Design, Fabrication, And Thermal Analysis of Parabolic Trough Collector

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A thesis submitted to the National University of Sciences and Technology, Islamabad,

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Supervisor: Dr. Majid Ali

Co-Supervisor: Dr. Mariam Mehmood

US.Pakistan Center for Advance Studies in Energy (USPCAS-E)

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Islamabad, Pakistan

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No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the USPCASE in partial fulfillment of the requirements for the degree of Master of Science in the Field of Thermal Engineering Department of the National University of Sciences and Technology, Islamabad.

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PTC	Parabolic trough collector
CSP	Concentrated solar power
HTF	Heat transfer fluid
PTSC	Parabolic trough solar collector
ST	Solar time
L_{ST}	Standard meridian of a local zone time
L_{OC}	Longitude of a location
E	The equation of time
n	Day of the year
D_o	Mean Earth-sun distance
I_o	Solar constant
I	Extraterrestrial radiation
I_b	Beam radiation
I_{bn}	Beam radiation in direction of rays
I_d	Diffuse radiation
R_r	Mirror radius
f	The parabola focal length
W_a	Parabola aperture
C	Geometric concentration ratio of the tubular absorber
DNI	Direct Normal Irradiance

ABSTRACT

Fossil fuels are the primary source of energy worldwide, which account for about 75% of all greenhouse gas emissions. Such dependence on non-renewable energy sources is a key reason for global warming. In addressing environmental issues, support of eco-friendly, economical, and sustainable energy alternatives is important. Pakistan has a significant potential for solar energy due to its geographical location which provide abundant sunlight throughout the year. Parabolic Trough Collectors are distinguished among the several technologies for utilizing solar energy by virtue of their greenness. The Parabolic Trough Collectors as solar thermal technology, produce energy without greenhouse gases emission and, therefore, the Parabolic Trough Collectors are a zero-emission solution. This research paper aims to conduct a detailed analysis of a Parabolic Trough Collector system that was fabricated and tested in the extreme climatic area of Islamabad, Pakistan. The humidity and heat of the location enable a specially designed investigation to verify the accuracy and performance of the Parabolic Trough Collectors. A series of detailed experiments were conducted. These parameters were tested in different climate conditions to investigate the performance of the system. The maximum surface temperature reached on the receiver was 83. 3°C, while the maximum outlet temperature at the receiver was 52. 6°C. The peak heat gain of the system was achieved at 1104. 3J and had a thermal efficiency of 66%. In addition, the maximum exergy efficiency achieved was 38% indicating the capabilities of the solar Parabolic Trough Collectors system to efficiently utilize solar energy. Therefore, the results of this study show how solar Parabolic Trough Collectors systems using readily available resources may serve as an added sustainable source of energy in Pakistan and regions that are with a similar climate. The thermal and exergy efficiencies which are improving (66% and 38%), this clearly highlights that the Solar parabolic trough collector system is the most effective in the capture of the sun rays that is why it is green energy technology that is to be employed in the future.

Keywords: Solar parabolic trough collector, green technology, thermal efficiency, Heat transfer, self-sustainable system

CHAPTER 1: INTRODUCTION

Energy demand is rising due to the world's population's rapid growth as well as urbanization, industrialization, and rising living standards. Primary sources of energy are fossil fuel which contribute to about 75% of Global greenhouse gas emission which is the main source of climate change[1]. The global energy landscape is undergoing a profound transformation as the world pivots toward a net-zero carbon future. The Paris Agreement, a landmark international accord adopted in 2016, set ambitious goals to limit global warming to below 2°C, ideally no more than 1.5°C above pre-industrial levels, through substantial cuts in greenhouse gas emissions which reached 55 billion tons in 2022[2]. The undeniable impact of greenhouse gas emissions on the climate has catalyzed coordinated global efforts across academia, industry, politics, and policymaking to promote renewable energy technologies.

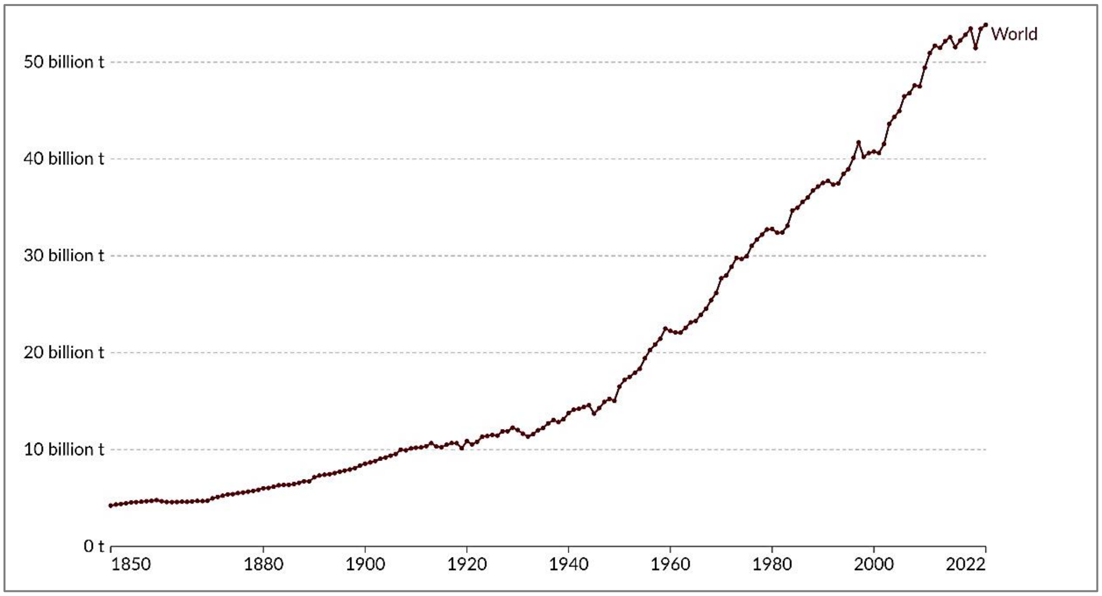

Figure 1.1: Global greenhouse gas emissions [3] .

The graph shows the trajectory of greenhouse gas emissions worldwide over the last several years, emphasizing the upward trend that emphasizes the significance of switching toward more green energy sources such as Solar, wind and hydro energy.

1.1 Pakistan’s Energy Mix & Solar Potential

Pakistan is facing a significant energy crisis for a long time due to their dependency on traditional energy sources. Traditional and non-renewable energy sources are diminishing and are inadequate to meet the energy demand. The ministry of energy report that the thermal system which include oil, coal and gas remains the dominant source of power generation in Pakistan accounting for 59.42 % of total. This is followed by hydropower energy, nuclear energy and renewable energy contributing to 30.52 %,7.82 % and 2.23 % respectively[4].The country energy mix is show in Figure 1.2.

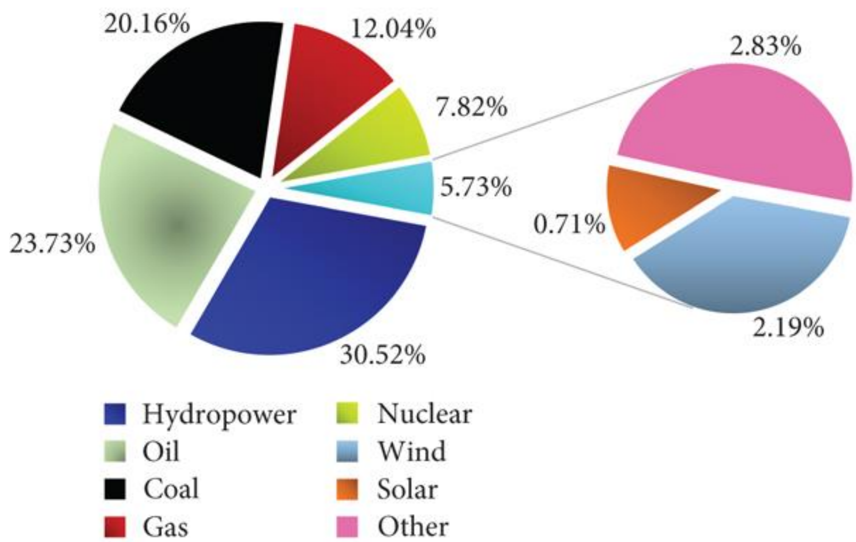

Figure 1.2: Pakistan energy mix [5]

Pakistan’s solar potential presents an opportunity to address its energy crisis. Pakistan is still in the early stages of renewable energy development. The country enjoys approximately 300 days of sunshine annually, with an average of 7-8 hours of sunlight per day, Pakistan has tremendous potential to Solar energy. The average Solar direct horizontal Irradiation (DHI) in Pakistan is 2071 KWh/m^2. In Baluchistan, Punjab, and Sindh, the average DHI values are 2319, 2156, and 2333 KWh/m^2 respectively, while KPK, Northern, and Azad Kashmir possess comparatively low solar irradiation [6].Overall DNI of the country is shown in Figure 1.3

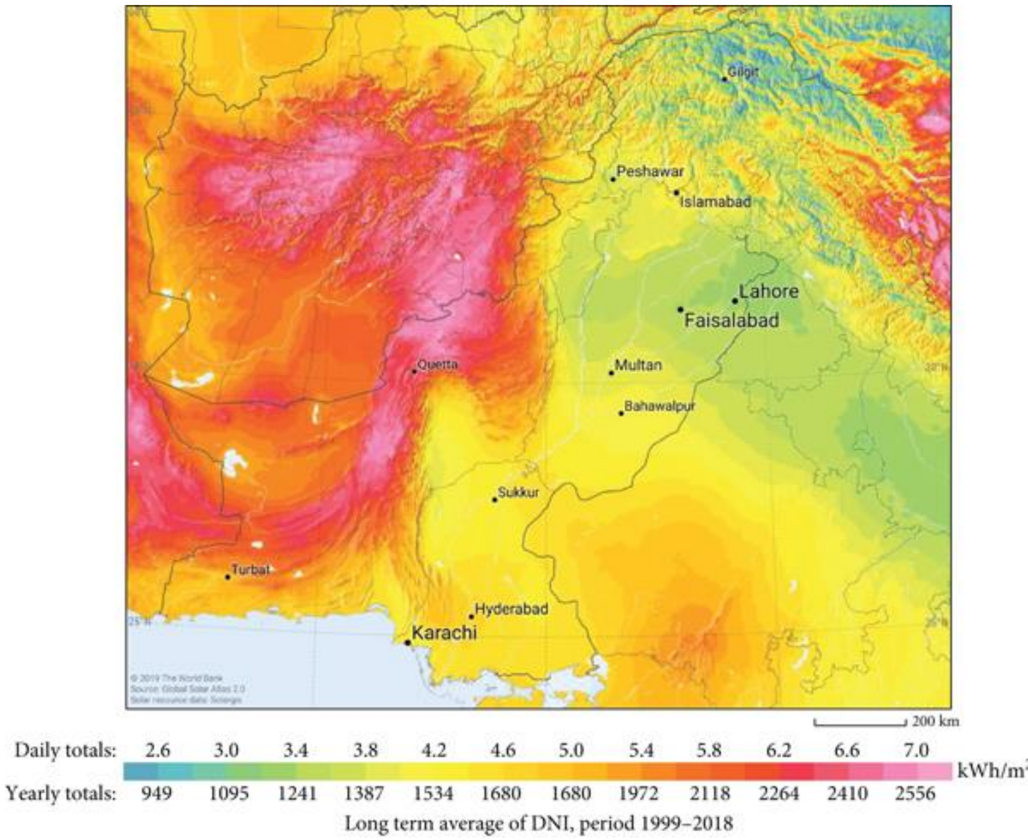

Figure 1.3: Pakistan DNI map [7]

1.2 Solar Energy Technologies

Solar energy stands as a clean and renewable energy source, accessible worldwide. There are two primary sources to harness solar energy: solar photovoltaic systems and Concentrated solar thermal systems.

