

Performance Enhancement of Solar Thermal System using Phase Change Materials

Submitted in partial fulfilment of the requirements for the award of Bachelors of
Engineering degree in Mechanical Engineering

By

KAMARSU SAI SRI NIMAY (Reg. No. 39150063)

CHAVALA DINESH (Reg. No. 39150022)



**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade “A” by NAAC | 12B Status by UGC | Approved by AICTE

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

APRIL- 2023



SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with "A" grade by NAAC
Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119
www.sathyabama.ac.in



DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of KAMARSU SAI SRI NIMAY (Reg. No. 39150063), CHAVALA DINESH (Reg. No. 39150022) who carried out the project entitled **"PERFORMANCE ENHANCEMENT OF SOLAR THERMAL SYSTEMS USING PHASE CHANGE MATERIALS"** under our supervision from December 2022 to April 2023.

Internal Guide

Dr. A. KARTHIKEYAN, M.E., Ph.D.,

Head of the Department

Dr. G. ARUNKUMAR, M.E., Ph.D.,

Submitted for Viva voce Examination held on 10.05.2023

Internal Examiner

External Examiner

DECLARATION

We KAMARSU SAI SRI NIMAY (Reg. No.39150063) CHAVALA DINESH (Reg. No. 39150022) hereby declare that the Project Report entitled “**PERFORMANCE ENHANCEMENT OF SOLAR THERMAL SYSTEMS USING PHSE CHANGE MATERIALS**” done by us under the guidance of **Dr. A. KARTHIKEYAN, ME., PhD.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.



DATE: 10.05.23

SIGNATURE OF THE CANDIDATE

PLACE: CHENNAI

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to Dr. S. Prakash, M.E., Ph.D., Dean, School of Mechanical Engineering and Dr. G. Arunkumar, M.E., Ph.D., Head of the Department, Dept. of Mechanical Engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide Dr. A. Karthikeyan, M.E., Ph.D., for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

Solar-based technology started flourishing more than 70 years. Among the various available renewable energy sources such as wind, geothermal, tidal, bio mass, etc., harnessing of solar energy has become quite popular in most of the countries. Solar energy plays a major role because it is safe and inexpensive at all times. Among various solar collectors, the parabolic trough collector (PTC) is considered to be the best option for medium temperature (150–400 °C) heat requirements. The parabolic trough collector has diversified applications like heat generation, power generation and desalination. In the present study an attempt is made for the performance improvement of parabolic trough collector (PTC) by modifying the absorber tube. The absorber tube, also called the receiver tube or heat collection element, is one of the main functional units of a solar PTC in addition to other elements. The absorber tube is fabricated with copper tubes inside a metal housing. The copper tubes are then punched to create heat vortex or heat zones for more effectively heating the HTF flowing through the copper tubes which is surrounded by pcm. Parabolic mirrors reflect to a focal point and concentrate falling sun rays onto an absorber tube. Enhancing the heat transfer in the absorber tube improves effectively both the thermal efficiency and the structural safety of the parabolic trough receiver (PTR). In parabolic trough collector, evacuated or non-evacuated glass tubes are more valuable for medium and high-temperature applications to reduce the heat losses from the absorber tube.

TABLE OF CONTENTS

Chapter No	Title	Page no
	ABSTRACT	v
	LIST OF ABBREVIATIONS	viii
	LIST OF FIGURES	ix
	LIST OF TABLES	x
1	INTRODUCTION	1
	1.1. Heat Transfer Fluid	2
	1.2. PCM in Solar Thermal System	3
2	LITERATURE SURVEY	4
3	AIM AND SCOPE OF THE PROJECT	7
	3.1. Aim	7
	3.2. Scope	7
4	EXPERIMENTAL DESIGN	8
	4.1. Materials and methods	8

	4.2. Design and Development of PTC	9
	4.3. Absorber Tube	12
	4.4. Performance Parameters	13
5	RESULTS AND CONCLUSION	14
	5.1. Water Outlet Temperature	14
	5.2. Convective Heat Transfer Coefficient	19
	5.3. Nusselt Number	21
	5.4. Thermal Efficiency	21
6	SUMMARY AND CONCLUSION	23
	REFERENCES	24

LIST OF ABBREVIATIONS

Abbreviation	Abbreviation Name
Aa	area of the aperture (m ²)
A	area of the receiver (m ²)
CP	specific heat of water (kJ/kg. K)
Dri	inner diameter of receiver (m)
Dh	hydraulic mean diameter of the tube (m)
Eu	useful exergy (W)
Es	sun exergy (W)
f	friction factor
Ga	solar radiation (W/m ²)
H	convective heat transfer coefficient (W/m ² K)
K	thermal conductivity of water (W/m. K)
L	length of receiver (m)
M	mass flow rate (kg/s)
Nu	Nusselt number
Wp	pump power (W)
P	perimeter of receiver (m)
DP	pressure drop (N/m ²)
Qu	useful heat absorbed by water (W)
Qs	input solar energy (W)
Ta	ambient temperature (K)
Ti	inlet temperature (K)
To	outlet temperature (K)
Tm	mean temperature of water (K)
Tr	receiver tube temperature (K)
Tsun	sun temperature (K)
η _{th}	thermal efficiency (%)
μ	dynamic viscosity (kg/m. s)
ρ	density (kg/m ³)

LIST OF FIGURES

Figure no.	Figure Name	Page no
4.1.1	a) Experimental setup of the parabolic trough collector. B) Pyranometer. c) Focalpoint on the receiver tube on the PTC. d) Schematic setup of the PTC.	11
4.2.1	Dimensions of the modified solar receiver tube and conventional receiver tube	12
5.1.1	Solar Radiation and ambient temperature for Type-I and Type-II respectively at (a) 0.05kg/s and (b) 0.2kg/s. (c) 0.05kg/s. (d) 0.2kg/s respectively.	19
5.2.1	<i>CHTC at different mass flowrates with respect to time for (a) Type-I (b) Type-II</i>	20
5.3.1	<i>Nusselt Number at different flowrate with respect to time for (a) Type-I (b) Type-II</i>	21
5.4.1	Thermal Efficiency at different flowrates for (a) Type-I (b) Type-II	22

LIST OF TABLES

Table no.	Table Name	Page no
4.1	Dimensions and Materials of Selected PTC	8
4.3	Dimensions of Absorber Tube	12
5.1	Measuring Instrument	14

CHAPTER 1

INTRODUCTION

The demand for energy is increasing quickly, and the available energy resources cannot keep up. Furthermore, burning fossil fuels harms the environment and fastens the depletion of their finite resources. As a result, alternative energy that comes from sources that are renewable is becoming more and more common. PTC is one of the most suitable massive solar power technologies now accessible, and it is also one of the most tested and affordable solar power technologies available. Enhancement of heat transfer in a solar collector with a parabolic trough. The numerous methods used to improve the transmission of heat in the solar PTC's receiver tube are the main subject of this section. The receiver tube's HTF needs to absorb all of the heat produced by the collector. This section is mostly concerned with the numerous methods used to improve the transfer of heat in the solar PTC's receiver tube. The receiver tube's HTF needs to absorb all of the heat produced by the collector. Therefore, the HTF should be able to absorb all of the heat that is supplied to the system by the source. All of the literature that is currently available is divided into various methods or techniques for improving heat transfer on the tube that receives electricity of the solar PTC, including (a) reducing heat loss, (b) installing turbulators inside the receiver, (c) utilising nanofluids, and (d) applying selective coatings to the receiver tube. One of the most well-known and promising methods used to convert solar energy into usable heat for processing or steam that can be used for the generation of electricity through a Rankin cycle is the parabolic trough collector. The absorber tube located at the focus plane of the troughs collector receives the electromagnetic energy affecting on the reflecting surface in reflection. The PTC system's major component that affects the thermal endurance of the system is an absorber tube. Therefore, in order to improve the absorber tube's thermal performance, researchers made a number of modifications. A Heat Transfer Fluid is pumped or blown through the heated receiver. Depending on the application, the HTF can achieve temperatures of up to 400°C as it circulates around the receiver while absorbing thermal energy from the tube in the form of water, thermal fluid, molten salt, or gas. Within the receiver tube, the fluid that transfers heat circulates and gains energy through forced convection for use in a variety of

thermal applications. To stop the tubes from bending under the weight of the fluid, the wind load, and one's own weight, intermediary support attached to the PTC pressure tube are used to hold the absorber tube. To reduce convection and radiation losses, the tube is enclosed with a glass jacket that is either evacuated or not. Contrarily, numerous studies have concentrated on enhancing the absorber's geometrical properties in order to speed up the rate at which heat is transferred to the fluid. More specifically, the fundamental principle is to enhance the degree of turbulence within the flow, which raises the coefficient of heat transfer and promotes greater mixing within the flow. Numerous methods have been investigated, including introducing in the flow and changes to the absorber surface that create passive vortices. The primary effect of the parabola collector is increased in this work by enhancing the absorber tube and increasing PCM. Copper tubes are used inside a rectangular metal enclosure. The PCM is likewise housed inside the metal enclosure made up of two tubes made of copper. In order to properly heat the HTF fluid flowing through the copper tubes, numerous holes are bored into the copper tube's surface. Additionally, local overheating due to the highest temperature on some areas of the surface of the absorber may endanger the stability and shorten the lifespan of the heated oil and coating.

