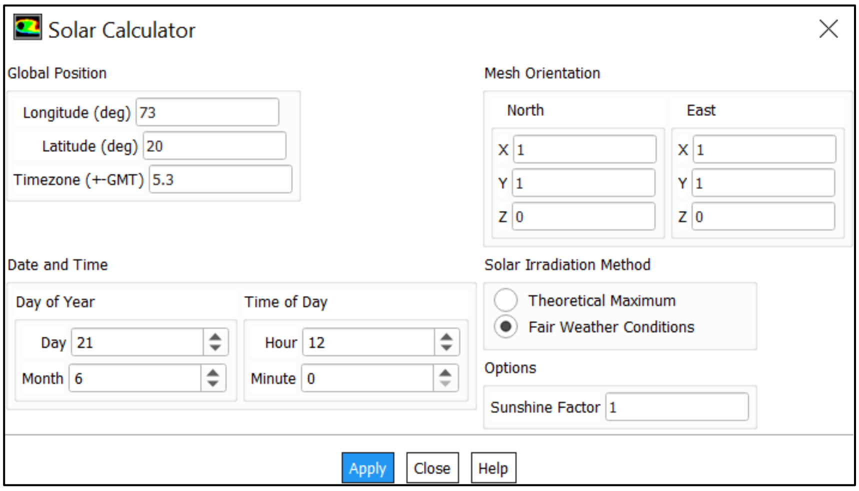

Figure 9. Solar Load Calculator according to specified position

4.5 Mesh

To solve the challenge and acquire the outcomes, the generation of mesh is another vital factor. To achieve results that are not dependent on meshing, several meshes are generated. Elements ranging from 24,000 to 40,000 are used to construct the meshes. The computation domain grid is constructed using tetrahedral element. Figure 10 shows meshing.

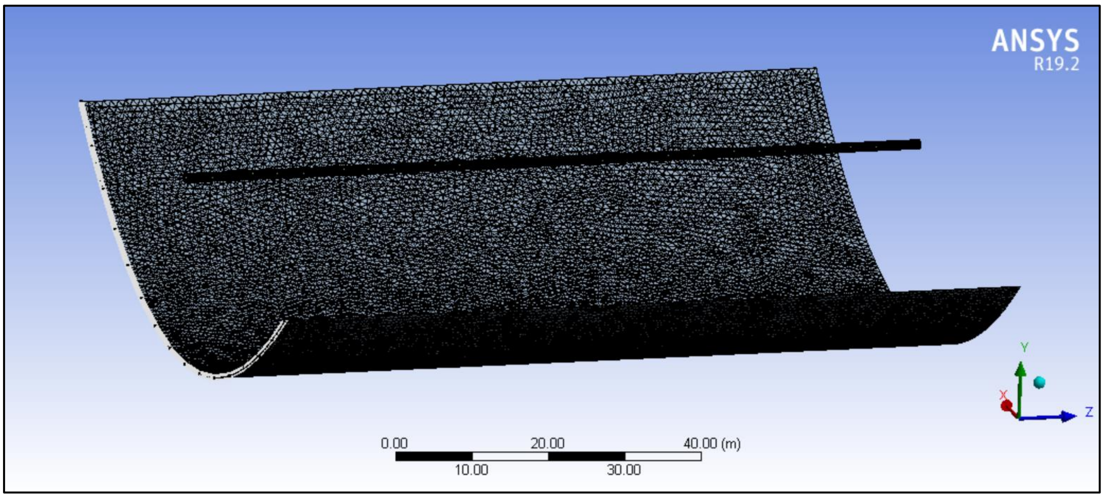

Figure 10. Mesh after splitting into elements

4.6 Setting the boundary conditions

ANSYS Workbench software, in conjunction with the K-e Realizable fluid models and the Solar Roseland Radiance model with the Solar Calculator, is used to simulate the intended model. For various mass flows of 0.25 kg/hr, the simulation is run independently. At 05:30GMT, Nashik is located at 73.0E Longitude and 20.0N Latitude, according to the solar calculator.

Continuity Equation (Zheng, Hu, Wu, and Zhang 2023).