1.2.1 Solar Photovoltaic System

PV system directly convert solar energy into electricity using solar panel made up of semiconductor material. Solar PV can be installed on rooftops or in large solar forms to generate electricity for residential, industrial, and commercial uses.

1.2.2 *Concentrated Solar Thermal Technology*

Solar Thermal Technology or CSP collect and concentrate sun radiation to generate electricity or to provide heating or cooling for industrial and buildings. There are several types of Solar Thermal Technology are shown in Figure 1.4

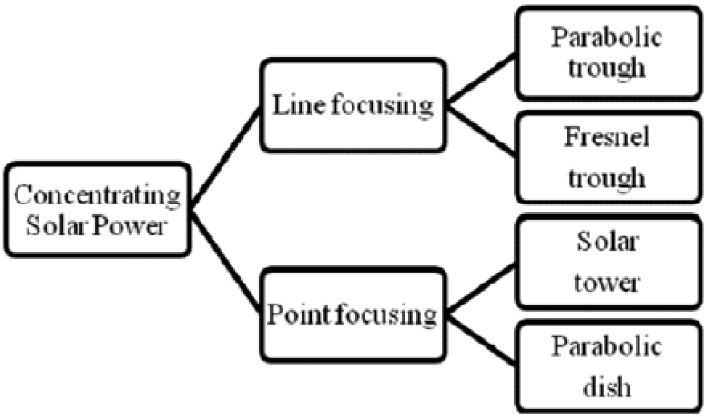

Figure 1.4: Types of CSP [8]

Among all these types of CSP, Parabolic trough collector is widely used and established. The temperature of the focal line or absorber tube of PTC can be as high as 350–400 °C which makes them suitable for residential as well as industrial thermal energy requirements. PTCs are also versatile and can be easily integrated with thermal storage systems, enabling continuous power generation even when sunlight is not available. Additionally, their modular design allows for scalability, making them suitable for a wide range of applications, from small-scale heating systems to large power plants.

1.2.2.1 Line Focus Solar Collector

Linear concentration is a CSP technology that involves concentrating solar energy on a line using parabolic or Fresnel troughs. The collectors are positioned in a North-South direction, and a straightforward adjustment perpendicular to the East-West direction realigns the concentrated image of the sun onto the receiving tube situated at the concentrator's focal point. The concentration level varies from 60 to 400, depending on the season and time of day.

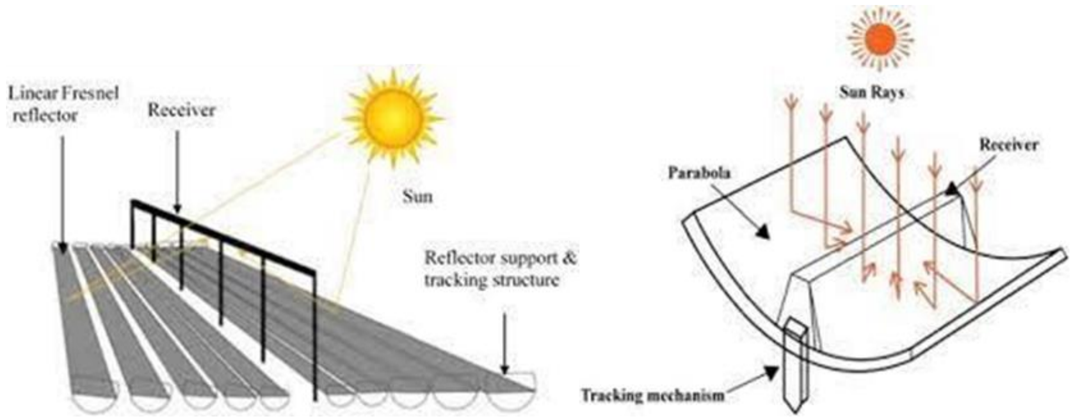

Figure 1.5: Line focusing CSP Technology [9]

The cost of producing glass in a parabolic shape for parabolic trough collectors is a significant factor in the overall cost of the technology. To lower costs, research groups are developing prototypes of Fresnel linear focusing collectors. These collectors approximate the parabolic shape using a series of plane mirrors, sacrificing some focusing ability of the parabolic trough. The parabolic shape is approximated by flat mirrors that are adjusted based on the sun's position. A secondary set of fixed mirrors redirects the sunlight toward the receiving tube. This focusing technique is simpler, easier to construct, and more cost-efficient than the traditional parabolic method.

1.2.2.2 Point Focus Solar Collector

Point focusing is a form of Concentrating Solar Power (CSP) technology that is utilized to concentrate solar energy onto a single point, producing high temperatures that are suitable for generating electricity. It is typically employed for high-temperature applications. Solar power tower technology utilizes a group of sun-tracking mirrors, known as heliostats, to concentrate sunlight onto a central receiver positioned at the top of a tall tower. The receiver then transforms the concentrated solar radiation into thermal energy, which can be utilized to generate electricity. One of the key benefits of solar power towers is their capacity to produce electricity on a larger scale than other CSP technologies, making them an appealing choice for utility-scale power generation.

Figure 1.6:100 MW Concentrated Solar Power Tower project, China [10].

Parabolic dish systems focus sunlight onto a receiver situated at the focal point of a parabolic dish-shaped reflector. The concentrated solar radiation is transformed into thermal energy by the receiver and used to generate electricity. While these systems usually have lower power generation capacities than solar power towers, they are very effective in remote locations. Still, their modular design is useful because it makes the building and maintenance processes easier.

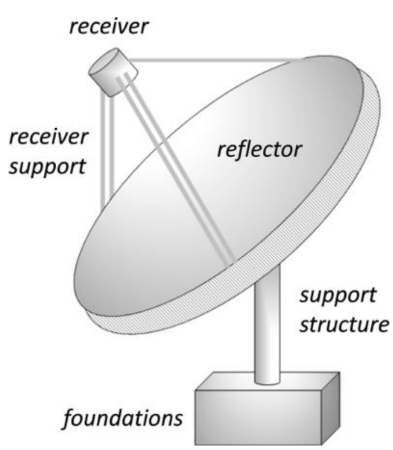

Figure 1.7: Solar Dish System [11]

1.2.2.3 Parabolic Trough Collector

The selection of a solar collector is based on the radiation ratio that reaches the receiving area relative to the total incident radiation. Mirrors or lenses that reflect or refract sunlight from a larger collection area onto a smaller receiver area can be used to concentrate solar radiation. The ratio between the collection area and the receiver area is represented by the dimensionless geometric factor known as the concentration factor. It is more than 1 for concentrating technologies and it is essential for figuring out how efficient solar concentration is. Numerous materials, each with pros and cons of their own, can be used to build solar collectors.

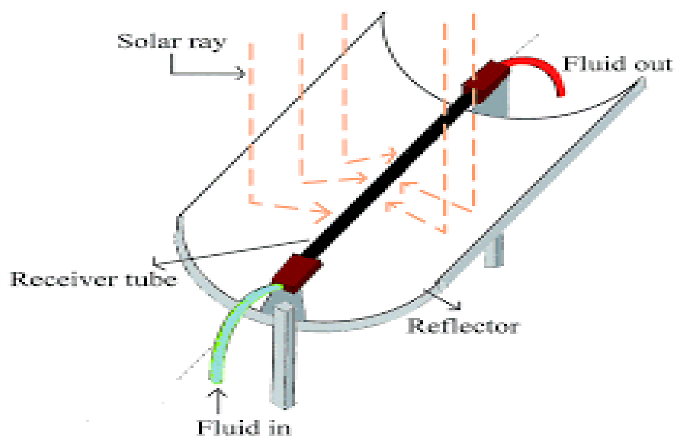

Figure 1.8: Parabolic Trough Collector [12]

The key to the system uses the receiver. The main role is to absorb the solar thermal radiation successfully and convey the energy to the Heat Transfer Fluid (HTF). The material composition of receiving devices largely depends on the usage type. One is metal mostly used for solar heating and solar glass for solar disinfection. Among these parts, the pipe, the cover glass, and the solar-selective coating (SSC) are the main construction elements when designing a receiver in heating applications. The primary function of pane glass is to prevent fractured pipes and minimize heat escape. To increase the absorption of solar heat flux, the outer surface of the pipe is coated with solar selective coatings or SC. In evacuated receivers, heat losses are minimized by creating a vacuum in the annular space between the glass and the tube, and vacuum losses are avoided by sealing the receiver. Bellows enable the pipe and glass cover to expand thermally without compromising the vacuum in the annulus. Hydrogen getters are employed to adsorb any residual hydrogen that may form because of the thermal degradation of the HTF. The glass-to-metal seal helps alleviate mechanical stresses caused by variations in thermal expansion.