1.1. HEAT TRANSFER FLUID

In solar thermal power plant (STPP) applications, the Heat Transfer Fluid (HTF) has the job of gathering the thermal energy absorbed by the receiver and transferring it to the storage system or straight to the power block. The selection of the right HTF is application-specific and is based on the installation's unique design characteristics as well as its operational circumstances. HTFs should ideally have strong thermal stability, be able to operate safely across the target temperature range, have acceptable chemical compatibility with the materials used to make the tubing wall, and be inexpensive and ecologically safe. Additionally, a high thermal conductivity, high heat capacity, and large heat transfer coefficient are normally desired to maximize the heat transfer effectiveness, together with a low viscosity and a small thermal expansion coefficient to reduce pumping power and thermal expansion concern

1.2. PCM IN SOLAR THERMAL SYSTEM

Solar energy is currently the most popular renewable energy source in terms of both costs and benefits. However, the main issue is that solar energy is not available for very long. As a result of their application of latent heat, PCMs are used as a medium to store the solar energy. The substance in the PCMs absorbs and stores heat when it is exposed to solar thermal energy. The PCM can be used in a variety of solar applications. The research that has been done in the field of PCM combined with solar thermal systems is reviewed in this article.

A phase change material (PCM) is a component that releases or absorbs enough energy during a phase transformation to deliver usable heat or cooling. During the phase transition, it was found that phase change materials have a large capacity to store and release latent heat. PCMs can be classified as solid-solid, solid-liquid, solid-gas, or liquid-gas. Out of these four options, solid-liquid PCMs are the most effective at storing thermal energy. Phase changes frequently produce or absorb less energy than fusion heat. When a phase change material melts and solidifies at the temperature required for the phase transition, heat can be stored and released. Every time a substance undergoes a state change—from solid to liquid, or vice versa—or when its structural makeup changes, heat is either absorbed or released. For final application, the solid liquid phase change materials are encapsulated and maintained in the liquid state. Phase change materials may be micro-encapsulated in some applications. The ability of the material to remain solid after the PCM core has melted is due to micro-encapsulation in the form of small bubbles. PCMs can be categorized into three groups: eutectic, inorganic, and organic. The main differences, advantages, and disadvantages are briefly covered in this section.

The phase change materials used in the experiment in this investigation are a mixture of sodium nitrate (NaNO_3) and potassium nitrate (KNO_3). The melting point of sodium nitrate is between 275 and 325 °C, and its latent heat content is significant (178 kJ·kg⁻¹). As PCM, potassium nitrate (KNO_3) has been chosen. It has a melting point of approximately 334 °C and a calorimetric fusion energy of KNO_3 of 116 kJ·kg⁻¹. The mixture has a melting point of 224.30°C, and it varies depending on how much of each component is present.

CHAPTER 2

LITERATURE SURVEY

An extensive review of various technologies for enhancing the thermal and optical performances of parabolic trough collectors- Nabeel Abed/Imran Afgan

A wide variety of engineering industrial applications demand that the system's thermal and optical efficiency be maximized with a tolerable low friction factor penalty and consequently low-pressure losses. A wide variety of engineering industrial applications demand that the system's thermal and optical efficiency be maximized with a tolerable low friction factor penalty and consequently low-pressure losses. Parabolic trough collectors (PTCs), a member of the family of concentrated solar power systems, suffer comparable difficulties despite receiving a lot of recent attention. The current paper provides a thorough analysis of PTC systems, contrasting modern and historical advancements that are frequently employed to boost thermal and optical efficiency. In-depth discussions have also been had regarding the methods utilized for modelling single- and two-phase flow in numerical simulations, design factors, and experimental procedures. The study also offers various numerical and analytical implementation strategies for nonuniform solar distributions with various design characteristics. Changing the working heat transfer fluids, replacing the working fluids with nanofluids (single and hybrid), inserting different tabulators with various design configurations, and finally combining the benefits of nanofluids and swirl generators in the same application are the four main technologies that are comprehensively addressed to effectively improve the thermal performance of the PTCs. The paper also provides a critical summary of the studies looking into improving thermal performance through the usage of PTCs with unique designs and passive heat transfer augmentation methods.

Numerical Study and Optimization of Parabolic Trough Solar Collector Receiver Tube - Anissa Ghomrassi |Hatem Mhiri|Philippe Bournot

The performance of the parabolic trough collector (PTC) is examined in this study. The adopted approach consists of two primary steps to accomplish this purpose. The SOLTRACE software calculates the concentrated solar heat flux densities in the solar concentrator focal zone in the first stage. To assess and improve the thermal performance of the tube receiver, computational fluid dynamics (CFD)

simulations are run in the second step. As wall heat flux boundary conditions for the receiving tube, the SOLTRACE software's predicted heat flux densities are employed. Study is done on how variations in receiver tube diameter affect PTC thermal performance. An experimental receiver tube is used. This latter has a metallic layer covering it. For various diameters, the performance of a tube receiver covered in a metallic layer is compared to that of a tube receiver with the same diameter but no metallic thickness. In comparison to tubes with the same diameter and flow rates, it has been discovered that increasing tube metallic thickness improves PTC system performance.

Design, development and techno economic analysis of novel parabolic trough collector for low-temperature water heating applications- Bhargav H, Hitesh Panchal, F.A. Essa

The fundamental goal of this study is to create and test indigenous PTC capable of providing hot water for low-temperature applications. It is created a novel parabolictrough collector that is simple to collect and move. It enables simple receiver pipe, reflector sheet, and heat transfer fluid replacement. The contemporary design also permits modifying the geometrical specifications of the trough. A glass cover and anautomatic tracking system can be attached according to the design. Three various attachments, including manual tracking without a glass cover, manual tracking witha glass clover, and automatic tracking without a glass cover, are tried with this novelPTC. For all three PTC systems, experimental, optical, and theoretical efficiencies were computed. Average PTC with manual tracking experimental efficiency. The payback period for a PTC system for manual tracking is found to be equivalent to 4years for all, while it is determined to be equivalent to 5 years for PTC systems for manual tracking with a glass cover and automatic tracking. The experiment was carried out in March 2020 at the designated site in Godhra, Gujarat, India.

Enhancing the optical and thermal efficiency of a parabolic trough collector – A review - G.K. Manikandana, S. Iniyamb, Ranko Goic

Among the different accessible renewable energy sources such as wind, geothermal, tidal, bio mass, and so on, harnessing solar energy has grown rather popular in most nations. Different collectors have been modeled, designed, built, and tested to function in a variety of temperature ranges, including low temperaturecollectors (flat plate 30-80 °C, evacuated tube 50-200 °C, and compound parabolic

collector 60-240 °C), medium temperature collectors (linear Fresnel reflector 60-250 °C, cylindrical trough 60-300 °C, parabolic trough 60-400 °C), and high temperature collectors (The parabolic trough collector is discovered to be the most popular one among the other collectors in applications like the delivery of process heat and steam production. For nearly three decades, numerous theoretical and experimental study investigations have been conducted to improve the system's optical and thermal efficiency. The overall loss coefficient, which accounts for conduction, convection, and radiation losses, determines the thermal efficiency. Metal glass evacuated tubes and certain surface coatings on the receiver have reduced convection and radiation losses. Conduction losses are ongoing and are influenced by the structure's substance. Investigations have shown that a number of issues contribute to heat loss, including vacuum failure, hydrogen buildup in the receiver, and tube fracture at the receiver's end.

Performance analysis of internally helically v-grooved absorber tubes using nanofluid- Suresh Biswakarmaa, Sujit Roya, Biplab Dasa,b, Biplab Kumar Debnath In the current study, a modification to the absorber tube with an internal helically groove is produced in an effort to increase the performance of the parabolic trough collector (PTC). The PTC system's major component that affects the thermal performance of the system is an absorber tube. Therefore, in order to improve the absorber tube's thermal performance, researchers made numerous changes to it. The thermal properties of the collector can be improved by using nanofluids as the working fluid. For improved thermal performance, aluminum oxide (Al_2O_3) nanofluid (3–8% by volume) is used in place of water as the basis working fluid. Tests are conducted with heat fluxes of 600, 800, and 1000 W/m^2 at the tube's outer surface. The issue is simulated using ANSYS Fluent 14.0 while taking into account two different Reynolds numbers (Re) of 4000 and 6000. The results show that the pressure drop increases by 14.5% when Al_2O_3 concentration rises from 3% to 8%. When operating with a heat flow of 1000 W/m^2 and $\text{Re} = 4000$, the nanofluid's heat transfer coefficient can be increased by as much as 13.8% when compared to base fluid. Furthermore, the heat transfer coefficient with nanofluid increases by up to 41.3% from a value of Re of 4000 to 6000.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1. AIM

- To study the performance of parabolic trough collector with modified absorber design
- To study the performance of the best absorber design using PCM materials experimentally
- To study the performance of modified absorber design experimentally using PCM material.

