SOLAR WATER HEATING SOLUTION BY USING A PARABOLIC TROUGH

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Mechanical Engineering

by

Zain Mustafa

Muhammad Hassan Arif

Muhammad Ali

Muhammad Qasim Hussain

June 2023

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Zain Mustafa	297132
Muhammad Hassan Arif	287127
Muhammad Ali	282855
Muhammad Qasim Hussain	286311

Titled: "SOLAR WATER HEATING SOLUTION BY USING A PARABOLIC TROUGH" be accepted in partial fulfillment of the requirements for the award of B.E. Mechanical Engineering degree with grade ___

Supervisor: Dr. Waqas Khalid	____________________ Dated:

______________________ (Head of Department)

____________ (Date)

COUNTERSIGNED

Dated: ________________

__________________________ (Dean / Principal)

ABSTRACT

Standard geysers have been a common method of water heating in households for many years. However, their use is associated with several challenges, particularly in areas where electricity and gas shortages are common. Studies indicate that standard geysers are highly dependent on electricity and gas, which can lead to water heating issues during power outages or shortages. In addition, standard geysers are not always energy-efficient and can contribute significantly to household energy bills. The use of standard geysers can also lead to environmental concerns, such as greenhouse gas emissions from fossil fuel-based energy sources. Furthermore, the maintenance and repair of standard geysers can be challenging, especially in areas where specialized services are not easily accessible. The study also highlights the safety risks associated with the use of standard geysers, such as the potential for explosions or scalding accidents.

The proposed model is intended to address the issue of electricity and gas shortages commonly faced by households. It focuses on the domestic sector as it is where the impact of energy shortages is most acutely felt. The result is a parabolic trough solar collector developed with the goal of obtaining a self-sustainable system and achieving maximum efficiency in terms of heat absorption and transfer.

ACKNOWLEDGMENTS

We are extremely grateful to Allah Almighty for providing us the strength to let go of all the difficulties while working on this project. A warmest thank you to our supervisor, Dr. Waqas Khalid, for providing us utmost guidance during each phase of our project. Lastly, we are thankful to our seniors for helping us with their valuable knowledge and expertise.

Thesis

ORIGINALITY REPORT

15%	10%	11%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.degruyter.com	Internet Source	4%
2	Proceedings of ISES World Congress 2007 (Vol I – Vol V), 2009.	Publication	2%
3	Submitted to Higher Education Commission Pakistan	Student Paper	1%
4	s3.amazonaws.com	Internet Source	1%
5	Submitted to Trident University International	Student Paper	1%
6	1library.co	Internet Source	<1%
7	Pablo D. Tagle-Salazar, Krishna D.P. Nigam, Carlos I. Rivera-Solorio. "Parabolic trough solar collectors: A general overview of technology, industrial applications, energy market, modeling, and standards", Green Processing and Synthesis, 2020		<1%

Publication

8	tudr.thapar.edu:8080 Internet Source	<1%
9	Submitted to Monash University Student Paper	<1%
10	hdl.handle.net Internet Source	<1%
11	Submitted to University of Hull Student Paper	<1%
12	Wolf-Dieter Steinmann. "Thermal Energy Storage for Medium and High Temperatures", Springer Science and Business Media LLC, 2022 Publication	<1%
13	Submitted to Leeds Beckett University Student Paper	<1%
14	Submitted to New Jersey Institute of Technology Student Paper	<1%
15	doc.morningstar.com Internet Source	<1%
16	gfzpublic.gfz-potsdam.de Internet Source	<1%
17	"Advances in Mechanical and Materials Technology", Springer Science and Business	<1%

	Media LLC, 2022 Publication	
18	web.archive.org Internet Source	<1%
19	Submitted to Victoria Shanghai Academy Student Paper	<1%
20	www.solarequipments.com Internet Source	<1%
21	Submitted to University of Cape Town Student Paper	<1%
22	www.ee.co.za Internet Source	<1%
23	Ali Naci Celik, Nasır Acikgoz. "Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four- and five-parameter models", Applied Energy, 2007 Publication	<1%
24	J.H. Lou, J.Y. Lin, Y.K. Chuah. "Parametric study of immersed-coil heat exchanger", Proceedings of the 24th Intersociety Energy Conversion Engineering Conference, 1989 Publication	<1%
25	C. Alexandru, C. Pozna. "Different tracking strategies for optimizing the energetic efficiency of a photovoltaic system", 2008 IEEE	<1%