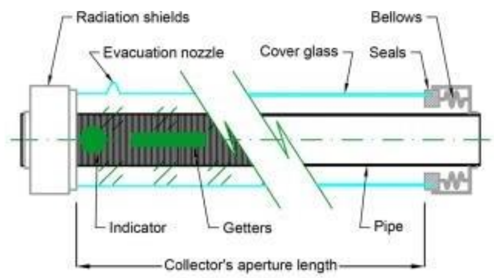

Figure 1.9: Receiver for heating applications[13]

Stainless steel is widely favored as the material for pipe receivers due to its excellent corrosion resistance, low thermal expansion, and high thermal conductivity. However, its low thermal conductivity can result in some heat loss. The cover glass should possess high transmittance, low reflectance, and a low refractive index to allow the maximum amount of incident radiation, reflected from the mirrors, to pass through. Non-evacuated receivers are typically utilized in small-aperture collectors and prototypes.

1.2.2.4 Evacuated Tube Collector

Evacuated receiver tubes are designed for high-temperature applications and can withstand high operating temperatures without degradation. They are composed of a steel pipe, a glass cover, and an absorber coating. The steel pipe is coated with an absorber material that converts solar radiation into heat, while the glass cover prevents heat loss and protects the absorber coating from degradation. A vacuum is created between the glass cover and the steel pipe to minimize heat loss due to conduction and convection.

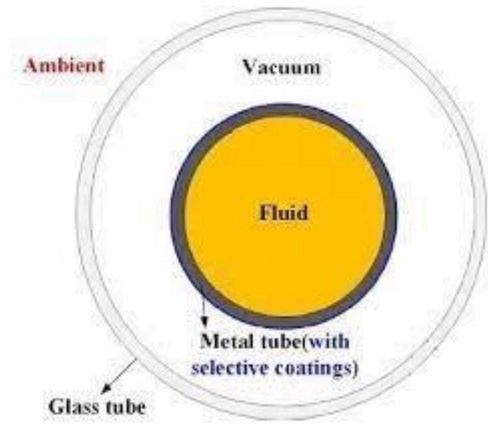

Figure 1.10: Evacuated Receiver Tubes [14]

1.2.2.5 Non-Evacuated Tube Receiver

Receivers with non-evacuated tubes are designed for low temperature uses where resistance to high temperatures is not necessary. They don't go through evacuation and are usually made of materials like copper, aluminium, or plastic. Compared to evacuated receiver tubes, their design is more straightforward and consists of a metal pipe coated with an absorber.

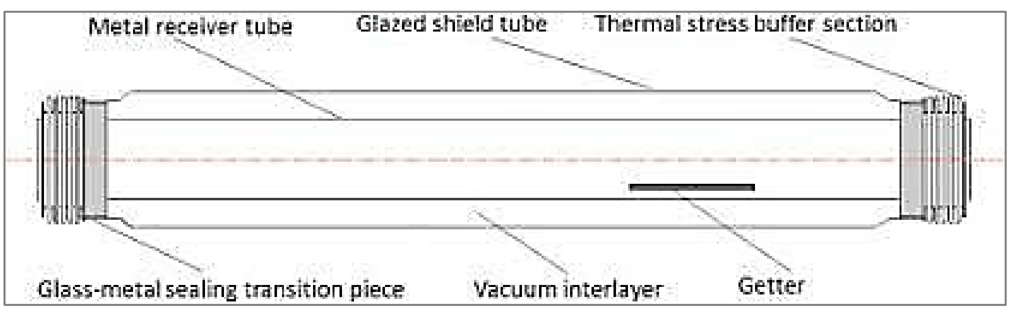

Figure 1.11:Non-Evacuated Receiver Tubes[15]

1.3 Heat Transfer Fluid

HTF (Hexagonal Close Packing) is one of the most important for most heat transfer systems. Its ability to absorb heat from a receiver to transform process energy is its main function. Good thermal conductivity and high specific heat, slight viscosity coefficient, low thermal expansion, corrosion resistance, little toxicity, and thermal and chemical stability over the entire temperature range of operation are all special requirements of HTF.

As far as HTFs' capacity to transfer heat is concerned, they have superior heat transfer properties, so liquids are the most used HTFs. For the academic staff to narrow down to the most suitable HTF for the specific use mentioned, a literature review on this topic must be comprehensively conducted to review the various groups of HTF and their associated properties. The growing trends in HTF technology for the enhancement of heat transfer effectiveness and system capability are also crucial to be included in the relevant paper.

A heat transfer medium (HTM) is employed in parabolic trough solar collectors for the collection of solar radiation and its subsequent transportation of the heat to some heat storage and power-generating devices. Much of the parabolic trough system's overall efficiency and cost of the HTF plant is directly affected or dependent on the HTF. Because of their excellent thermodynamic stability, which enables them to operate up to 400°C, the recommended HTFs for parabolic trough systems include Thermion VP-1, Dowtherm A, and Syltherm XLT. The salts that have dissolved and mostly are the combinations of Solar Salt which is a mixture of potassium nitrate and sodium nitrate, have been gaining heat transfer mediums (HTFs) 'fame' of late. Liquid salts as thermal energy carriers, can store them from 565 to 1000°C [16].

By using water in parabolic trough systems, the HTF is in solution, and therefore, thermal stress can be reduced as a vacuum has to be maintained at the low pressures that water cannot withstand. As water is reserved mostly for low-conditioned and direct steam generation, the net amount is not always high.

Because of its renewability nature and environmentally friendly characteristics, vegetable oil is now there in the heat transfer applications that were used for synthetic fluids earlier. Instead of being toxic and resistant to temperature, and also this compound is eco-friendly, and it is biodegradable are the reasons for its increase in popularity.

Oils extracted from all kinds of vegetables like soybean, palm, rapeseed, and sunflower will act very well as blending agents in the hydrogenated paraffin wax. Firstly, being capable of functioning at a temperature of 350°C and having high flash points, sunflower, and rapeseed oils fit the bill when explosive applications are required. Another example is the different oil displays in low-temperature applications – Soybean and Palm usually being the oils chosen because they have a very low flash point.

Being compared with petroleum, vegetable oil offers a significant useful substitution since it is a renewable and sustainable energy source. On the contrary, the renewability of plant-based oils owing to the regeneration of the resources they come from is a plus that restrains this possibility of exhaustion in a certain time perspective. Additionally, vegetable oils are environmentally kinder as they emit smaller quantities of carbon into the atmosphere, as compared to conventional ones.

However, as HTFs, vegetable oils have certain disadvantages. Long-term use of these oils can lead to oxidative degradation, and their higher viscosity than synthetic oils can affect performance. Further research is necessary to improve the performance of vegetable oils as HTFs, and novel technologies should be investigated to overcome these constraints.

Table 1.1: Comparison of various HTF [17]

HTF	Working Temperature(ºC)	General Properties	Advantages	Disadvantages
Water	Up to 100	• Odorless • Relative low viscosity • non-toxic	-Non environment risks (pollution or fire) -Low operational pressures Simple plant design	-Only for low enthalpy applications -Requires water treatment
Glycol	50-300	High heat transfer properties (with combined with water), low viscosity, toxic (depending on the preparation)	-Anti-freezing properties (with the proper concentration)	-Environmental risks and degradation -Used only in low enthalpy applications (when mixed with water)
Pressurized air and other gases (CO_2, He, Ne, N_2)	Up to 900	Low cost because of its abundance from atmosphere, low viscosity, low energy density, need to dehumidify(air)	-Higher steam temperature -Thermal storage enhancement -Non environment risks -Nontoxic & chemical inert -Minimum corrosion	-Poor heat transfer in receiver -More complex solar field control -Higher operational pressures
Super Critical CO2	-	A super critical gas works as a signal phase liquid with filling properties of gas, higher temperature operation, abundant	-Gas with Liquid like properties -Higher thermal performance when compared sub critical CO_2	-Challenging Operation (leakage, pressure, etc.) -Thermal fatigue of pipes -Corrosion -Under investigation
Synthetic Oil	90-400	High thermal capacity, low flow properties (compared with water), flammable, toxic	-Higher thermal efficiencies are achieved (compared with others) -Relatively low operational Pressures	-Requires fire protection system -Environmental risk (Toxicity) -Heat exchanges required (for power generation)

In conclusion, vegetable oils appear to have potential as HTF substitutes for conventional synthetic oils. The application and temperature requirements determine which vegetable oil is best. Adopting vegetable oils as HTFs may help the industry move toward a more ecologically friendly and sustainable future.

Table 1.2: Comparison of various HTF (OIL) [18]

Oil Type	Flash Point	Thermal Conductivity	Biodegrade-ability	Cost-per Liter	Specific Heat Capacity
	(Tf)	(W/mm)			(j/gk)
Mineral Oil	100-170	0.11-0.16	Slow to degrade	Rs. 1600	1.6-2.0
Synthetic Oil	300-310	0.15	Very slow to degrade	Rs. 6000	1.5
Vegetable Oil	275-328	0.16-0.17	Readily Biodegradable	Rs. 500	1.2-2.1

1.4 Support Structure

A solar collector system's stability and performance are greatly influenced by its supporting structure. It oversees stabilizing the system and giving the collector parts a sense of security. Usually constructed from sturdy materials like steel or aluminum, the structure is designed to withstand loads and stress from the environment.

Three essential components make up the structural supporting framework of a PTC: the receiver brackets, the frame, and the main support. The collector's primary anchor, the main support, guarantees the collector's stability and correct placement. Given that the collector's aperture is frequently exposed to the wind, this component needs to be able to withstand the wind loads that the collector experiences.

The supporting structure's frame element is essential in boosting the mirrors' rigidity and guaranteeing that they always retain their parabolic shape. Preventing misalignments that may lower performance is essential. In addition, the frame bears the responsibility of transmitting the torque produced by the tracking system, an essential function that keeps the collector oriented optimally toward the sun.