The aim of solar thermal storage using Phase Change Materials (PCM) is to store the thermal energy generated by solar collectors during periods of high solar radiation, so that it can be used during periods of low or no solar radiation.

3.2. SCOPE

The scope of solar thermal storage using PCM includes the design, development, and implementation of thermal energy storage systems that use PCM to store heat. The scope also includes the investigation and optimization of various parameters such as the type of PCM used, the melting temperature of the PCM, the design of the storage container, and the operating conditions of the system. The use of PCM in solar thermal storage systems offers several advantages such as high energy density, low heat losses, and the ability to maintain the stored energy for extended periods of time. These advantages make PCM-based thermal storage systems a promising technology for the efficient use of solar energy, particularly in applications such as space heating, domestic hot water, and industrial process heating.

Therefore, the aim and scope of present investigation is to enable the efficient use of solar energy, by developing and implementing thermal storage systems that can store and deliver the energy as needed.

CHAPTER 4

EXPERIMENTAL DESIGN

4.1. MATERIALS AND METHODS

Two distinct types of PTC receiver tubes are used in the experiment, which is run at two different mass flow rates. It uses a conventional receiver (Type-A), which is a round tube made of mild steel. The upgraded receiver (Type-B), which consists of a rectangular channel filled with PCM, is constructed using circular copper tubes that are equally spaced apart. The inner diameter of the 1.4 m long, circular receiver tube is 25 mm. The 60 mm wide by 25 mm tall rectangular channel receiving tube is 1.4 metres long. The copper tubes are welded shut after being lined with 1 mm thick circular copper tubes. To allow for fluid flow and surface contact with the PCM in the rectangular channel, the tubes are welded at equal intervals of 25 mm along their entire length. The positioning of copper tubes in a PCM is a crucial factor that affects the outlet temperature and improves heat transmission.

A water storage tank, pump, valves, a water flow metre, a reflector surface, and a receiver make up the experimental setup. Temperatures are recorded with Pt100 RTD thermocouples and an Agilent data recorder (Model 34970A). Solar radiation, wind speed, and outside temperature are all measured using a solar weather station (AT Delta-T Make, WS-GP2 Model). The observations are made at intervals of 30 minutes. The experiment is carried out at two different flow rates of 0.05 and 0.2 kg/s, both of which are controlled by a water flow metre and a valve. Table 4.1 provides information on the instruments' uncertainty. The experiment is carried out utilising a traditional circular receiver tube and a new rectangular channel receiver tube from 9 AM to 4 PM for a number of days at two distinct mass flow rates.

Table 4.1 Dimensions and materials of selected PTC

Parameters	Value
Material of the reflector	Stainless steel with mirror film
Dimension of new receiver tube (m)	0.06×0.025
Length of the receiver	1.4

Emissivity of mild steel	0.31
Emissivity of glass cover	0.85
Receiver material	Mild steel
Thickness of insulation (m)	0.024
Insulation material	Glass wool
Area of the collector (m ²)	2.096

4.2. DESIGN AND DEVELOPMENT OF PTC

A PTC design must take into account the trough length, focal length, aperture width, and rim angle. Designing a trough collector is a challenging task. In addition to important qualities, other influencing factors like average wind speed, HTF, application, number of loops, storage device, etc. are also taken into consideration while building a system. After considering all the above restrictions, an innovative absorber tube/receiver tube for PTC is produced. This absorber tube is simple to collect and send. This tube adds the specific ability to focus the maximum radiation on to the absorber tube as it has more area of contact, and good accompany goodflow of HTF. Table 1 contains the measurement details of PTC and circular receiver tube.

$$Y = \frac{1}{4f} X^2$$

The distance between the parabola vertex and the focal point is called focal length (f). Where X and Y are the axes, it is used to find the shape of a parabola.

Rim angle, focal length, and aperture width are the three main parameters that govern the completeness of the cross-section of a parabolic trough, i.e., its size and shape. Figure 1 illustrates the PTC experimental configuration. Any two known parameters can be used to calculate the third parameter. As a function of the rim angle, the ratio of the aperture width to the focal length can be expressed.

$$\frac{a}{f} = -\frac{4}{\tan\psi} + \sqrt{\frac{16}{\tan^2\psi} + 16}$$

The aperture area is given by the product of the length (l) and aperture width (a) of the trough.

$$A_a = a \times l$$



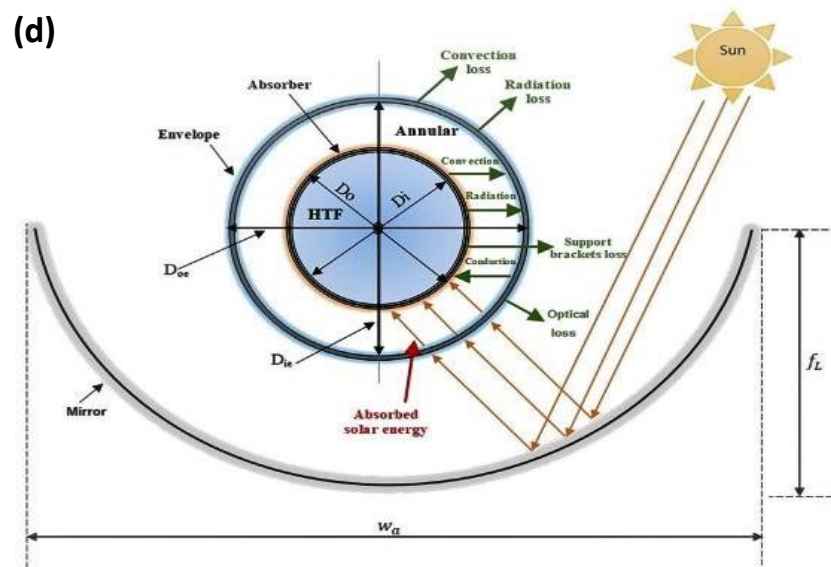


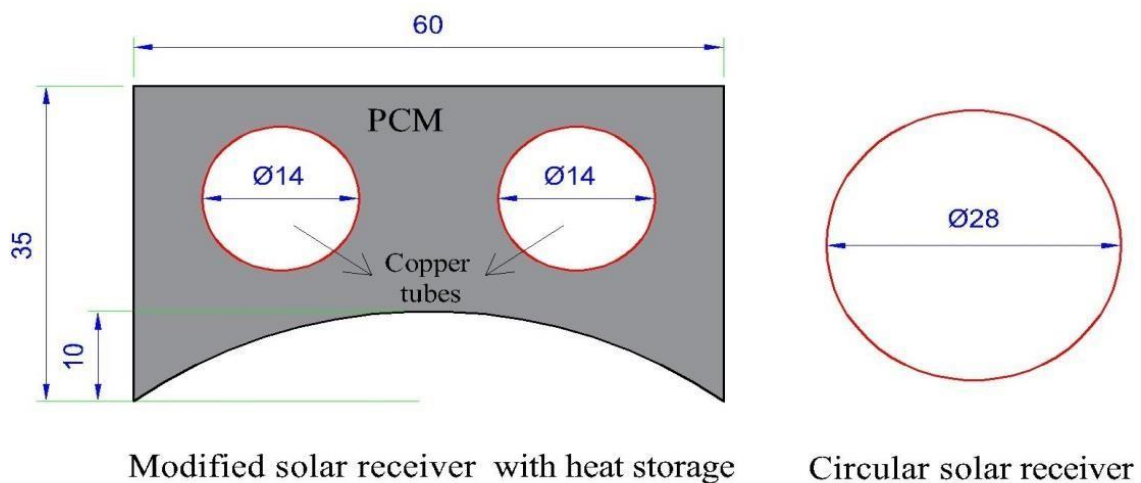
Figure 4.1 a) Experimental setup of the parabolic trough collector. B) Pyranometer. c) Focal point on the receiver tube on the PTC. d) Schematic setup of the PTC.

4.3. ABSORBER TUBE

The solar receiver converts the incident solar radiation it has absorbed into thermal energy and transports it through the absorber using the heat transfer fluid (HTF). The most important PTC system component, often referred to as a heat collection element (HCE) or receiver, is frequently constructed from a steel tube to provide excellent optical properties, low thermal emissivity, and strong solar absorptivity. The air pressure in the annular gap between the absorber tube and the glass envelope is typically kept at 0.013 Pa in order to further reduce heat losses. Two copper tubes inserted inside a rectangular chamber are also taken into account. The design is fabricated and the measurements of the receiver tube are mentioned in table 4.2;

Table 4.2 Dimensions of the Absorber tube

Parameter	Value
Length Of rectangular cavity (m)	0.06
Breadth of Rectangular Cavity (m)	0.035
Cavity protruding inside the rectangle (m)	0.01
Diameter of the copper tubes (m)	0.014



All dimensions are in mm

Figure 4.2 Dimensions of the modified solar receiver tube and conventional receiver tube.