International Conference on Automation, Quality and Testing, Robotics, 2008
Publication

26	docplayer.net Internet Source	<1 %
27	findmyrice.com Internet Source	<1 %
28	uknowledge.uky.edu Internet Source	<1 %
29	utpedia.utp.edu.my Internet Source	<1 %
30	www.researchgate.net Internet Source	<1 %
31	DONALD D. JOYE, AARON S. CÔTÉ. "Heat Transfer Enhancement in Annular Channels with Helical and Longitudinal Fins", Heat Transfer Engineering, 1995 Publication	<1 %
32	Mohammed Ali Elgendy, Bashar Zahawi, David John Atkinson. "Comparison of Directly Connected and Constant Voltage Controlled Photovoltaic Pumping Systems", IEEE Transactions on Sustainable Energy, 2010 Publication	<1 %
33	Submitted to University of Western Australia Student Paper	<1 %

34	helioscsp.com Internet Source	<1 %
35	oa.upm.es Internet Source	<1 %
36	www.solar-energy-at-home.com Internet Source	<1 %
37	www.tandfonline.com Internet Source	<1 %
38	Catalin Alexandru. "The design and optimization of a photovoltaic tracking mechanism", 2009 International Conference on Power Engineering, Energy and Electrical Drives, 2009 Publication	<1 %
39	E.R.G Eckert, R.J Goldstein, W.E Ibele, S.V Patankar et al. "Heat transfer—a review of 1991 literature", International Journal of Heat and Mass Transfer, 1992 Publication	<1 %
40	Enkhbayar Shagdar, Yong Shuai, Bachirou Guene Lougou, Enkhjin Ganbold, Ogugua Paul Chinonso, HePing Tan. "Analysis of heat flow diagram of small-scale power generation system: Innovative approaches for improving techno-economic and ecological indices", Science China Technological Sciences, 2020 Publication	<1 %

41	Hassan Fathabadi. "Novel low-cost parabolic trough solar collector with TPCT heat pipe and solar tracker: Performance and comparing with commercial flat-plate and evacuated tube solar collectors", Solar Energy, 2020 Publication	<1%
42	Hussein A. Mohammed, Hari B. Vuthaluru, Shaomin Liu. "Parabolic Trough Solar Collectors", Springer Science and Business Media LLC, 2023 Publication	<1%
43	Submitted to Kingston University Student Paper	<1%
44	Leo Sampaio Ferraz Ribeiro. "Cross Domain Visual Search with Feature Learning using Multi-stream Transformer-based Architectures", Universidade de Sao Paulo, Agencia USP de Gestao da Informacao Academica (AGUIA), 2023 Publication	<1%
45	Submitted to Queen Mary and Westfield College Student Paper	<1%
46	Yinghong Cui, Juan Chen, Zhenhua Bei, Yinghong Yang. "Economy Analysis of the Solar Supported Coal-Fired Power Generation	<1%

(SSCPG) System", 2009 Asia-Pacific Power and Energy Engineering Conference, 2009
Publication

47	Zhiyong Tian, Bengt Perers, Simon Furbo, Jianhua Fan. "Thermo-economic optimization of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series", Energy Conversion and Management, 2018 Publication	<1 %
48	academy.paulmueller.com Internet Source	<1 %
49	dokumen.site Internet Source	<1 %
50	myprservices.com Internet Source	<1 %
51	J HERNANDEZGALAN, L ALBERTOPLAUCHU. "Determination of·fouling factors for shell-and-tube type heat exchangers exposed to los azufres geothermal fluids", Geothermics, 1989 Publication	<1 %
52	Tomasz Sobota. "Experimental and numerical analysis of heat transfer in the helically coiled heat exchanger", International Journal of Numerical Methods for Heat & Fluid Flow, 2019 Publication	<1 %

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Hot water is an essential requirement in the domestic sector, as it is necessary for a range of activities, including cleaning, bathing, and cooking. The lack of hot water supply can have significant negative effects on households, such as reduced hygiene levels and discomfort. In areas with limited access to hot water, families may be forced to rely on unsafe or unhygienic methods for water heating, which can have serious health implications. The provision of hot water is thus crucial in ensuring the health, safety, and well-being of households, particularly in areas with limited access to energy resources.