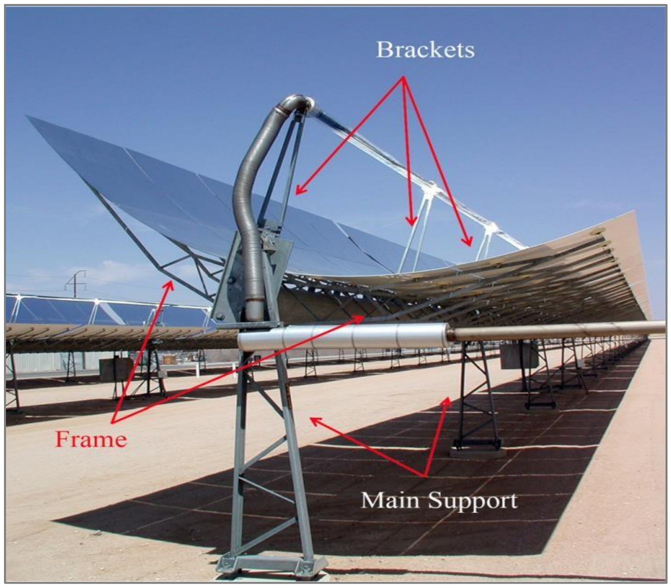

Figure 1.12: Structural division of a PTC [19]

The receiver is fastened along the parabola's focal line by the brackets that are fastened to the mirror support. Usually, an insulator is positioned between the receiver and the bracket to minimize heat loss. The preservation of the parabolic mirror shape and precise placement of the receiver relies heavily on the design and construction of the supporting structure framework. Any misalignment can lead to significant reductions in efficiency, emphasizing how important it is to carefully evaluate the framework's mechanical properties during production. Important factors to consider during the design stage are bending and torsion caused by the weight of the framework and wind forces. The longevity and ideal performance of the solar collector system are ensured by a structurally solid framework.

1.5 Tracking System

In terms of enhancing the common efficiency of solar collectors utilizing direct beam radiation such as PTCs, solar tracking systems are mandatory. They do so by traditional tracking, performing one-axis rotation for maximum efficiency. Solar trackers come in two varieties: active and dynamic. The actual ones draw the signals from electronic conversion while the latter ones use the thermosiphon effect to straighten the collector. Because of the tendency to be deflected by wind forces, these systems show low efficiency for big PTC installations; consequently, such passive tracking systems are not preferred. There are two types of tracking systems of PTC.

1.5.1 Single Axis Tracking Systems

PV-tracking systems mostly utilize single-axis tracking systems, which are the simplest of such systems. Such systems are capable of repeatedly rotating mirrors around a single horizontal axis, and this axis is usually turned between east and west. It is unfolded that by doing this the mirrors can best reflect sunlight onto the receiver tube since following the path of the sun as it moves across the sky from east to west.

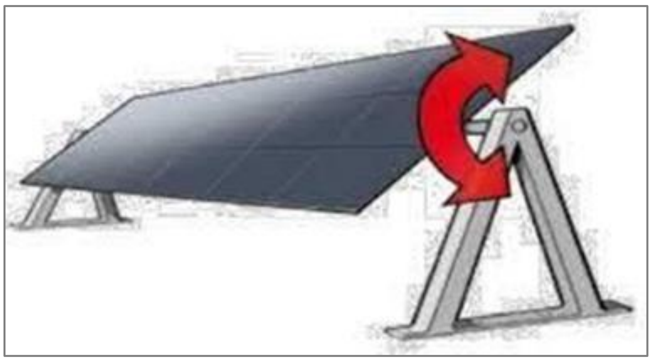

Figure 1.13: Single axis tracking systems [20]

1.5.2 Dual Axis tracking systems

Mirrors can rotate around both horizontal and vertical axes with more complex two-axis tracking systems. The mirrors' ability to track the sun's movements in both horizontal and vertical directions across the sky improves the amount of sunlight reflected onto the receiver tube. Two-axis tracking systems can attain higher efficiency than single-axis systems, but they are more expensive and require more maintenance.

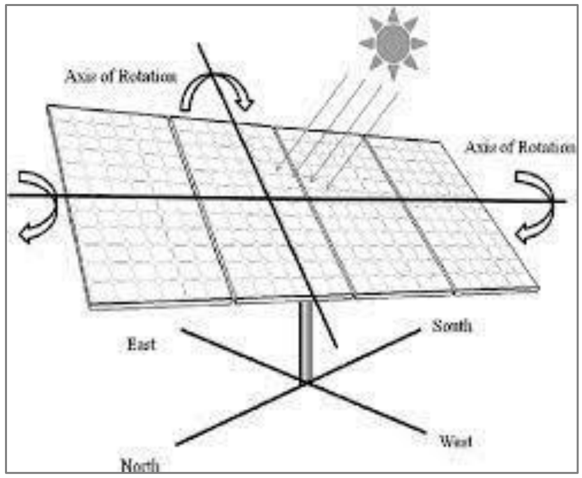

Figure 1.14: Two-axis tracking systems [21]

1.5.3 Seasonal Tracking system

Seasonal tracking systems are designed to improve PTC performance all year long. They allow the mirrors to adjust their angle of inclination to match the changing position of the sun throughout the year. This can significantly improve the performance of PTCs in regions with a large variation in the angle of the sun during different seasons.

1.6 Background

A method for utilizing solar energy for thermal purposes is the PTC. Although parabolic mirrors have been used to concentrate sunlight for heating purposes since the 19th century, major developments in solar energy technology were made during the energy crisis of the 1970s, which sparked a renewed interest in the field[22]. The present PTC was created because of engineers and researchers looking into ways to improve the efficiency and affordability of solar thermal systems.

The basic design of a PTC consists of a mirror with a parabolic shape that reflects and focuses sunlight onto a receiver tube placed at the mirror's focal line. An HTF that is inside the tube of a collector or a solar concentrator that absorbs solar radiation to increase the temperature of HTF [23]. Subsequently, this hot fluid is either used directly for heating or is converted into electricity by having a heat exchanger and a steam turbine.

The capacity of PTCs to generate heat at high temperatures is what makes them the most suitable for applications that produce high heat like industrial processes or power generation. This key advantage is the one that sets them apart from others. One of the reasons PTCs could be economically attractive for the power industry is their simple integration into existing power plants. Thus, they become the most affordable means of improving the sustainability and efficiency of current traditional power production systems. Besides, PTCs are also scalable and modular so that different-sized solar fields can be created to cater to a variety of applications.

The objectives of research and development over the years have been to enhance the PTC's efficiency, lifetime, and affordability. Improvements in materials, production procedures, and control systems have led to a great increase in performance and reliability of these systems and made them a perfect choice for using solar energy in thermal applications.

1.7 Motivation

The need for developing Solar PTCs is driven from the demand for sustainable and autonomous thermal energy solutions across various sectors. Industries need hot steam for dryers, heaters, furnaces, and distillation processes. Power generators rely on condensed or gaseous steam, typically driven by fossil and costly non-renewable like diesel, furnace oil, heavy fuel oil, coal, and natural gas. These traditional sources have huge environmental impacts and are expensive. Therefore, the effect is that we should consider making a shift towards more affordable and clean energy sources. The objective of this regulating the size of a family come from the restriction of one child and both mother and father's relationships towards this news change with these results.

The PTC proposes a feasible and durable solution to these matters. It chooses renewable energy sources, the solar energy mainly. Solar energy heating involves the use of solar-powered technologies and heat to warm buildings, rather than burning fossil fuels, gas, or electricity. This approach reduces energy bills, lowers environmental impact, and elevates safety. Moreover, solar panels do not require much maintenance to serve for years.

1.8 Problem statement

The usage of traditional sources, which are fossil fuels (coal, oil, and natural gas), in domestic thermal (heating and cooking) applications leads to several serious development issues. These resources are finite and non-renewable, engendering concerns for the future of energy security and the availability of these resources. Moreover, the burning of fossil fuels gives out greenhouse gases and individual pollutants which accelerate environmental destruction and climate change. The digging out, transporting, and processing of fossil fuels also cause great deals of harsh impacts on the environment, i.e., habitat loss, water pollution, and air quality decline. Moreover, the price of fossil fuels is subject to uncertainty in the market run by political factors which could result in fluctuation in the prices of energy and thus economic instability. The switch to more renewable and sustainable heat sources can help civilizations in tackling the problem. It shows a way of a clean and safe energy future.

The purpose of the research, therefore, is to build a PTC which operates on self-sufficiency. This solution aims to make it possible to get a reliable and sustainable source that, at the same time, solves the issues related to the traditional approaches. Such a project may turn out to be successful but still shows the necessity for thermal energy in certain industries to reduce the negative effect on the environment.

1.9 Objectives

Following are the objectives of my research work.

- To design and fabricate a Parabolic Trough Collector System for sustainable energy utilization.
- To study and develop a thermal model for the fabricated Parabolic Trough Collector.
- To perform a thermal analysis of the fabricated Parabolic Trough Collector to evaluate its performance across different operating conditions.

1.10 Summary

The current chapter has presented the global trend on renewable energy generation, which has been inspired by the ambitious climate goals to combat global warming. Concentrated Solar Power has been identified as an effective clean and reliable energy type that can substantially support global warming targets with its generation of on-demand energy. Given the context of Pakistan, the chapter has addressed the urgent necessity to shift the energy matrix due to the regular blackouts and increased demand. Additionally, the chapter presented the past evolution of the source, its status, and several technologies, parabolic trough collectors, and CSP systems in general, to demonstrate its capacity to support the global energy agenda.

CHAPTER 2: LITERATURE REVIEW

Several research studies have recommended different methods to enhance the effectiveness of solar technologies. One prominent approach involves implementing hybrid system setups to increase efficiency and minimize electricity costs. These studies encompass a wide range of areas, including design, modeling, simulation, energy assessment, techno-economic analysis, experimental investigation, review of traditional stove and geyser systems, hybrid configurations, and the development of control strategies aimed at optimizing system parameters.

2.1 Exploring Concentrated Solar Power (CSP) Technology

Wang Fuqiang et al explore the theoretical framework and practical applications of CSP technology using PTC systems. It includes the derivation of maximum concentration ratios, various options for heat transfer fluids, methods to enhance heat transfer, and strategies to mitigate thermal deformation in tube receivers. Additionally, it provides an overview of commercial CSP plants utilizing PTC systems, highlighting their cost-effectiveness and ease of integration with other energy sources, and suggests future research directions and application guidance[24].

2.2 Transient Simulation Model for Industrial Water Heating with PTC

Saad D. Odeh presents a transient simulation model for assessing industrial water heating systems using PTC. It addresses the issue of temperature fluctuation during unsteady radiation conditions, emphasizing the importance of thermal storage tank size and water flow rate adjustment. Conclusions imply that an area of 14.5 liters of collection tank per square meter is sufficient to prevent turbulence and that, while changing the water flow length twice will breathe normality back into the system, the recovery of normal conditions in the intensity of radiation will take 1.5 times more time under instability conditions. [25].