4.4. PERFORMANCE PARAMETERS

4.4.1. Energy analysis

The useful heat absorbed by water (Q_u) is calculated with

$$Q_u = h \times (A) \times (T_r - T_m) \quad \text{Equation 1}$$

T_m is the mean temperature of water. T_r is the receiver temperature and A is the area. The heat transfer area of a rectangular channel is calculated from its hydraulic diameter.

$$A = \pi \times D_h \times L \quad \text{Equation 2}$$

$$D_h = \frac{4A}{P} \quad \text{Equation 3}$$

In order to determine the receiver's CHTC, the amount of convective heat transfer is multiplied by the heat absorption from the temperature difference of water is calculated

$$h = \frac{mC_p(T_o - T_i)}{(\pi D_{ri} \times L) \times (T_r - T_m)} \quad \text{Equation 4}$$

Nusselt number (Nu):

$$Nu = h \times \frac{D_h}{k} \quad \text{Equation 5}$$

The thermal efficiency of the PTC can be determined by

$$\eta^{th} = \frac{mC_p(T_o - T_i)}{A_a \times G_a} \quad \text{Equation 6}$$

CHAPTER 5

RESULTS AND DISCUSSION

The absorber tube was made exceptionally well, as was its design. It can be transferred from one place to another. It can correct significant problems that have arisen in the receiver joint. In this configuration, the receiver is stationary. Utilizing a glass cover helps reducing heat losses caused by wind. It can also reduce dust accumulated on the reflector. Under nearly equal radiation and temperature settings, experimental investigation on the rectangular modified and classic receivers is carried out. Specifically for Chennai, Tamil Nadu, India (12° 59' N and 79° 58' E, respectively). The experiments continued uninterrupted for several days. For the computation of the thermal performance parameters at each flow rate for the two configurations, the recorded measurements of comparable solar weather conditions are used. During the calculation, the average of two values is taken into account for 30 minutes. The outcomes are displayed at an average interval of 30 minutes. The ambient temperature and solar radiation ranged from 30 to 41 °C and 600 to 980 W/m², respectively. The CHTC, Nusselt number, thermal efficiency are computed based on the measurements, and the findings are explained. Variations in solar radiation and the surrounding temperature for Type-A and Type-B designs with mass flow rates of 0.05 and 0.2 kg/s. The instrument details are mentioned in table 5.1

Table 5.1 Measurement instruments details

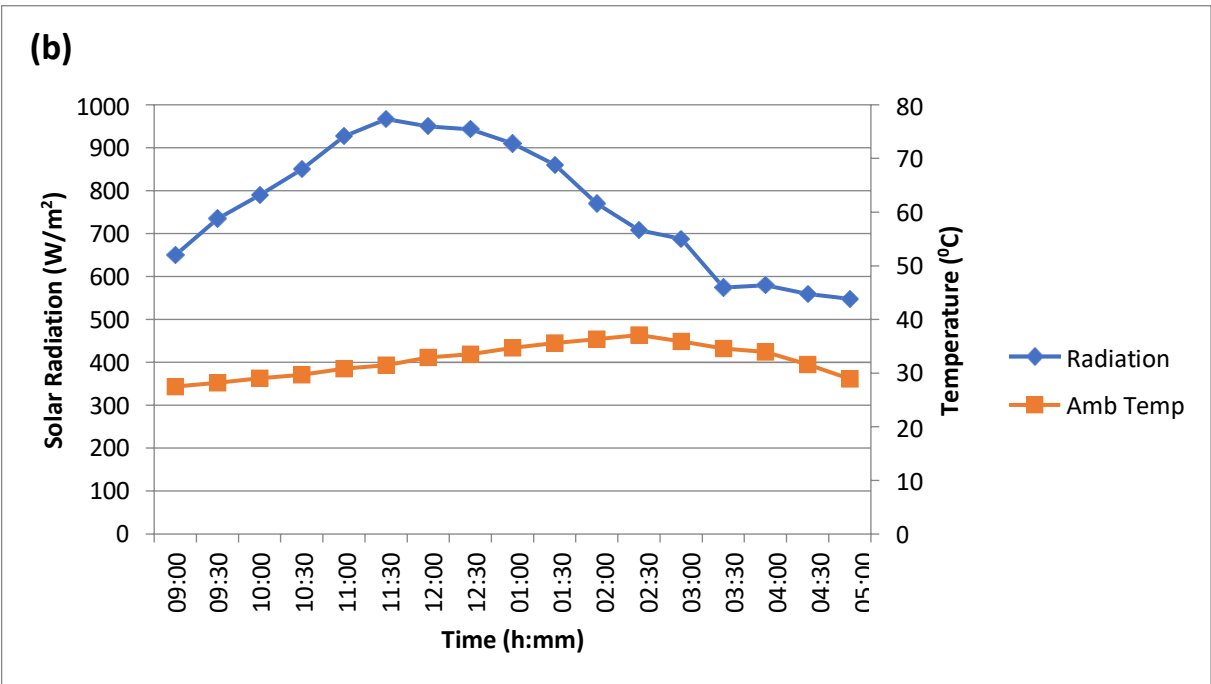
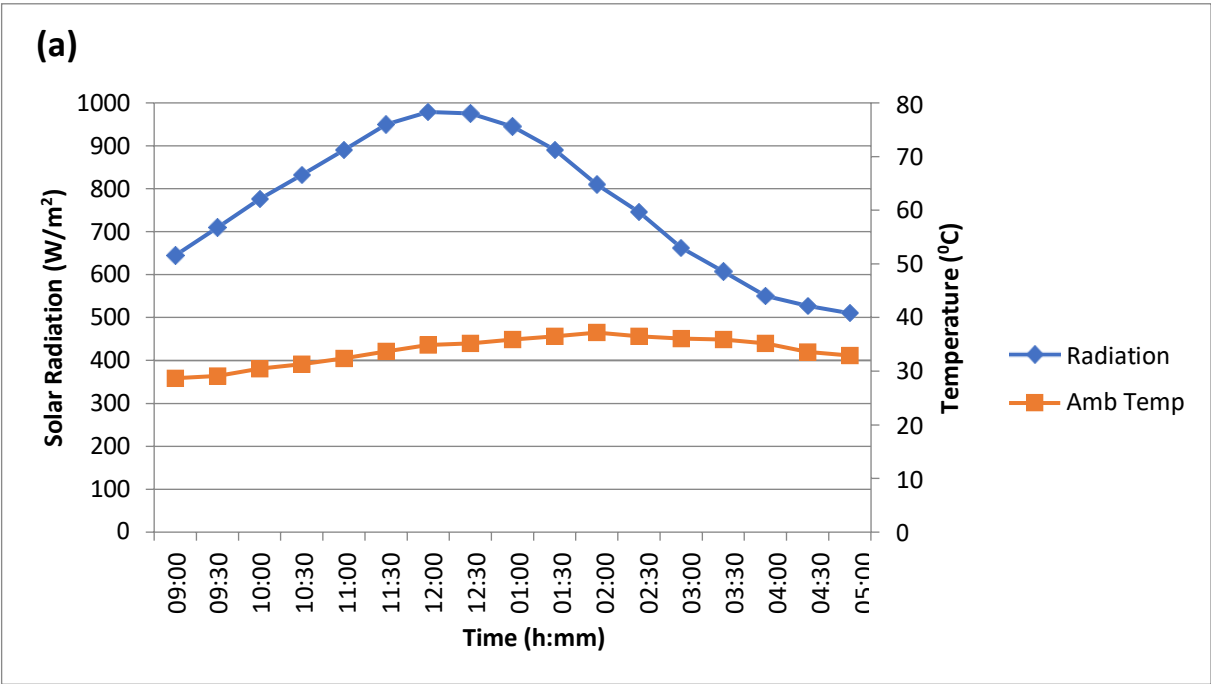
Instrument	Range of measurement	Uncertainty
Flow meter	0-0.055 kg/s	± 0.0012 kg/s
K-type thermocouple	-200-1000°C	± 2.2°C
Pyranometer	0-4000 W/m ²	± 22 W/m ²
Anemometer	0-25 m/s	± 0.04 m/s