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_j\right)=0 \qquad (12)$$

Momentum equation:

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_i}\left(\rho u_i u_j\right)=\frac{\partial}{\partial x_j}\left[-\rho\delta_{ij}+\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{x_i}\right)\right]+\rho g_i \qquad (13)$$

Energy Equation:

$$\frac{\partial}{\partial t}\left(\rho C_p T\right)+\frac{\partial}{\partial x_i}\left(p u_i C_p T\right)-\frac{\partial}{\partial x_j}\left(\frac{\lambda \partial T}{\partial x_j}\right)=s_T \tag{14}$$

Mathematical versions of the conservation rules of fluid mechanics are the Navier-Stokes equations, which regulate fluid both heat and flow transfer. A systematic description of the changes in energies, momentum, and mass as the flow traverses the boundaries of discrete physical volumes in a fluid domain can be obtained by applying these conservation laws to these volumes. One way to express the resulting equations is as:

Turbulence Kinetic Energy:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\frac{r_k \partial k}{\partial x_j}\right)+G_k-Y_k+S_k \tag{15}$$

Specific Dissipation Rate:

$$\frac{\partial}{\partial t}(\rho \omega)+\frac{\partial}{\partial x_i}(\rho \omega u_i)=\frac{\partial}{\partial x_j}\left(\frac{r_\omega \partial \omega}{\partial x_j}\right)+G_\omega-Y_\omega+D_\omega+S_\omega \tag{16}$$

As part of the governing equation closure for the Hamilton Average Navier Stokes equation, the turbulent viscosity must be determined, and then certain extra transport equations pertaining to the instability kinetic energy along with a particular dissipation rate must be solved. In order to combine the k-ϋ and k-ε turbulence simulator using a blending factor, this analysis makes use of the form that.

The terms source, dissipation, diffusion, and generation make up the right side of the previous equation (not included in this analysis). An extra term that takes into consideration the impacts of cross-diffusion is included in the particular dissipation rate equation.

4.7 Calculations for simulation

In this section length of the parabola is discussed where it has been shown the viscous model and pressure velocity coupling .

4.7.1 Length of parabola

The parabola length reflector is 1.3 meters in

1.5 meters in width,

1.3-meter-long, 1-millimeter-thick copper tube serves as the receiver

focal length30 cm

concentration ratio 30:1

$$Q=mCp.\Delta T \tag{17}$$

Q is the heat input (in watts).

m is the mass flow rate in kg/s.

Cp is the specific heat of the fluid in J/kg.K.

ΔT is the temperature increase (in K).

Intensity of Radiation (IB) = 450 W/m2.

Intensity of Radiation on the Collector = IB.AC = 195.75 W/m.

$$\Delta T=T_{outlet}-T_{inlet} \tag{18}$$

$$\Delta T=384\ K-300\ K$$

ΔT=84 K

Copper Pipe:

copper = (0.5 kg/hr · 1/3600 kg/s) · (390 J/(kg \cdotp K)) · 84 K Qcopper=4.78W

The following Figure 11 shows the viscous model.