Background:

Hot water is an essential requirement in the domestic sector, as it is needed for a range of activities such as cleaning, bathing, and cooking. The provision of hot water is critical in ensuring the health, safety, and well-being of households. The lack of hot water supply can have significant negative effects on households, such as reduced hygiene levels and discomfort.

In areas where hot water is not readily available, families may be forced to rely on unsafe or unhygienic methods for water heating. These methods can lead to serious health implications. For example, boiling water over an open fire can lead to indoor air pollution and respiratory problems. The use of kerosene stoves or gas cylinders for water heating can also increase the risk of burns and explosions.

Moreover, the provision of hot water has a significant impact on the quality of life of households. Lack of hot water can affect personal hygiene levels, leading to a higher incidence of infections and diseases. It can also result in discomfort and inconvenience, especially during cold weather conditions. Children, elderly people, and those with disabilities are particularly vulnerable to the negative effects of hot water shortage.

To address the issue of hot water shortage, various devices have been developed over the years. One of the most common devices for hot water supply is the geyser or water heater. However, the use of standard geysers is associated with several challenges, particularly in areas with electricity and gas shortages. These challenges include increased energy bills, environmental concerns, safety risks, and the need for specialized maintenance services.

In recent years, alternative and sustainable solutions for hot water supply have been developed. These include self-sustainable parabolic trough solar collectors, which use renewable energy sources for water heating. The use of solar energy for water heating has several advantages over conventional methods, such as reduced energy bills, decreased environmental impact, and increased safety. Moreover, solar water heaters are low-maintenance and can last for several years.

Motivation:

The motivation behind the development of a parabolic trough solar collector is driven by the need for sustainable and self-sufficient solutions for hot water supply in the domestic sector. The issue of hot water shortage is particularly prevalent in areas with limited access to electricity and gas. In these areas, families are forced to rely on unsafe and unhygienic methods for water heating. The use of conventional methods such as standard geysers is also associated with several challenges, including increased energy bills, environmental concerns, and safety risks.

The parabolic trough solar collector provides an alternative and sustainable solution to these challenges. It uses renewable energy sources, namely solar energy, to heat water. The use of solar energy for water heating has several advantages over conventional methods, such as reduced energy bills, decreased environmental impact, and increased safety. Moreover, solar water heaters are low-maintenance and can last for several years. By developing a self-sustainable parabolic trough solar collector for domestic water heating purposes, the motivation is to provide households with a reliable and sustainable source of hot water, while addressing the challenges associated with conventional methods.

Problem statement:

The problem addressed in this FYP is the shortage of hot water supply in the domestic sector, particularly in areas with limited access to electricity and gas. Conventional methods for water heating, such as standard geysers, are associated with several challenges, including increased energy bills, environmental concerns, safety risks, and the need for specialized maintenance services. These challenges have resulted in reduced access to hot water, leading to negative effects on personal hygiene levels, discomfort, and inconvenience, especially during cold weather conditions. Children, elderly people, and those with disabilities are particularly vulnerable to the negative effects of hot water shortage.

To address this problem, the FYP aims to develop a self-sustainable parabolic trough solar collector for domestic water heating purposes. The motivation behind this solution is to provide households with a reliable and sustainable source of hot water, while addressing the challenges associated with conventional methods. The success of this project would ensure that households have access to hot water, improving their quality of life and reducing the negative impacts of hot water shortage on personal hygiene levels and overall well-being.

Objectives:

A list of objectives has been formulated according to the project's time and resource limitation.

- Providing households with hot water for washing, cooking and cleaning purposes.
- Design and fabrication of a sustainable Parabolic Trough Solar Collector System.

- Design and fabrication of an efficient heat exchanging device.
- Development of a thermostatic feedback control system.
- Development of a back-up system, that stores solar energy in a DC battery, to obtain a self-sustainable system.

CHAPTER 2: LITERATURE REVIEW

In this section, we will discuss all the literature associated with the various key components and areas of our project.

REFLECTION TECHNOLOGIES:

Solar energy can be directly used to generate electricity, but it needs to be concentrated to produce usable temperatures. The concentration factor determines the intensity of concentration and the resulting temperature. There are four primary types of CSP technology utilized to concentrate and capture sunlight for the purpose of converting it into heat.