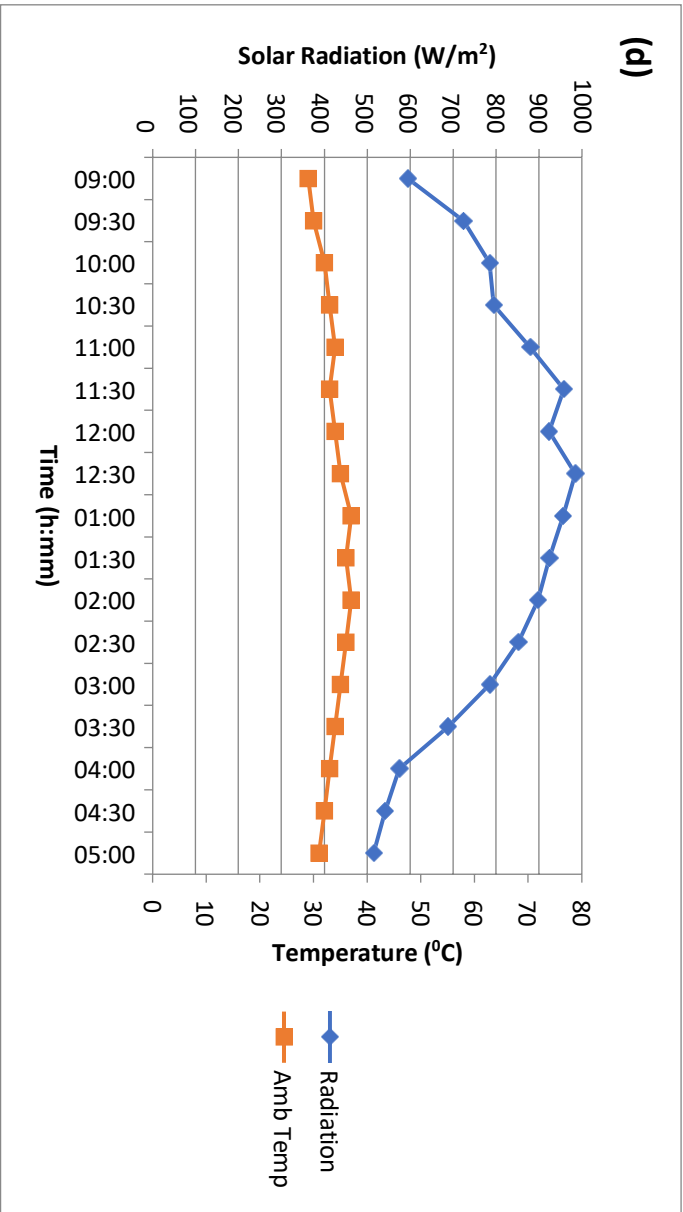
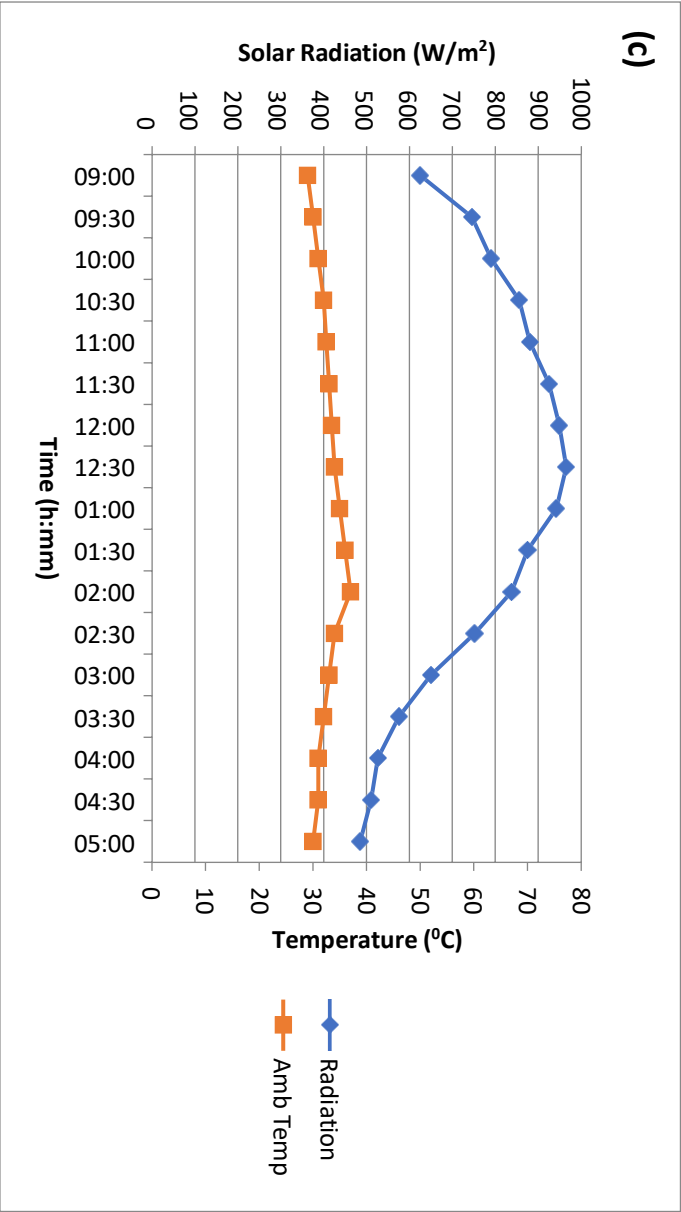
5.1. WATER OUTLET TEMPERATURE

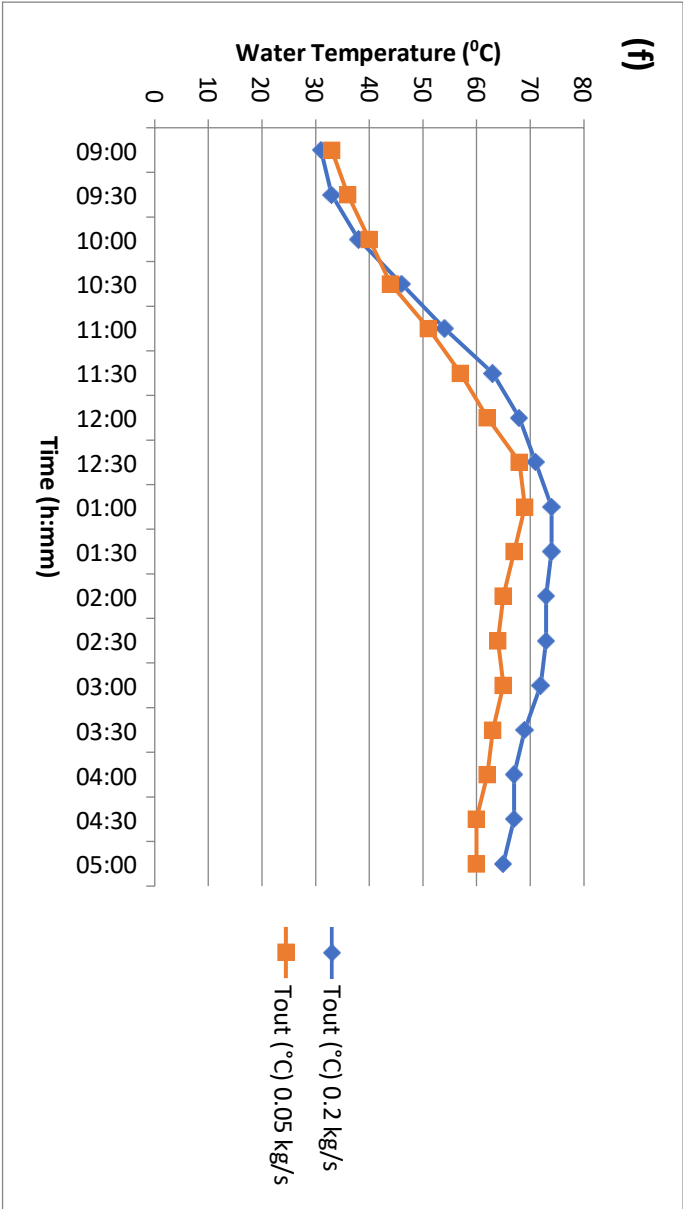
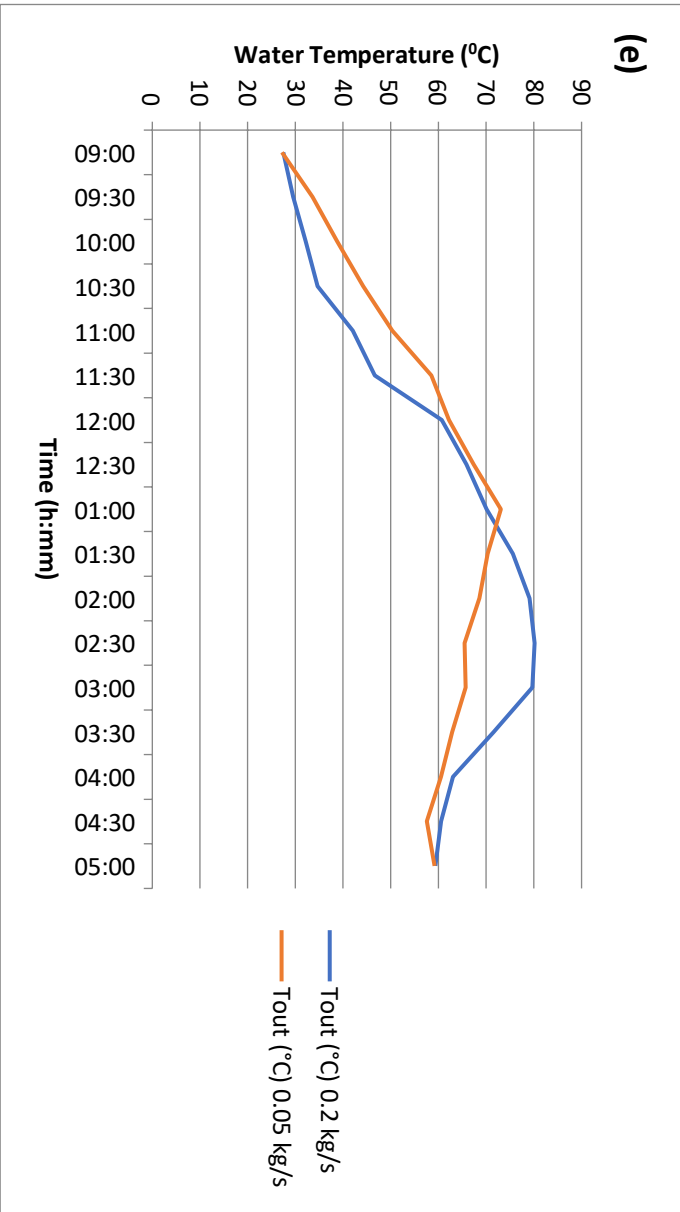
Calculations of thermal performance are based on output water temperature readings that are taken every 10 minutes for an average of 30 minutes. Water is