2.3 Modeling Approaches for Parabolic Trough Solar Collectors (PTSCs)

The many types of applications of solar-thermal energy transformations are illustrated in the speech by Anubhav Goel, in which the usage of Parabolic Trough Solar Collectors (PTSCs) to generate electric power is also pointed out. Model-based techniques are a vital evaluation approach to PTSC's performance due to their high capital and complex infrastructure needs. In this chapter, current modeling approaches for Parabolic Trough Solar Collectors (PTSCs), which involve statistical and uniform models, were summarized. It involves the trend key ones like tracking schemes, mirror coatings, and heat liquids (HTF). Besides that, it gives critical information about the area by tracing the Parabolic Trough Solar Collectors (PTSCs) progress from inception to maturity as well as offering analysis of its potential application scenarios through modeling-based studies.[26].

2.4 Large-Scale Utilization of Parabolic Trough Collectors (PTCs) for Solar Thermal Energy Generation

The new research focusing on the large-scale usage of PTCs to generate solar thermal energy is presented by the author Bhargav H. Upadhyay. The selection of Heat Transfer Fluid (HTF), receiver, reflector, storage, and thermal systems are discussed in detail, with an emphasis on their optimum performance and applied use. PTCs are solar thermal technology with a widely known name indicated in the review and literature description covering all of its advantages, uses, and meanings [27].

2.5 Performance Assessment of a Developed PTC System

To highlight the performance of the previously developed PTC system based on the TRNSYS simulation model, by Panayiotis Ktistis, a scenario regarding a soft drink manufacturing factory will be provided. The outcome has brought to light a very strong relationship between power generation and operational factors; hence the average percent accurate estimation of daily steam production is 6.32 %. The study introduces a novel product by making available a one-stop choice tool that enables industries to select the Parabolic Trough Collector (PTC) systems that are the most suitable for their respective need for thermal energy and targeted steam temperatures. The payback period estimations are a useful source and vary from 2 to 6 years [28].

2.6 Energy Production and Efficiency Analysis of a Prototype PTC System with Evacuated and Non-evacuated Receivers

K.S. Reddy studies the energy production of an intermediate temperature process for the application of a PTC (prototype parabolic trough collector) system. The system consists of both an evacuated receiver (ER) and a non-evacuated one. (WER) To help measure the optic and the assimilation coefficient of the PTC system based on the ASHRAE under its environment, the tests were conducted at IIT Madras in Chennai, India. Over 72% of the optimal surface efficiencies were calculated using the ER cavity and 68% by utilizing the NER enhancement. Besides, at various mass flow rate settings, the optimum thermal efficiencies can reach to 64% and 66% respectively for the NER and ER. Efficiency, thermal, and instantaneous about the environment including weather as well as the temperatures of the heat transfer fluid at the system's inlet and outlet was also measured.[29].

2.7 Enhancing Parabolic Trough Solar Collector (PTSC) Efficiency through Nanofluids and Magnetic Fields

Even though solar energy is a free and unlimited source, its conversion into electrical power is quite complicated. A possible solution emerging as a result of the Parabolic Trough Solar Collectors (PTSCs) is that they enable the generation of heat and electricity as they run. At the present day the main objectives of such research are to finalize the best-desired solution using nanofluids and also adding the effectiveness of magnetic fields, and end up improving PTSC efficiency to the maximum in terms of structure as well as material. Therefore, this study gives pictorial descriptions of PTSCs, heat transfer formulas, and a numerical example solved by Mohammad Malekan with ANSYS FLUENT software [30].

Kai Zhao proposed A new approach to improve the thermal efficiency of PTCs, which includes applying several solar selective-absorbing coatings (SSCs) in various parts of the collector loop. Two systems were examined: an ideal system with optimal SSCs and a multi-section system with practical SSC materials. The findings indicated a 29.3% decrease in heat loss and a 4.3% improvement in thermal efficiency, indicating a cost-effective utilization of solar energy[31].

2.8 Development of a Test Method for Verifying Optical and Thermal Properties of Large PTCs

The test method developed by Loreto Valenzuela is on the outside to verify the optical and thermal properties of the large PTCs, the main applicants of solar power electric power plants. Technologies used in optical performance are described by max efficiency and longitudinal range that is adjustable, and these are measured at the tepid ambient conditions. Thermal loss performance is analyzed at different solar field operation temperatures in the solar field full spectrum range. Insulation ensures that absorber pipes that can be exposed to high solar radiation intensity are sustained at the ambient temperature of the heat transfer fluid. The test process defines a set of performance characteristics that are critical for the evaluation of the collection systems.[32].

2.9 Energy and Exergy Analysis of a DSG Solar Thermal Power Plant Design

Execution of an energy and exergy analysis was demonstrated on a design idea of a DSG (direct steam generation) solar thermal power plant (STPP) by M.K. Gupta. The condenser and solar collector field proved to be the component source of maximum energy loss, while the solar collector field was the most power-losing supply, analyzing the data. The research work involved means to increase the plant efficacy that includes FWH count, bleed pressure, and the mass fraction of bleed steam designs which enhances the receiver temperature entering the steam cycle. As the trial indicates, the efficiency could improve greatly by considering multiple FWHs and adding more than one FWH could lead us to even greater gains [33].

2.10 Design and Evaluation of Small-Scale Solar PTC for Water Heating in Developing Countries

The concept presented by Muhammad Faheem et al specified the creation, design, construction, and assessment of a small-scale solar parabolic trough collector to heat water in developing countries. The collector plan was made up of a laser red light and stainless-steel ruler template, then optimized through a MATLAB simulation. Experimental evaluation has indicated that efficiency effectiveness is achieved when the collector is aligned in an East-West direction as opposed to a North-South direction (61.66% versus 48.28%), with 5 hours needed to heat 100 liters of water to 60º C which is suitable for domestic use in appliances where electricity and fossil fuels are limited.[34].

2.11 Comparative Study of Compound Parabolic Collectors with Fixed and Variable Concentration Ratios for Intermediate Temperature Applications

Hamza Riaz compares the optical and thermal performance of compound parabolic collectors (CPC) with fixed and variable concentration ratios for an intermediate temperature range of 50–300 °C. Using a model-based transient simulation approach, two CPC profiles were analyzed for subtropical climate conditions. The analysis, conducted in MATLAB for design and TracePro for optical assessment, showed that the CPC with a variable concentration ratio (4.5 to 5.7) outperformed the fixed ratio (4), with optical efficiencies of 79% and 72% respectively. Thermal analysis in ANSYS indicated higher maximum temperatures achieved with the variable concentration ratio profile (367 K) compared to the fixed ratio profile (352 K), demonstrating the superior performance of the variable concentration ratio design[35].

2.12 Design and Fabrication of Small-Scale CSP Plant Using Linear Parabolic Trough Collectors

Ahmed Ullah focuses on designing and fabricating a small-scale concentrated solar power (CSP) plant using linear parabolic trough collectors, known for their high efficiency. The research aims to identify the most suitable thermal fluid for optimal heat transfer. Detailed energy balance schemes and modeling for various thermal fluids were conducted, with the fabricated system used to verify and compare theoretical results, offering insights for designing linear parabolic troughs in both small and large-scale applications[36].

2.13 Review of Design Parameters, Mathematical Techniques, and Applications of Parabolic Trough Solar Systems

A.Z. Hafez et al review design parameters, mathematical techniques, simulations, and applications of parabolic trough solar systems. It discusses recent studies on their deployment globally, operational plants, software, and test methods developed since 1981. Mathematical models for the design, analysis, testing, and validation of solar parabolic trough systems are explored, with optical efficiency values nearing 63% and theoretical peak optical efficiency reaching 75%[37].

2.14 Low-Cost PTC Prototype UNIVPM.01 for Industrial Process Heat Applications

Gianluca Coccia presents a low-cost parabolic trough collector (PTC) prototype, UNIVPM.01, designed for industrial process heat applications from 70 to 250 °C. The PTC features a 90° rim angle, a small concentration ratio of 9.25, and is constructed using fiberglass and extruded polystyrene for cost-effectiveness, lightweight, high mechanical resistance, and ease of manufacture. The prototype's thermal efficiency was evaluated using a test bench following ASHRAE Standard 93-2010, achieving comparable results to similar collectors with an intercept of 0.658 and a slope of -0.683[38].

2.15 Enhancing Thermal and Optical Efficiencies of PTC for Concentrated Solar Power Systems

Nabeel Abed reviews strategies to enhance thermal and optical efficiencies of parabolic trough collectors (PTCs) for concentrated solar power systems. It compares recent and past technologies, discussing single and two-phase flow modeling, design variables, and experimental processes. The study addresses four main technologies for enhancing PTC thermal performance: changing heat transfer fluids, using nanofluids, employing tabulators, and combining nanofluids with swirl generators. Future research suggestions include novel PTC designs and passive heat transfer enhancement techniques[39].

2.16 Summary

This Chapter focuses on research on solar technologies, especially regarding PTC, focuses on increasing efficiency and to lower cost through hybrid systems. These studies explore practical applications, transient simulations and theoretical frameworks for water heating, industrial process heat and PTC modelling techniques. These efforts focus on enhancing heat transfer, mitigate thermal deformation and optimizing system parameters. Research also focuses on potential of PTCs to generate electricity, also offers insight into design, optimization strategies and construction for best performance in different applications such as industrial process and small-scale heating systems in developed countries.

CHAPTER 3: METHODOLOGY

3.1 Design Considerations

After conducting the literature review to identify existing research and knowledge on solar parabolic trough collector systems, several steps were taken before the design was finalized:

3.1.1 Site Assessment

Conducting a site assessment to evaluate the location of the property, including the orientation, shading, and available space for installing the solar water heating system. For this purpose, a prototype was developed which includes a parabola reflector made from a GI sheet. Several experiments were carried out which identified any necessary upgrades or modifications.

3.1.2 Experimental Setup

Determining the design parameters for the PTC, including the size of the collector, the capacity of the storage tank, and the type of heat transfer fluid to be used. This involved the use of Parabola calculator tools to model the PTC:

i. *Parabola Calculator:* This software calculates the focal point of a parabola using the sheet dimensions and input prompts provided by the user.