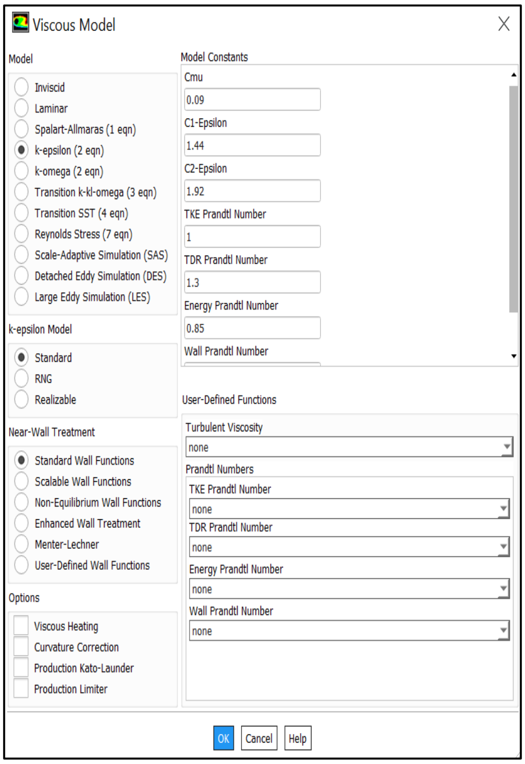

Figure 11. Viscous model with specific k-epsilon

Figure 12 shows the Pressure Velocity Coupling

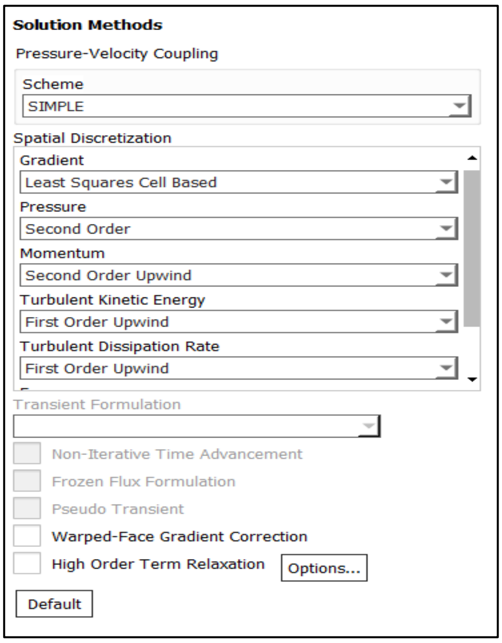

Figure 12. Pressure-Velocity coupling with least square cell

4.8 Simulation

During the course of the research, the Circular trough collector is simulated, and the outcomes of this analysis are detailed below. Can see the temperature gradient between the collector and receiver in figure below . Near the water outlet sector of the absorber, the ultimate receiver surface temperature is determined to be 384K, whereas the collector surface temperature is found to be constant.

The results coverage successfully within 70 iterations. Figure 13 shows the Simulation iteration plot.

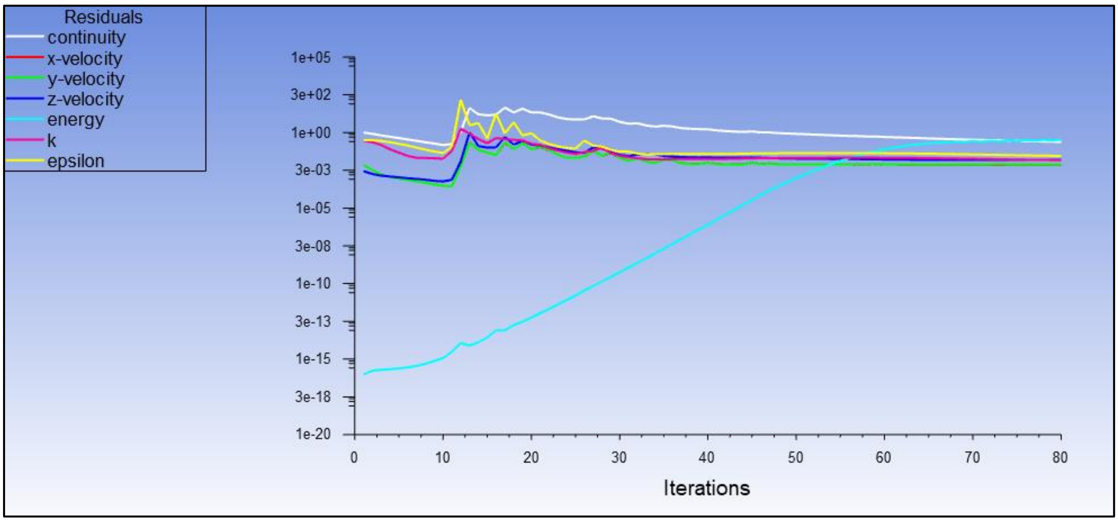

Figure 13. Simulation and multiple iterations plot

4.9 Inlet

The below image shows that how the inlet temperature which is normal temperature that's why it is showing blue colour. Figure 14 shows the Inlet values.