made accessible to the receiver using a water pump and collector at the storage tank. Occasionally, the water in the storage tank is drained and then filled again in preparation for the test the next day. The receiver connects to the pump and the tank at opposite ends. The observation shows that the Type-A receiver tube has a higher outlet temperature than the Type-B receiver tube. Circular receivers allow water to flow without disturbing the tank. As a result, following each pass, the receiver gives water a brief heating phase. As a result, the water's exit temperature is lower. The heat exchange rate increases when the HTF comes into closer contact with the surface of the absorber. The PCM integrated rectangular cavity improves heat transfer between the receiver and the water running through the copper tube. The outlet temperatures observed for PTC with the conventional circular receiver are 56.8 °C and 57.5 °C, respectively, at mass flow rates of 0.05 kg/s and 0.2 kg/s. The rectangular channel receiver has 58.6 °C and 61.0 °C at 0.05 kg/s and 0.2 kg/s, respectively. Additionally, the reduction in temperature disparities is a result of the increased mass flow rate. Because of the reduced mass flow rate, the water moves more slowly, giving it more time to absorb heat and reach the bigger temperature difference. But at higher flow rates, water moves faster, so it takes in less heat from the receiver in a shorter period of time. The heat loss is primarily caused by the receiver's elevated surface temperature. By absorbing more heat from the receiver, the temperature of the receiver can be lowered, which also lowers heat loss to the environment. The heat loss from the receiver can be decreased by adding insulation. The top facing of the rectangular channel receiver is lined with glass wool insulation to reduce top heat loss and overall heat loss. Due to a bigger mass of water absorbing more heat, the minimum temperature is seen at higher flow rates. The receiver temperature is 162.8 °C and 155.4 °C at 0.05 kg/s and 0.2 kg/s, respectively for the Type-B modified receiver tube. Because of

integrated PCM in the receiver tube, the redesigned receiver has a highertemperature, which suggests that the water's useful heat absorption is higher.







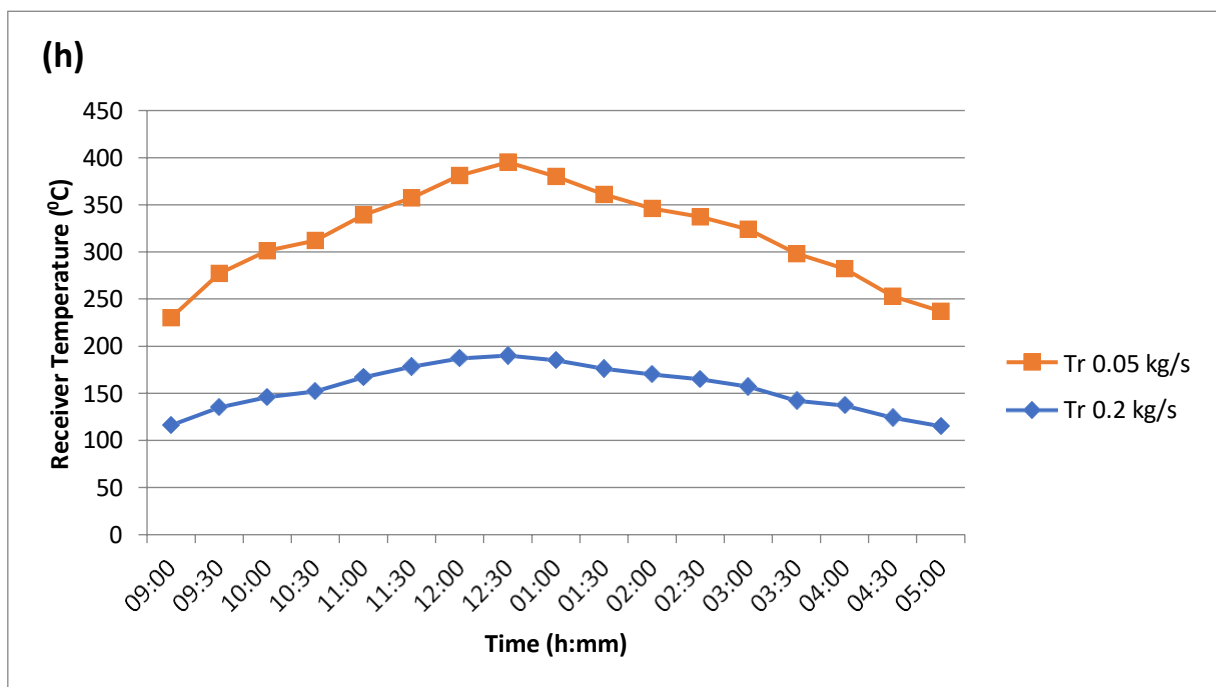
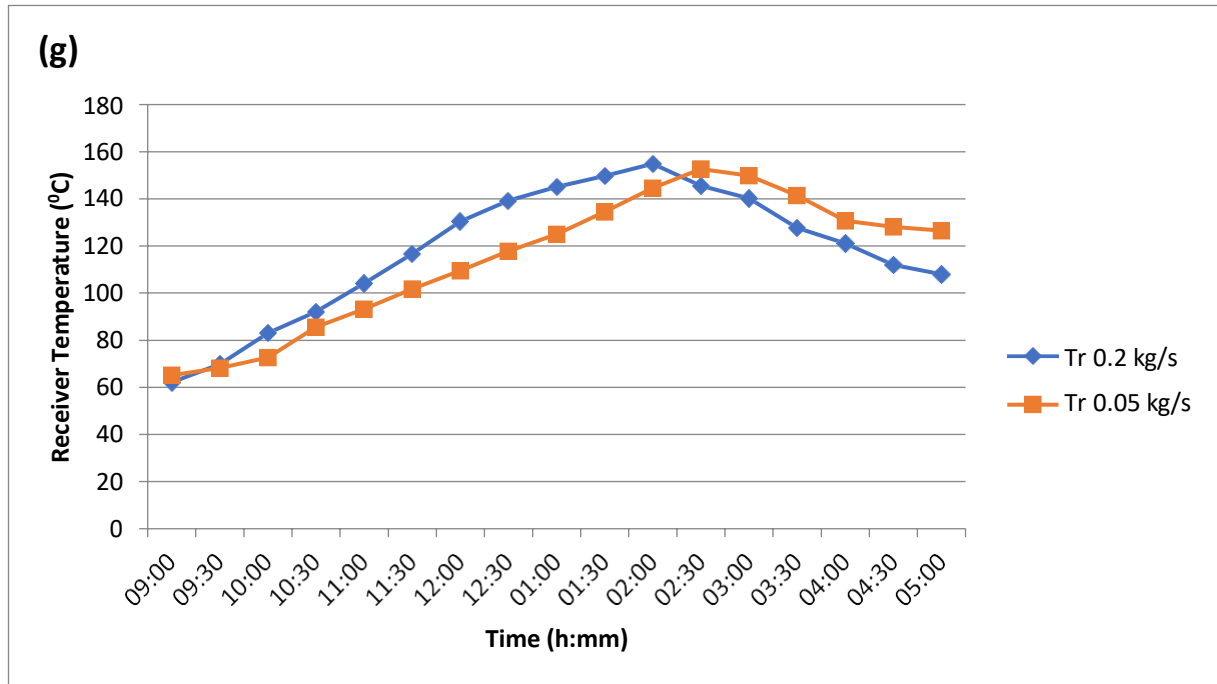


Figure 5.1.1 Solar Radiation and ambient temperature for Type-A and Type-B respectively at (a) 0.05kg/s and (b) 0.2kg/s. (c) 0.05kg/s. (d) 0.2kg/s respectively.

Outlet water temperature at 0.05kg/s and 0.2kg/s for (e) Type-1. (f) Type-B.

Receiver temperature for (g) Type-A. (h) Type-B.