After considering the above factors, the following design was finalized:

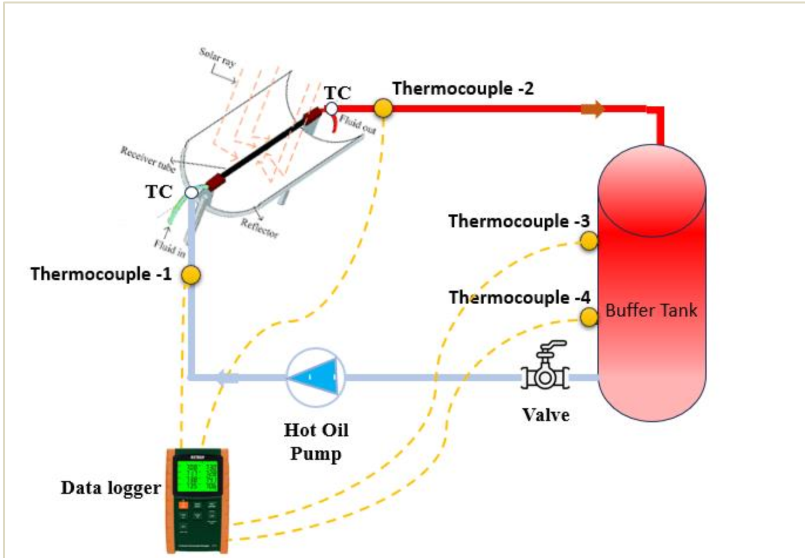

Figure 3.1: Systematic Diagram of the system

3.2 Components

3.2.1 Parabolic Trough Collector

In this system, we opted for a parabolic trough collector as our solar collector. We chose the parabolic trough collector over the flat plate collector for the following reasons:

- Parabolic trough collectors have a higher efficiency than flat plate collectors because they concentrate sunlight onto a smaller area, which results in a higher temperature of the heat transfer fluid. This means that parabolic trough collectors can provide more heat for a given area of collection.
- Parabolic trough collector is more effective in capturing sunlight even under the cloudy or dusty atmosphere through which the sunlight filters. This gap can be filled by the mirrors which are designed to do a different thing such that they can reflect light from the more distant sources of the sun and thereby concentrate on the light rather than destabilizing it.
- The installation of parabolic trough collectors within a confined space can be easier than that of flat plate collectors because these collectors can be made in a smaller area. When this functionality is essential, it may be for apartment or home heating functions where the area is insufficient.

- Paraboloid solar collectors are made of materials that have better properties of abrasion and heat resistance compared to flat plate collectors, so they are in most cases more reliable.

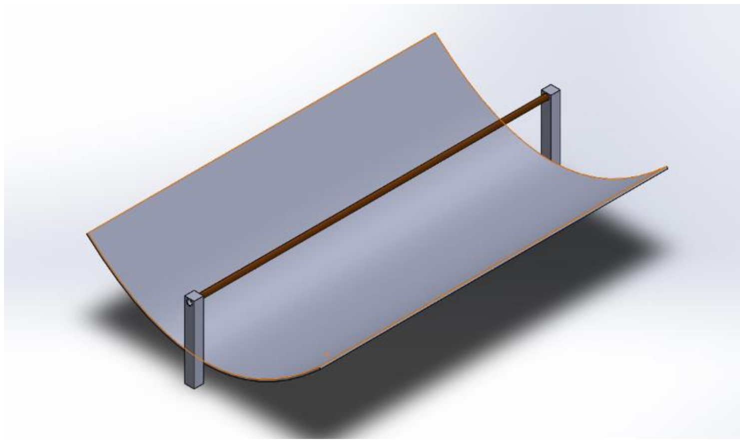

Figure 3.2: SOLIDWORKS Model Of PTC

Because of its advantages over alternative materials, galvanized steel was used to construct the parabolic trough collector:

- While in the case of outdoor purposes, such as parabolic trough collectors, they experience exposure to moisture and sunlight, galvanized steel becomes particularly useful, thanks to its great corrosion resistance. This mode of operation, therefore, eliminates the need for constant repairs or replacement to these galvanized steel collectors and can go for a series of long years.
- For its strength and durability, galvanized steel can cope with high temperature, and mechanical stress and therefore is a good choice for utilization on parabolic trough collectors. The baskets must be able to withstand the burden of the structure, therefore, supportable substances are needed for these collectors.
- With its relatively low cost, galvanized steel, as opposed to more expensive metals like aluminum or stainless steel, is a much better alternative from the point of view of financial feasibility for manufacturers of parabolic trough collectors.
- There is a greater reason why galvanized steel is considered one of the most preferred material choices that artists choose. This is because it is very easy and convenient to get one once you have the intention to do so.

- Waste and environmental footprint of parabolic trough collectors, which are made of highly reusable galvanized steel, are decreased when they are recycled in the future.

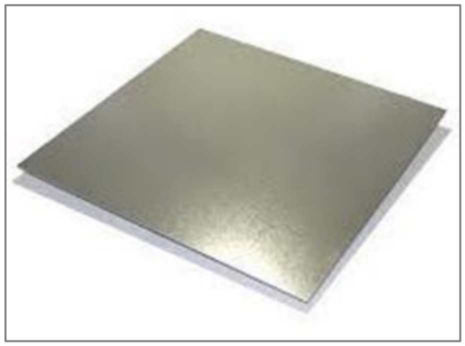

Figure 3.3: GI Sheet

Table 3.1: Parameter of Parabolic trough collector

Parameters	Value (m)
PTC length (L_s)	1.828
PTC width (W_s)	1.22
Height of the Solar PTC(H_s)	0.28
Reflectivity of PTC	0.85
Aperture Area of the PTC(A_a)	2.2
Focal length of the PTC(f)	0.33
Focal to Diameter Ratio (f/W_s Ratio)	0.27
Rim angle of the dish	85.55
Receiver length (L_r)	1.98
Receiver outer Dia	.03
Receiver inner Dia	.025
Concentration ratio	13.8

3.2.2 Receiver tube

For home solar water heating, the copper bare tube receiver was preferred over other varieties. The tube was one inch in diameter and six feet long. With the help of wooden side frames, it was fitted into the parabolic trough to create the arrangement that is seen below:

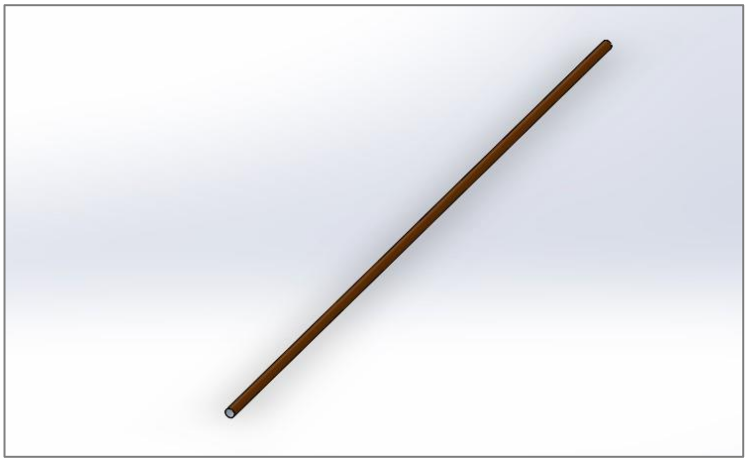

Figure 3.4: Bare Tube Receiver

The following factors were considered when choosing a bare tube receiver over an evacuated tube:

1. **High Efficiency**: The fact that the high absorption of bare tube receivers makes water heating more efficient proves the efficiency of this tool. Use our AI to write for you about ecotourism. Unlike the other types of receivers, which can only produce hot water at a slow rate, an evacuated-tube collector can radiate heat faster and better.
2. **Low Cost:** While attending to the issue of receiver types, the bare tube receivers are the benchmark as far as price and evacuated tubes or flat plates are concerned. It is also important in the preference of residential solar water heating systems for its low price. A price is often a key factor, especially when money is an important factor.
3. **Easy Maintenance**: Since bare tube receivers do not have intricate vacuum or insulation devices, they are not strenuous in terms of maintenance. As it has few parts, it eliminates the expensive maintenance costs and the chances of breakdowns caused by complex repairs.

4. **Durability:** Unlike bare tube receivers, bare stand receivers are less susceptible to environmental elements due to hailstorms, and are known to be strong and durable. Due to their dependability, they can supply a constant supply of hot water for years and years without much maintenance.

3.2.3 Support Structure

The main purpose of the supporting structure is to provide rigidity and stability for the entire system by stabilizing the collector's parts. It should also be able to tolerate shocks and wind tension forces, particularly in areas where strong winds are common. Steel was the material of choice for the support's construction.

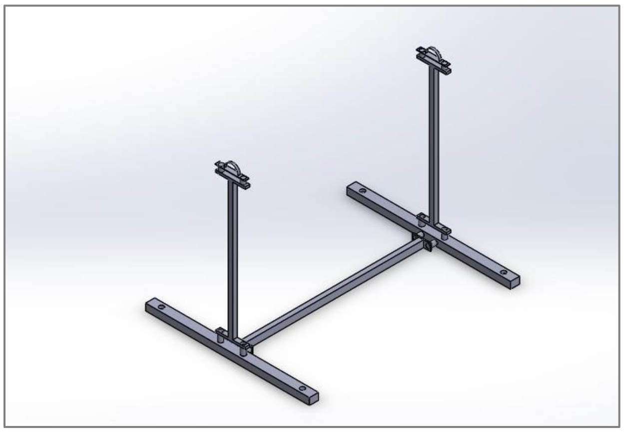

Figure 3.5: SOLIDWORKS Model of Support Structure for PTC

3.3 Working fluid

The Heat transfer fluid used in these experiments is Sunflower oil. This Heat transfer fluid is selected due to its good thermal conductivity and due to its applications, such as thermal reliability in the range of medium temperature applications. The Density of HTF is 930.62 kg/m^3 and the specific heat of HTF is 2115 J/kg*K. We have chosen Sunflower oil as the preferred working fluid for our system due to the following reasons:

- Canola oil is biodegradable, which means it can be easily disposed of without causing harm to the environment. This could be an advantage for some domestic applications where environmental considerations are a concern.
- The flash point temperature of Sunflower oil is above the operating temperature of our working fluid, which is greater than 300 degrees Celsius.
- Sunflower oil is non-toxic and safe for human consumption, which makes it a preferred option over other types of working fluids that may be toxic or harmful to humans.
- Sunflower oil is widely available and relatively inexpensive, making it an attractive option for use as a working fluid in solar thermal systems.
- Some types of vegetable oil have a lower freezing point than other oils, which means they can remain in a liquid state even at low temperatures. This could be an advantage for solar thermal systems located in colder climates.
- Sunflower oil has good heat transfer properties, which means it can efficiently transfer heat from the solar collectors to the heat exchanger or storage tank.