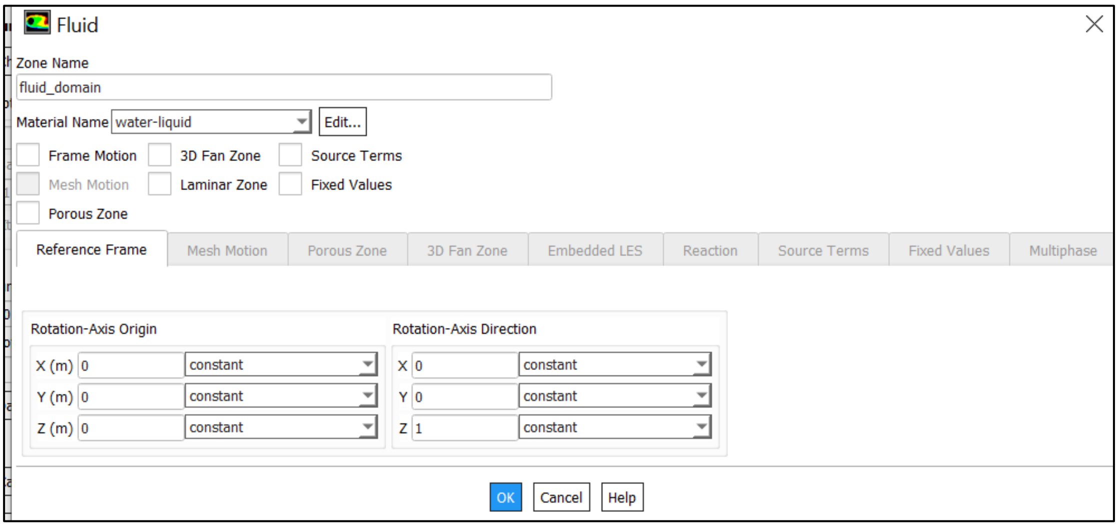

Figure 14. Inlet with defined fluid (Water-Liquid)

Figure 15 shows the inlet diagram.

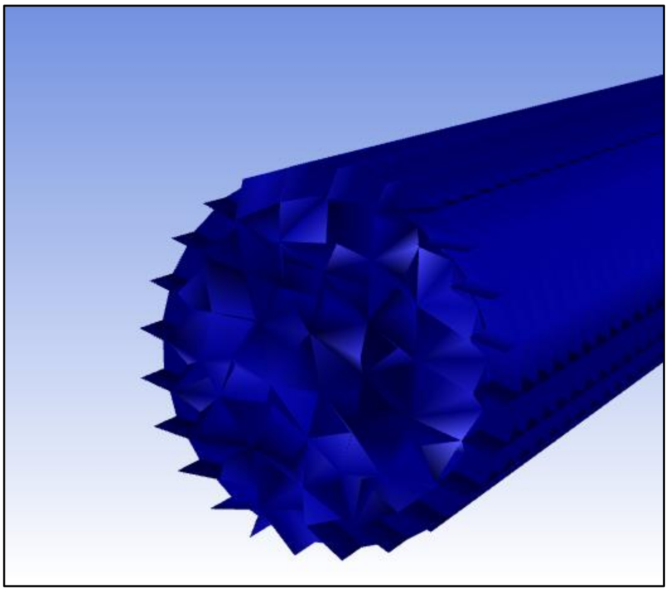

Figure 15. Inlet contour after simulation (Diameter of 25.4 mm)

4.10 Outlet

Similarly, here the red colour shows the high temperature which is over requirement in this case. This is shown in Figure 16.

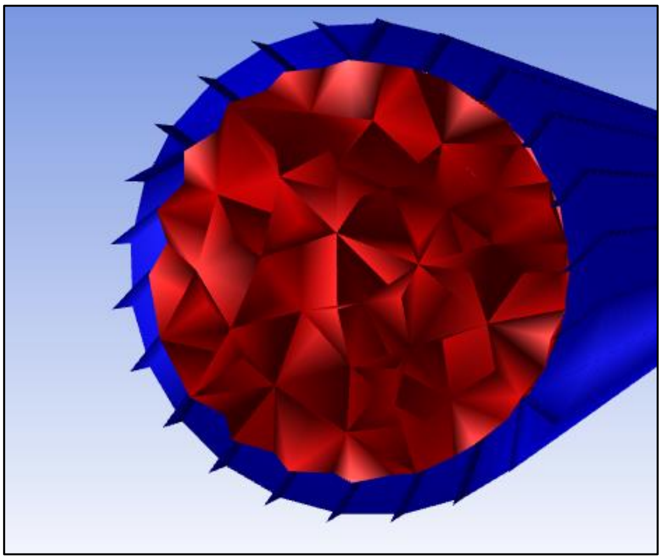

Figure 16. Outlet contour after simulation (Diameter of 25.4mm)