5.2. CONVECTIVE HEAT TRANSFER COEFFICIENT

Based on water's useable heat absorption and mass flow rates, the CHTC of HTF which is water is calculated for two types of receivers. Based on the hydraulic diameters, the heat transfer area can be calculated. The hydraulic diameters of both

receivers are nearly identical. The CHTC range of the Type-A receiver is less than the Type-B receivers at all mass flow rates because of the low heat transfer to water. The PCM that is injected into the channel of Type-A receivers acts as an additional source of heat and enhances the fluid's ability to absorb heat through the receiver. The tank may be filled with water immediately. The water may flow based on how the tubes are arranged in the channel. The CHTC of Type-B is enhanced by the receiver's surface area in contact with water. Water continues to be in contact with the PCM-filled tube, which still gets focused solar energy from the reflector but at a reduced rate. The convective heat transmission may be enhanced if there is more water in contact with the receiver channel. The CHTC is enhanced by the tubes, which also increase the water's surface area for heat transmission. The increase in water mass flow rate resulted in an improvement in the CHTC for both receiver types. At 0.2 kg/s and 0.05 kg/s, respectively, the Type-B receiver's maximum CHTC was 211.8 W/m²K and 133.6 W/m²K. At the corresponding mass flow rates, Type-A receivers have 165.9 W/m²K and 104.5 W/m²K, respectively. At 0.2 kg/s and 0.05 kg/s, respectively, the CHTC of the modified absorber tube is higher than the circular receiver.

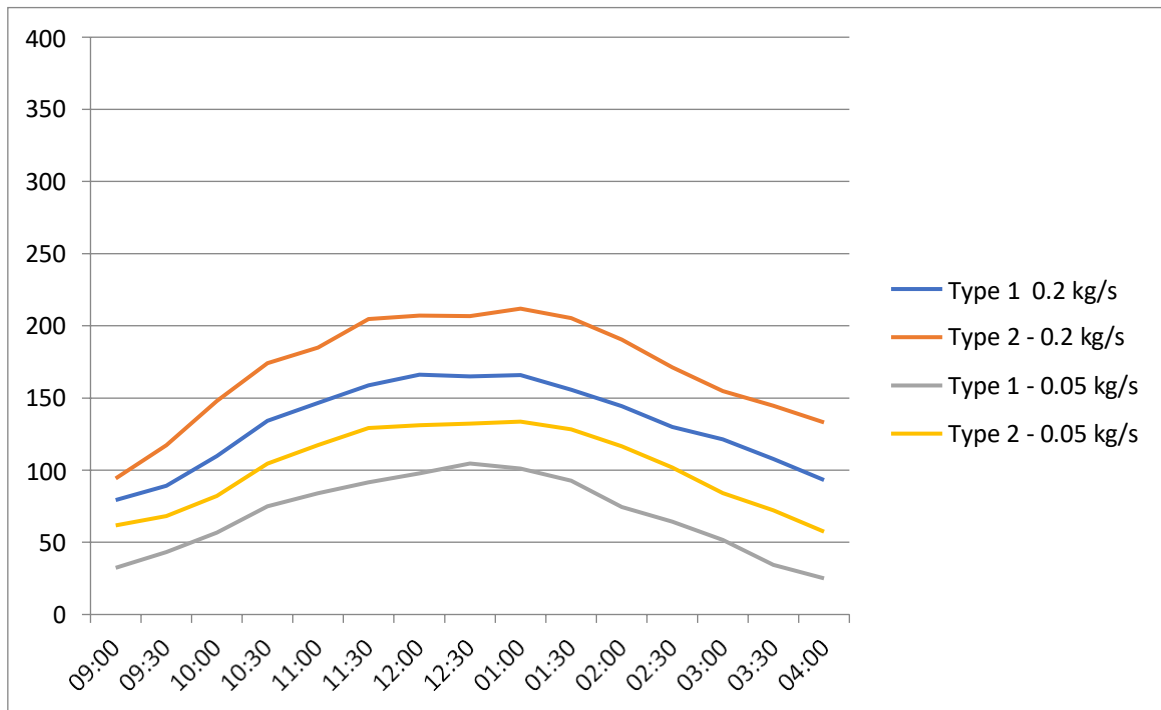


Figure 5.2.1. CHTC at different mass flowrates with respect to time with and without PCM for different flowrates

5.3. NUSSELT NUMBER

The Nusselt number is calculated for the whole day, based on CHTC at noon. Maximum Nusselt number values for Type-B are reached at two mass flow rates higher than Type-A. For Type-A and Type-B, respectively, maximum Nusselt numbers of 43.7 and 31.9 for Type-B and 39 and 24.6 for Type-A were observed at 0.2 kg/s and 0.05 kg/s. The Nusselt number's highest value shows that the internal CHTC to the HTF is enhanced as a result of PCM integration in the absorber tube. The rectangular receiver form gets more concentrated solar radiation at bottom side when compared to a circular receiver tube. The positioning of the copper tubes causes water to flow in the channel that is in touch with the receiver channel that is filled with PCM. The CHTC and Nusselt figures rise by a higher proportion because the redesigned receiver has a PCM for more time for heat exchange.

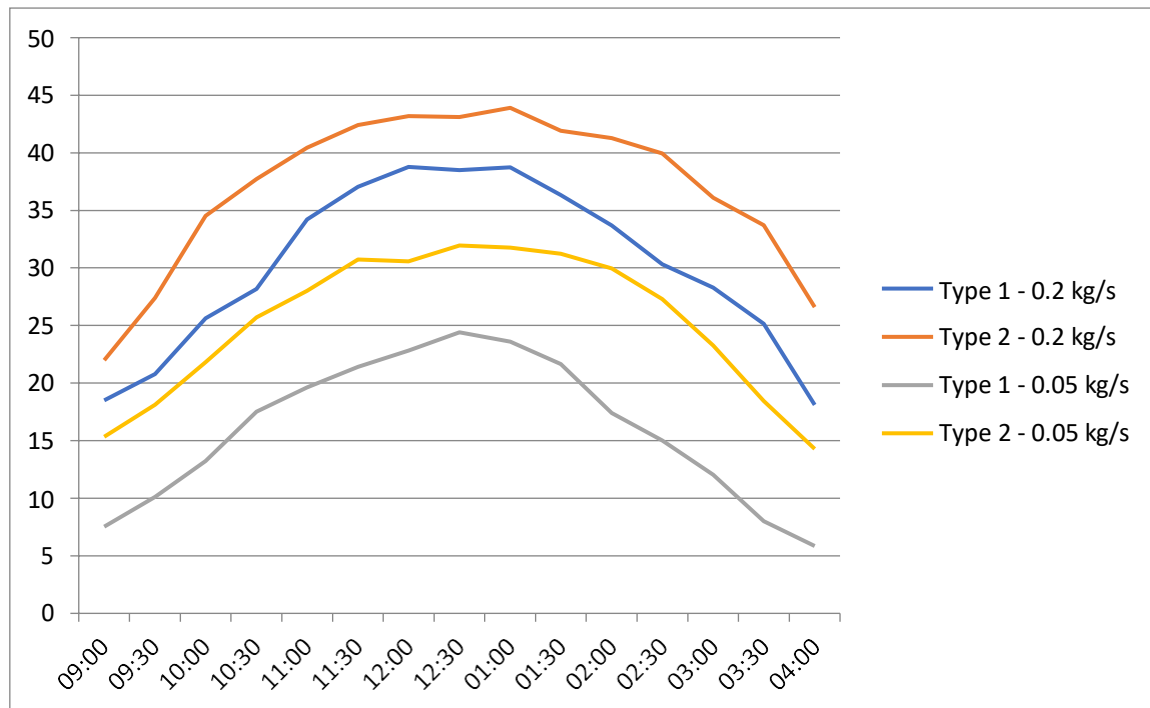


Figure 5.3.1 Nusselt Number at different flowrate with respect to time with and without PCM for different flowrates

5.4. THERMAL EFFICIENCY

The Type-B receiver consistently has a higher thermal efficiency than the Type-A receivers at both mass flow rates. Type-B receivers with PCM raise the temperature of HTF inside the receiver channel as it holds more heat. The improved heat transfer with PCM with the copper tubes in the rectangular channel resulted in higher thermal

efficiency of 72.9% at 0.2 kg/s flowrate, giving the rectangular channel receiver its maximum practical heat absorption. At the same mass flow rate, Type-A receiver's maximum thermal efficiency is 61.5%. The improved thermal efficiency was boosted by the higher mass flow rate of water because of its superior capacity to absorb usable heat. Compared to higher mass flow rates, thermal efficiency is reduced at lower mass flow rates. Type-B has the maximum thermal efficiency of 51.3% at mass flow rates of 0.05 kg/s, whereas Type-A has the thermal efficiency of 41.7% at the corresponding flow rates. At 0.05 kg/s and 0.2 kg/s, the thermal efficiency of Type-B receivers is greater than the thermal efficiency of Type-A receivers. When the mass flow rate of water is increased, more heat is absorbed by water from the receiver. Rapid water flow is the result of higher flow rate, the efficiency of the absorber tube is improved since bigger volumes of water absorbs more heat with less heat loss. Additionally, the PCM which is in rectangular receiver absorbs more heat which increases the amount of useable energy that water may absorb.