3.6 Hot Oil Pump

The specifications of the Motor which is used to circulate the hot oil pump from buffer to parabolic trough collector is given below.

Table 3.2: Specification of Hot Oil Pump

Parameters	Value
Volt	220/230
Ampere	5
Phase	Single
R.P.M	1450
H. P	1
cycles	50

3.7 Thermal Modeling of PTC

The given equations can be used to assess the PTC's thermal performance. The temperature of the HTF rises because of the absorption of solar radiation, producing usable energy (Qu).

The following formula provides the useful energy gain as shown in eq 1[40]

$$Q_u = \dot{m} c_P (T_{out} - T_{in}) \tag{1}$$

In the above equation $\dot{m}$ is mass flow rate of HTF, Cp is specific heat of HTF, T_{out} is outlet Temperature and T_{in} is inlet temperature of HTF.

Total absorbed energy is calculated by eq **2**[41]**:**

$$Q_s = I_a A_a \tag{2}$$

Where I_a is Solar irradiance and A_a is aperture area

The thermal Efficiency of PTC can be expressed using the equation 3[42]

$$\eta_{th} = \frac{Qu}{A_a I_a} \tag{3}$$

Where Q_u is total useful energy gain, A_a is area of aperture and I_a is solar irradiance.

The Exergy Efficiency of PTC is determined by eq 4[43]

$$\eta_{e_x} = \frac{E_{x_u}}{E_{x_s}} \tag{4}$$

Where E_{xu} is the exergy flow of solar irradiation and E_{xs} is instantaneous useful energy flow.

Where the instantaneous useful energy flow of PTC is determined using eq 5[44]

$$E_{x_s} = Q_s\left[1 - \frac{4}{3}\left(\frac{Ta}{Ts}\right) + \frac{1}{3}\left(\frac{T_a}{Ts}\right)^4\right] \quad (5)$$

Where T_a is Ambient Temperature, T_s is Sun Temperature and Q_s useful energy gain.

Moreover, the exergy flow of the solar irradiation is expressed by eq **6**[45]

$$E_{x_u} = \dot{m}C_P(T_{out} - T_{in}) - \dot{m}C_pT_{am}\ln\frac{T_{0ut}}{T_{in}} \quad (6)$$

Where Tam and Ts are ambient and sun temperature respectively. In eq (11), Ts is sun apparent temperature which is mentioned by Richard Petela taken as 6000K [46]

3.8 Summary

This chapter focuses on the design of solar PTC which includes site assessment, determining design parameters and selecting materials. Due to low cost and resistance to corrosion GI sheet was selected as a collector. This system includes a PTC, Sunflower Oil as a Heat Transfer Fluid, Copper Tube Receiver, and a Support Structure. The system performance was analyzed using a thermal modelling equation which includes thermal and exergy efficiency. The system was designed for low heating scale aiming for high durability and efficiency.

CHAPTER 4: RESULTS AND DISCUSSIONS

Experiments were carried out during 26 and 28 September and 4,5 and 11 October 2023 at the US-Pakistan Center for Advanced Studies in Energy, located at National University of Science and Technology, Islamabad, Pakistan (33°38'32.5" N, 72°59'03.6" E).

The main points of the experiment are as follows:

- The experiment was a day long from 9 AM to 5 PM.
- Thermocouples were attached to the inlets and outlets of both the hot fluid and water.
- This assessment is conducted at a specified mass flow rate of 0.09 kg/s.
- Real-time data logging was used to record temperature readings after each 45 min interval.
- The parabola was manually rotated throughout the experiment to provide maximum exposure to sunlight.

4.1 Testing Conditions

From the data available to us by the weather stations, the direct normal irradiance of Islamabad during the cloudy months of SEP and OCT, in which setup will face the least favorable conditions, was extracted.

Table 4.1: Average DNI and Ambient Temperature of Testing Days

Date	**DNI (W/m^2)**	**Ambient Température(ºC)**
26SEP2023	590.29	30.24
28SEP2023	373.90	28..30
04OCT2023	617.84	31.09
05OCT2023	671.01	30.86
11OCT2023	643.70	28.18

The average solar irradiance and ambient temperature of each day on which experiment is done are show in table 4.1. Figure 4.1 shows the irradiance and ambient temperature for all days of experimental days.

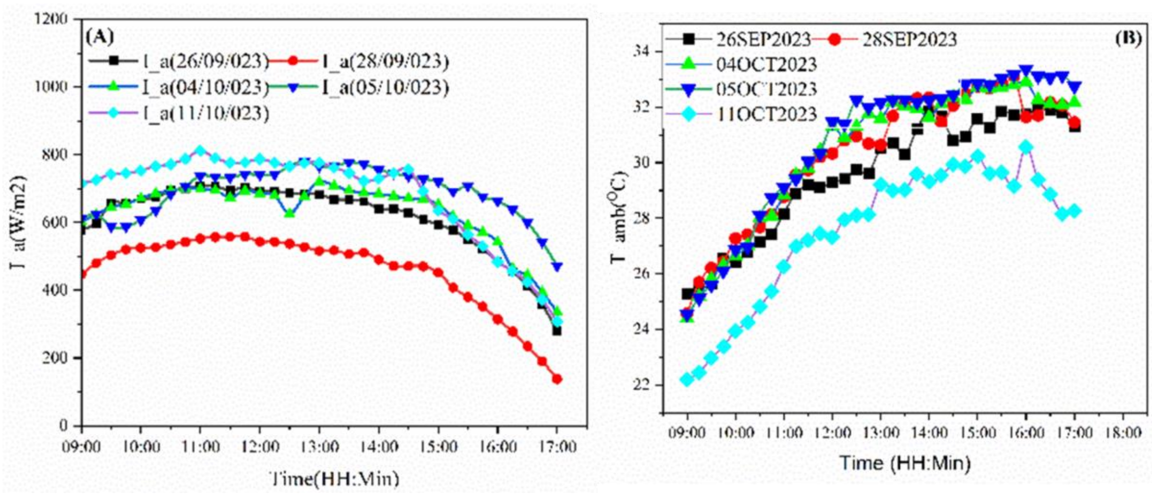

Figure 4.1: (A) Solar Irradiance (B) Ambient Temperature

4.2 HTF Inlet and Outlet Temperature of Receiver

The temperatures of the HTF at the inlet and outlet are influenced by both solar irradiance and ambient temperature.

Figure 4.2 illustrates the variation of the HTF inlet and outlet temperatures from the receiver over time. The outlet temperature of the HTF depends on both solar irradiance and ambient temperature, rising with higher levels of both factors. The figure above depicts the peak outlet temperature from the receiver, recorded at 52.6 degrees Celsius at 1:15 pm on October 5, 2023. This occurred on a day with an average ambient temperature of 30.86 degrees Celsius and an average solar irradiance of 671.01, marking the highest values observed throughout all experimental days.

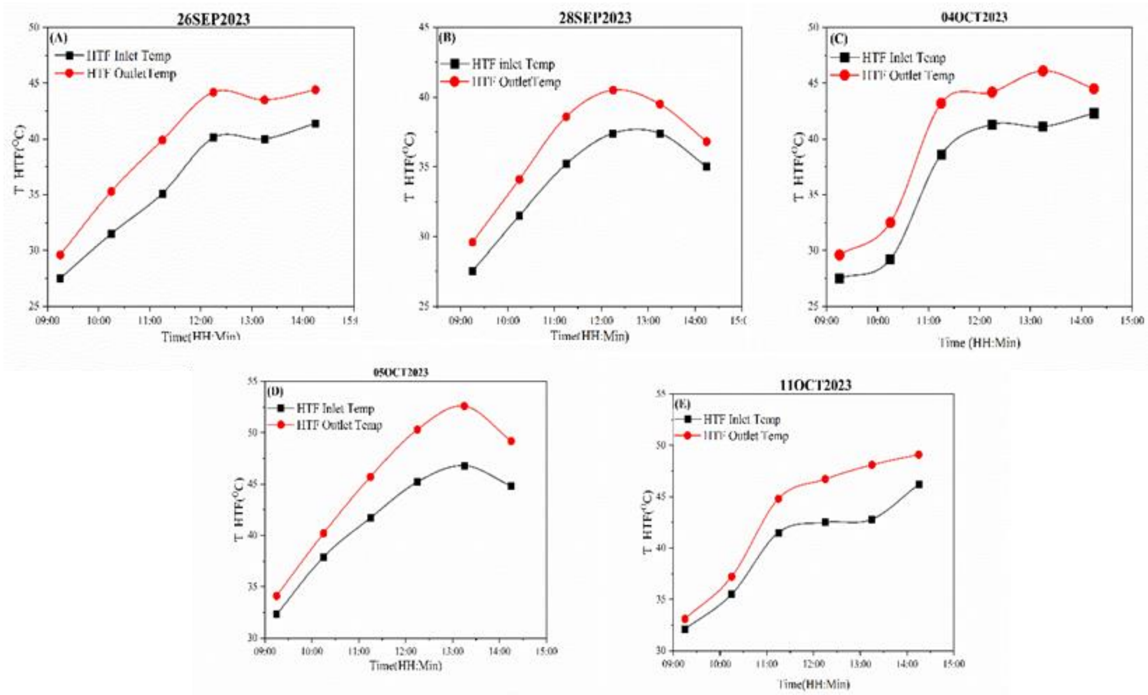

Figure 4.2: Temperature profiles of HTF inlet and outlet in a parabolic trough collector on (A) 26 Sep, (B) 28 Sep, (C) 4 Oct, and (D) 5 Oct 2023 (E) 11 October

4.3 Effect of Solar Irradiance on Thermal efficiency and heat gain

The assessment of PTC performance depends on the utilization of equations 7 and 9, which consider measurements of Irradiance, as well as the inlet and outlet temperatures of the HTF within the receiver. The useful energy gain increases or decreases with solar irradiance variation as it depends on solar irradiance that's why follows its variation. Figure 4.3 the variations in thermal efficiency and heat gain over several testing days concerning time and irradiance. The figures reveal that both thermal efficiency and heat gain exhibit an increasing trend as time progresses. However, a noticeable decline is observed predominantly after 02:00 pm, attributed to the reduction in solar irradiance. The highest recorded heat gain and thermal efficiency stand at 1104.3 joules and 66 percent, respectively, occurring on October 5, 2023, at 1:15 pm. Conversely, the lowest values for heat gain and thermal efficiency, recorded as 190.35 joules and 12 percent, respectively, are noted on October 11, 2023, at 09:15 am