The temperature of the person receiving it surface changes from the entrance to the outlet as shown in the figure below. Long distances towards the water outlet, at an average flow rate of 0.25 kg/hr, the pipe reaches a maximum temperature of 384 K. As the pipe is extended, it becomes clear that the surface temperatures of the pipe rise. Figure 17 shows Temperature Contour.

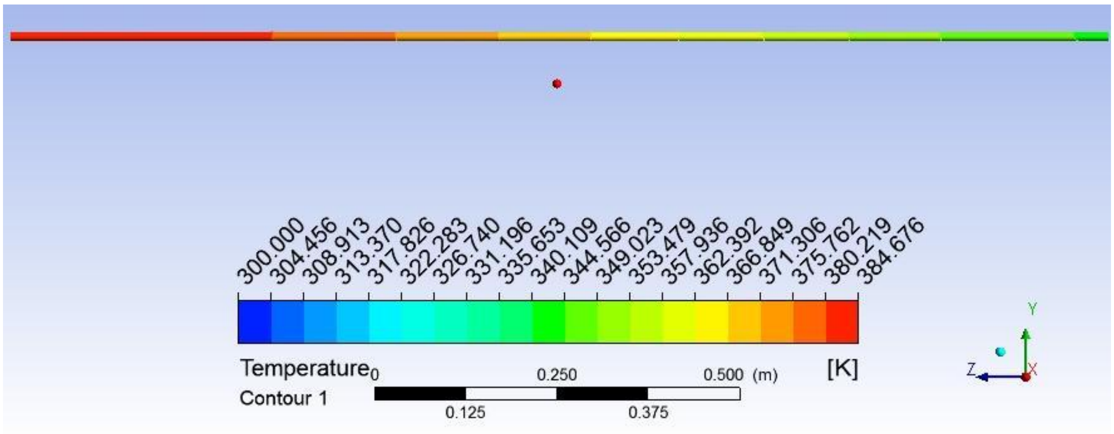

Figure 17. Temperature Contour throughout the pipe with water as liquid

In case 2

The use of ethylene glycol in other case is shown below but on the same collector the temperature is very high, so it is not useful. Figure 18 shows fluid values.

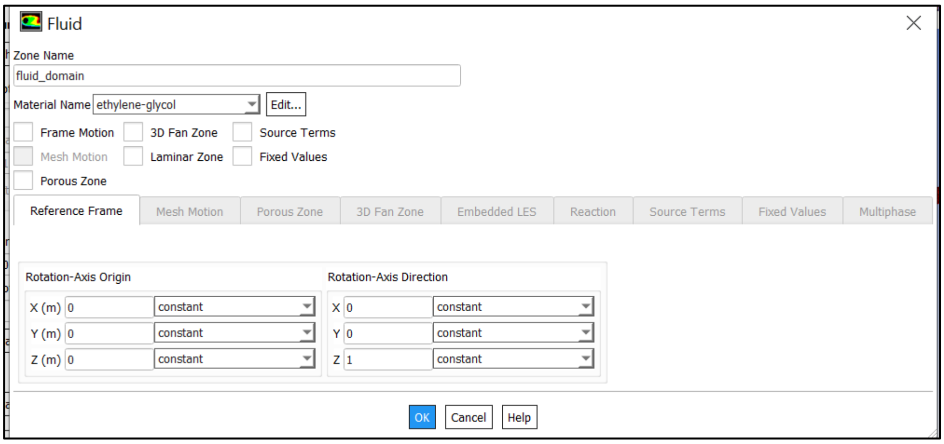

Figure 18. Fluid selected for second simulation (ethylene-glycol)

Figure 19 shows the Total Temperature.