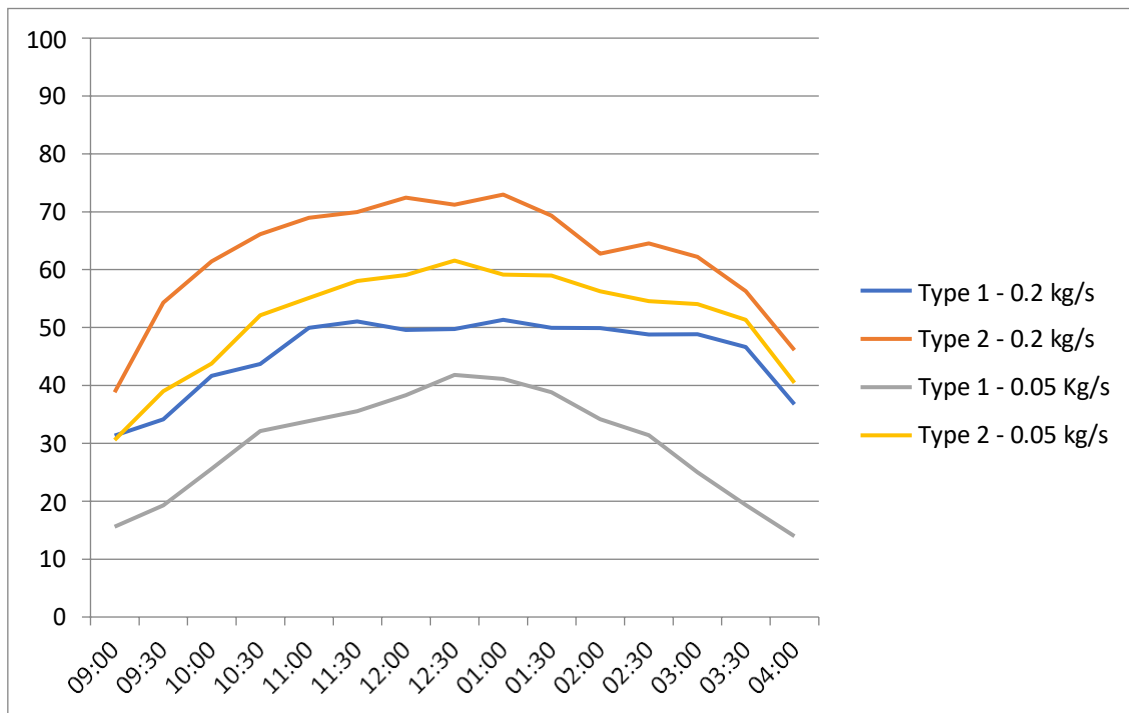


Figure 5.4.1. Thermal efficiency with and without PCM for different flowrates.

CHAPTER 6

SUMMARY AND CONCLUSION

When compared to the Type-B modified tube, which is consistent, we can see the inconsistency in the Type-A conventional tube. Although there is a slight difference in the average water outlet temperature between the two receiver tubes at different flowrates, the outlet temperature of the PCM-equipped receiver tube has consistently been higher than that of the conventional receiver tube. The modified receiver tube has higher heat transfer coefficient than standard receiver tube. Additionally, it has been noted that the flowrate of 0.2kg/s in the modified receiver tube has a higher CHTC than 0.05 kg/s. Thus, it follows that the CHTC and mass flowrate are directly proportional. The modified receiver tube has a better thermal efficiency than the standard tube. This application is not suitable during the cloudy/ rainy days.

REFERENCES

1. Abuşka, M., Şevik, S., & Kayapınar, A. (2019, 2). A comparative investigation of the effect of honeycomb core on the latent heat storage with PCM in solar air heater. *Applied Thermal Engineering*, 148, 684-693.
2. Allouhi, A., Ait Msaad, A., Benzakour Amine, M., Saidur, R., Mahdaoui, M., Kousksou, T., . . . Benbassou, A. (2018, 9). Optimization of melting and solidification processes of PCM: Application to integrated collector storage solar water heaters (ICSSWH). *Solar Energy*, 171, 562-570.
3. Bachchan, A., Nakshbandi, S., Nandan, G., Shukla, A., Dwivedi, G., & Singh, A. (2020). Productivity enhancement of solar still with phase change materials and water-absorbing material. *Materials Today: Proceedings*, 38, 438-443.
4. Bouhal, T., El Rhafiki, T., Kousksou, T., Jamil, A., & Zeraoui, Y. (2018, 10). PCM addition inside solar water heaters: Numerical comparative approach. *Journal of Energy Storage*, 19, 232-246.
5. Cabeza, L., Castell, A., Barreneche, C., De Gracia, A., & Fernández, A. (2011, 4). Materials used as PCM in thermal energy storage in buildings: A review. *Renewable and Sustainable Energy Reviews*, 15(3), 1675-1695.
6. Chaabane, M., Mhiri, H., & Bournot, P. (2014, 2). Thermal performance of an integrated collector storage solar water heater (ICSSWH) with phase change materials (PCM). *Energy Conversion and Management*, 78, 897-903.
7. Chen, K., Pu, W., Zhang, Q., Xing, X., Xiong, C., & Guo, M. (2021, 9). Thermodynamic and Economic Assessment on the Supercritical Compressed Carbon Dioxide Energy Storage System coupled with Solar Thermal Storage. *Journal of Energy Storage*, 41.
8. Cheng, W., Huo, Y., & Nian, Y. (2019, 4). Performance of solar still using shape-stabilized PCM: Experimental and theoretical investigation. *Desalination*, 455, 89-99.
9. Gautam, A., & Saini, R. (2020, 9). A review on sensible heat based packed bed solar thermal energy storage system for low temperature applications. *Solar Energy*, 207, 937-956.
10. Gautam, A., & Saini, R. (2020, 7). Experimental investigation of heat transfer and fluid flow behavior of packed bed solar thermal energy storage system having spheres as packing element with pores. *Solar Energy*, 204, 530-541.
11. He, M., Yang, L., Lin, W., Chen, J., Mao, X., & Ma, Z. (2019, 10). Preparation, thermal characterization and examination of phase change materials (PCMs) enhanced by carbon-based nanoparticles for solar thermal energy storage. *Journal of Energy Storage*, 25.
12. Iten, M., Liu, S., & Shukla, A. (2016, 8). A review on the air-PCM-TES application for free cooling and heating in the buildings. *Renewable and Sustainable Energy Reviews*, 61, 175-186.

13. Jahanpanah, M., Sadatinejad, S., Kasaeian, A., Jahangir, M., & Sarrafha, H. (2021, 2). Experimental investigation of the effects of low-temperature phase change material on single-slope solar still. *Desalination*, 499.
14. Javadi, F., Metselaar, H., & Ganesan, P. (2020, 8). Performance improvement of solar thermal systems integrated with phase change materials (PCM), a review. *Solar Energy*, 206, 330-352.
15. Kong, X., Wang, L., Li, H., Yuan, G., & Yao, C. (2020, 1). Experimental study on a novel hybrid system of active composite PCM wall and solar thermal system for clean heating supply in winter. *Solar Energy*, 195, 259-270.
16. Liu, M., Sun, Y., & Bruno, F. (2020, 6). A review of numerical modelling of high-temperature phase change material composites for solar thermal energy storage. *Journal of Energy Storage*, 29.
17. Mofijur, M., Mahlia, T., Silitonga, A., Ong, H., Silakhori, M., Hasan, M., . . . Ashrafur Rahman, S. (2019, 8). Phase change materials (PCM) for solar energy usages and storage: An overview. *Energies*, 12(16).
18. Mousa, H., Naser, J., Gujarathi, A., & Al-Sawafi, S. (2019, 12). Experimental study and analysis of solar still desalination using phase change materials. *Journal of Energy Storage*, 26.
19. Omara, A., Abuelnuor, A., Mohammed, H., & Khiadani, M. (2020, 2). Phase change materials (PCMs) for improving solar still productivity: a review. *Journal of Thermal Analysis and Calorimetry*, 139(3), 1585-1617.
20. Omara, A., Abuelnuor, A., Mohammed, H., Habibi, D., & Younis, O. (2020, 9). Improving solar cooker performance using phase change materials: A comprehensive review. *Solar Energy*, 207, 539-563.
21. Pomianowski, M., Heiselberg, P., & Zhang, Y. (2013). Review of thermal energy storage technologies based on PCM application in buildings. *Energy and Buildings*, 67, 56-69.
22. Raj, A., Srinivas, M., & Jayaraj, S. (2019, 1). A cost-effective method to improve the performance of solar air heaters using discrete macro-encapsulated PCM capsules for drying applications. *Applied Thermal Engineering*, 146, 910-920.
23. Rathore, P., & Shukla, S. (2019, 11). Potential of macroencapsulated pcm for thermal energy storage in buildings: A comprehensive review. *Construction and Building Materials*, 225, 723-744.
24. Raul, A., Jain, M., Gaikwad, S., & Saha, S. (2018, 10). Modelling and experimental study of