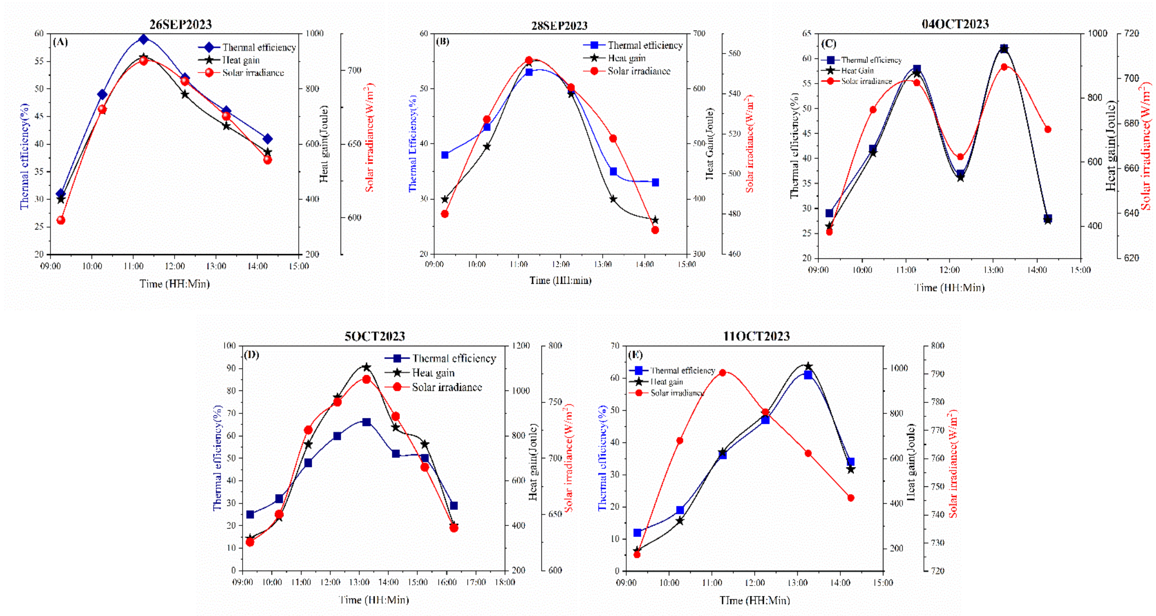

Figure 4.3: Variations in thermal efficiency, heat gain, and solar irradiance in a parabolic trough collector system over five different days in September and October 2023. The data is presented for (A) 26 September, (B) 28 September, (C) 4 October, (D) 5 October, and (E) 11 October

4.4 Exergy efficiency

Under varying solar intensities, the system's exergy efficiency shows an upward trend with an increase in the HTF inlet temperature. As inlet temperatures drop, energetic efficiency will eventually approach zero. This is because there are very few boundaries for work output at those stages due to the operating temperatures being close to ambient conditions.

The depicted Figure 4.4 indicates that exergy efficiency rises with an increase in the inlet temperature and decreases with a reduction in irradiance. The above figures illustrate the peak exergy efficiency, reaching 38 percent at 2:15 pm on 11-10-2023, with an inlet temperature of 46.2 degrees Celsius and an average solar irradiance of 653.50 W/m2. Conversely, the lowest recorded exergy efficiency is 10 percent at 9:15 am on 28-09-2023, characterized by an inlet temperature of 25.69 degrees Celsius and an average solar irradiance of 313.90 W/m^2.

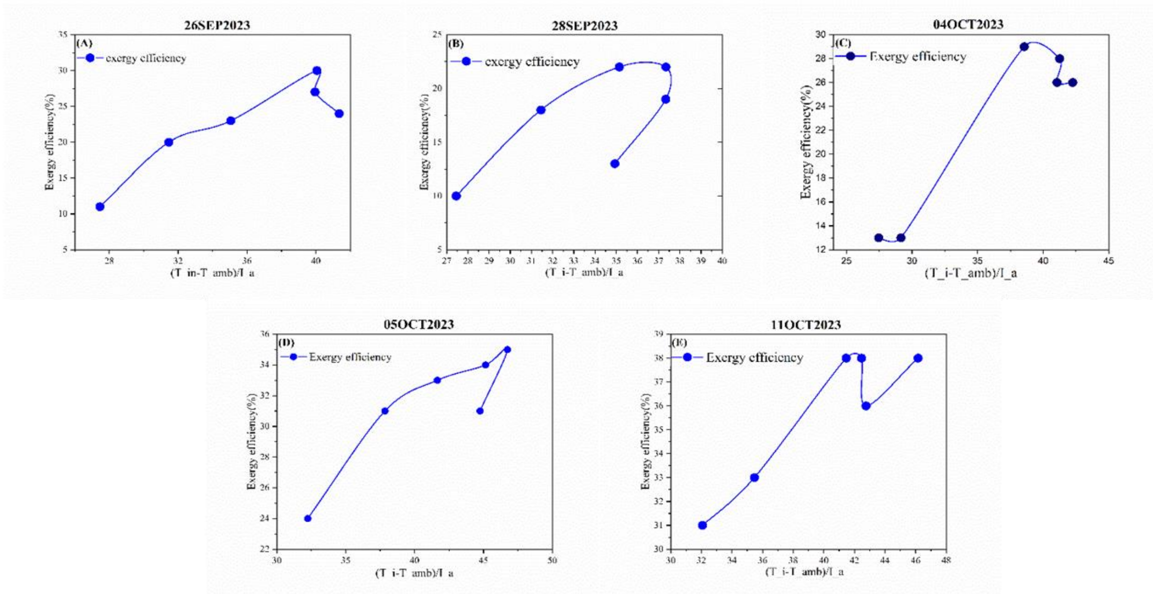

Figure 4.4: Exergy efficiency Profile recorded over five different days in September and October 2023. Panels show results from (A) 26 September, (B) 28 September, (C) 4 October, (D) 5 October, and (E) 11 October, illustrating the efficiency trends at increasing temperature gradients.

4.5 Summary

In this chapter experiments were done on PTC under open climate conditions in Islamabad, Pakistan. This study focuses on the effects of ambient temperatures and solar irradiance on PTC performance, showing variations in HTF Inlet and Outlet temperatures, heat gain and thermal efficiency. The results show an increase in thermal efficiency and heat gain directly with solar irradiance and ambient temperature. Also, the exergy efficiency varies with variation in HTF Inlet temperature and solar irradiance. The finding shows the potential of solar energy for thermal applications and suggests tracking system and insulation of system to enhance efficiency.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

In this study, a south-facing PTC was designed, constructed, and assessed under real-world climate conditions.

- The study focused on a south-facing Parabolic Trough Collector (PTC), which was meticulously designed and constructed to optimize its performance in capturing solar energy. The PTC's orientation and curvature were engineered to maximize exposure to incident solar radiation throughout the day, enhancing its ability to convert solar energy into heat.
- By fine-tuning the PTC to adjust to the varying levels of incident solar radiation, the system's heat gain can be significantly improved. This adjustment directly correlates with an increase in the thermal efficiency of the PTC, demonstrating that even minor modifications in solar radiation capture can have substantial effects on the system's performance.
- The Heat Transfer Fluid (HTF) plays a crucial role in the PTC's operation. The inlet and outlet temperatures of the HTF are sensitive to changes in solar irradiance and ambient temperature (T_{amb}). As both irradiance and T_{amb} escalate, there is a corresponding increase in the HTF's inlet and outlet temperatures, which indicates a more effective heat transfer process.
- There is a direct relationship between heat gain and thermal efficiency. As the PTC absorbs more solar energy, converting it into heat, the thermal efficiency of the system escalates. This efficiency is a critical measure of the PTC's capability to harness solar energy effectively.
- Exergy efficiency is a measure of the system's ability to utilize the available energy. It is primarily influenced by the inlet temperature of the HTF; higher inlet temperatures typically lead to increased exergy efficiency. Additionally, solar irradiance plays a dual role: while higher irradiance levels boost exergy efficiency due to increased energy input, lower irradiance levels can also lead to higher exergy efficiency by reducing thermal losses.

This study demonstrated significant potential for harnessing solar energy to meet thermal energy needs. The project successfully designed and implemented various components, parabolic trough collector, supporting structure, and thermostat system. However, the absence of a tracking system hindered the system's overall efficiency. Despite this limitation, the project would provide very useful information regarding the system installation, design, and thermal performance. The heating system maintained preset room temperature, the structural support retained solidarity, and the parabolic trough collector amplified solar rays.

5.2 Limitations

- The lack of a tracking system was a major downside; it led to passive movement tracking, and the efficiency of the collector diminished with the lack of active adjustment to the sun’s movement.

- The efficiency of the parabolic trough surface may be diminished in windy conditions due to the possibility of dust accumulation.

- As with all solar heating systems, when it's cloudy, our system's output and efficiency are likely to drop.

- With a copper coil, the setup costs are high initially.

5.3 Recommendations

The project's findings and limitations have led to the following suggestions being made:

- **Tracking System Integration:** A tracking system installation is an advisable step that is meant to increase system effectiveness levels. This will ensure appropriate utilization of energy and efficiency of the water heating systems by significantly improving performance.

- **Heat Storage System:** The installation of a heat storage system is the rightful supplement. Such a system can be used by solar thermal storage tanks or phased-change materials for storing the heat surplus that is made at times of high solar irradiance. At night, or during a period when the Parabolic trough collector is heating less than the absorber, this heat can be released.

- **Reflective Coating:** The performance of the parabolic trough collector can be substantially improved by combining the premium surface coating with it. Additionally, this technique can improve heat transfer to the HTF which passes through the coil enables a higher energy efficiency theoretically and boosts the system performance.

- **Insulation:** To prevent the loss of heat, operate the PTCs at high temperatures, and maximize energy output, functional insulation is key. When it comes to solar thermal energy, PTCs are undoubtedly important either for improving the efficiency and sustainability of your device or for correctly insulating your storage tank and receiver tube which are the parts that are responsible for holding the generated heat.

- **Collaborative Research and Development:** Through collaborating with business experts, research groups, and academic institutions, the process of innovation gets accelerated, and the exchange of knowledge materials becomes interesting. Taking part in research projects or attending industry forums connected to water heating systems and alternative sources of renewable energy also leads you to new thoughts, technologies, and funding resources. Joint activity can result in the generation of more advanced prototypes, state-of-the-art control systems, and well-performing components.

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