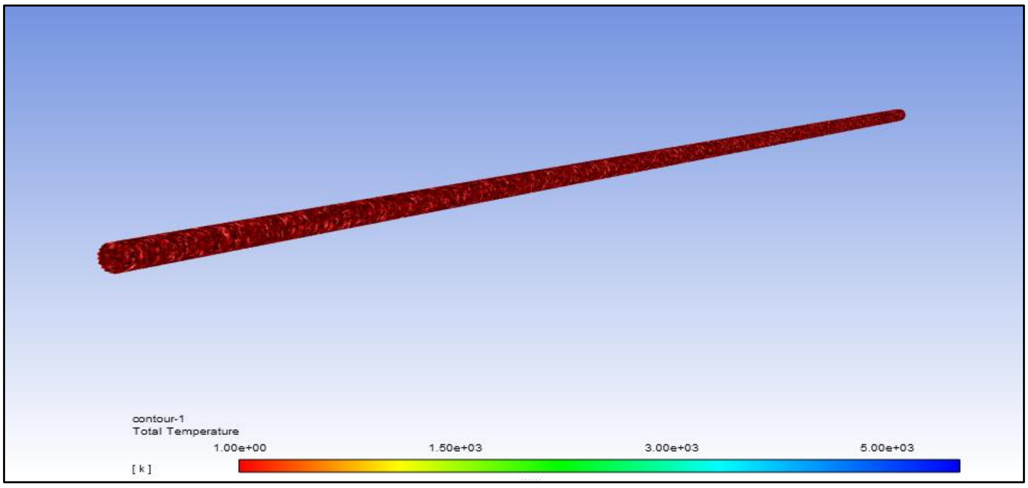

Figure 19. Total Temperature after simulating with ethylene-glycol fluid

The parabolic trough was modelled and ran simulations in Ansys Workbench to check the different fluents flows through it. Parabolic trough collector simulations for solar loading make use with the Roseland irradiation model in conjunction with the solar calculator. So overall the water based liquident will be preferable then the ethylene glycol it is because in over case that much high temperature is not required.

The above Results are dependent on iteration and size of components. By varying the parameters and size of design the output values will change accordingly.

5 Discussion and Future work

A systematic analysis has been conducted through multiple iterations to enhance the accuracy of the simulated data. As a result, a substantial amount of interpretable information has been yielded, which will be explored and interpreted in the ensuing chapter.

5.1 Discussion

An appealing method of converting thermal sun energy into usable electricity, parabolic solar collectors have a wide range of potential applications in the field of concentrated solar power. Detailed procedures for simulating PTCs, or parabolic trough solar collectors, are laid out in this master thesis. In the first paragraph of the thesis, solar concentrate solar technology is briefly described, with a special focus on vertical trough solar collectors. This model of a trough of par solar collector is designed and built with an extra layer of flat glass covering the hole similarly to the research presented by Rosti et al.(Rosti, B., Omidvar, A., & Monghasemi, N. (2019).). This adds thermal insulation and protects the reflector and glass envelope from environmental factors like rain, dust, and wind, which can degrade their optical properties. The CFD software ANSYS was used to simulate the effects of heat and liquids. This established method was also utilized by Costa et al. (Costa, A. L. H., & Queiroz, E. M. (2007)). Then, in order to broaden the scope of the findings, the program's output was contrasted with the theoretical computations of this (PTC) model. Calculated the impact of solar collector length, mass flow, and the presence or absence of a flat glass cover on the temperature of the water leaving the system, and subsequently on the thermal efficiency. Results indicate, that to make up for the loss of efficiency caused by weather and other environmental factors, the PTC's glass cover increased thermal efficiency by 8 percent during the solar radiation's peak intake. When it comes to high-temperature thermal storage, the best materials are molten salts that have great characteristics as stated by Kumar et al. (Kumar, S. D., & Chandramohan, D. (2019).). Due to inadequate heat transfer, many applications require improved heat transfer. For this application, graphite composites and metal foams were found to be suitable materials.

The design process for the parabolic trough collector commenced with its creation in SolidWorks. Subsequently, to obtain insightful results, a analysis was undertaken using Ansys Fluent software. Meshing, a crucial step in the simulation process, was executed using a tetrahedral meshing technique, ensuring precision and accuracy in capturing details of the design. Two distinct fluids, namely water and ethylene glycol, were employed within the Fluent environment to simulate different operational scenarios. By employing these fluids, the study aimed to elucidate the thermal performance and efficiency variations of the collector under varying conditions. Through this comprehensive approach, the research sought to derive insights into optimizing the design and operational parameters of the parabolic trough collector for enhanced functionality and efficiency. Near the absorber's water outlet, the receiver's surface temperature peaked at 384 K, contrasting with a consistent collector temperature. Within 70 iterations, Figure 13 illustrated the simulation's progression. Inlet analyses (Figure 14 and 15) depicted standard temperatures, while outlet evaluations (Figure 16 and 17) highlighted elevated temperatures reaching 384K at a flow rate of 0.25 kg/hr. Conversely, employing ethylene glycol (Figures 18 and 19) led to impractical temperature spikes, endorsing water-based liquids over ethylene glycol due to excessive temperatures. Overall, simulation outcomes underscored the importance of design parameters and component sizes in influencing results.

This study also looked closely at solar trough collectors with the goal of adding metal foams and graphite composites to increase their efficiency similarly to Karwa et al. (Karwa, Rajendra, G., (2023)). The idea was to figure out how these materials could improve solar energy generation trough collector performance. The initial theories were backed by real-world data obtained from simulations, which also emphasised and confirmed the projected improvements. When this is compared to the previous data on heat exchanger efficiency optimisation, patterns with the common goal of improving solar system efficiency become apparent. Decisions like material choice and how it affects performance as demonstrated by the solar thermal power study-align with the goal of enhancing solar trough collectors. For example, the use of materials such as copper tubes and aluminium with a mirror coating shows a balance between cost and performance. The significance of effective energy storage is made clear by looking at the solar thermal energy storage computations from the earlier data. The study's focus on metal foams and graphite composites as sources of concentrated solar power is in line with the demand for efficient energy storage. Both studies illustrate the difficulties in ensuring that these systems operate flawlessly by acknowledging unforeseen difficulties or anomalies. It emphasises how important it is to continue researching to have a thorough grasp. When considering the larger picture, the results indicate that applying metal foams and graphite composites in solar systems is a major advancement rather than merely a small adjustment. It acts as a disruptive catalyst within the concentrated solar power sector, coinciding with the preceding study's focus on technical development, cost containment, and environmental sustainability. This study adds precise details to the core ideas from the solar thermal power study, providing a more sophisticated knowledge of solar trough collectors. It proves that researching solar energy requires a diversified strategy.

5.2 Future work

This thesis primarily aimed to research fluid dynamics and heat transport in a collector that has a par for CSP systems. Consideration of the parabolic collector's thermal behavior under varying operating conditions was a part of the research. Analytical findings from the literature and actual measurements have confirmed the established methodology. Nonetheless, many enhancements and additional research might be undertaken to gain a more accurate understanding of their behavior in light of practical solar plant circumstances such as presented by Kumar et al. (Kumar, S. D., & Chandramohan, D. (2019).).. A potential enhancement could involve conducting research on the heat transfer and fluid dynamics within an intricate array of solar collectors featuring a parabolic trough design. In addition, future work may involve improving the suggested correlations to account for the impact by the wind and angles of pitch on environmental convection heat transfer.

6 Conclusions

In conclusion, parabolic trough solar collectors have a wide range of potential applications in the field of concentrated solar power and are an appealing method of converting thermal sun energy into usable electricity. Following section lists the main findings of this master's thesis.

- A novel design of a parabolic trough solar collector with an additional flat glass layer was designed with SolidWorks. This additional glass layer serves to insulate thermally and protect against environmental degradations.
- Using Computational Fluid Dynamics software ANSYS Fluent, heat and fluid dynamics within the collector were simulated. These simulations were critical in comparing theoretical models and practical outcomes.
- The research demonstrated that adding a flat glass cover to the collector can increase thermal efficiency by 8% at peak solar radiation times.
- The study identified molten salts as superior for high-temperature thermal storage due to their thermal stability and efficient heat conduction. Additionally, metal foams and graphite composites are recommended for their lightweight nature and high thermal conductivity.

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