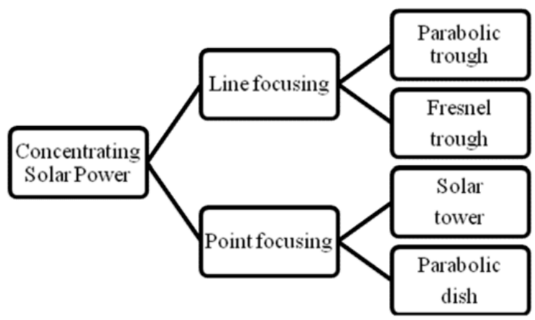

Figure 1: The different types of CSP

Line Focusing:

Linear concentration is a CSP technology that involves concentrating solar energy on a line using parabolic or Fresnel troughs. The collectors are aligned in the North-South direction, and a simple orientation perpendicular in the East-West direction brings back the image concentrated on the sun to the receiving tube located at the focal point of the concentrator.

The concentration varies between 60 and 400 depending on the season and time of day.

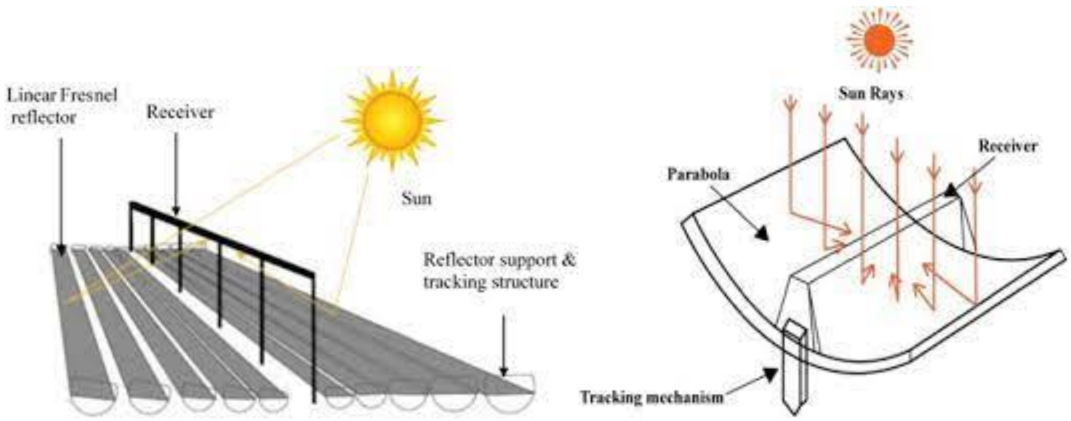

Figure 2: Line focusing

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 reduce this cost, 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 parabola is reconstructed roughly using flat mirrors, which are regulated according to the position of the sun. A second stage of fixed reflection redirects the radiation towards the receiving tube. This focusing is simpler, easier to construct, and less expensive than the previous parabolic method. The table below gives a detailed comparison between the two types.

Table 1: Comparison of PT and LF

	Capacity Unit(MW)	Concentration	Peak solar efficiency (%)	Annual solar efficiency (%)	Capacity solar factor (%)	Temperature output(°C)	Land use per MWh/y (m^2)
Parabolic Trough	10-200	70-80	21	17-18	25-70	300-550	6-8
Linear Fresnel	10-200	25-100	20	9-11	25-70	250-500	4-6

Point Focusing:

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 usually used for high temperature applications. Solar power tower technology uses a collection of sun-tracking mirrors, known as heliostats, to focus sunlight onto a central receiver placed atop a tall tower. The receiver then converts the concentrated solar radiation into thermal energy, which can be used to produce electricity. One of the primary advantages of solar power towers is their ability to generate electricity on a larger scale compared to other CSP technologies, making them an attractive option for utility-scale power generation.

Figure 3: 100 MW Concentrated Solar Power Tower project, China

Parabolic dish systems concentrate sunlight onto a receiver situated at the focal point of a parabolic dish-shaped reflector. The receiver then transforms the concentrated solar radiation into thermal energy, which is harnessed to generate electricity. These systems are most efficient in remote areas and have a smaller power-generating capacity compared to solar power towers. However, they are advantageous due to their modular design, which simplifies their construction and maintenance.

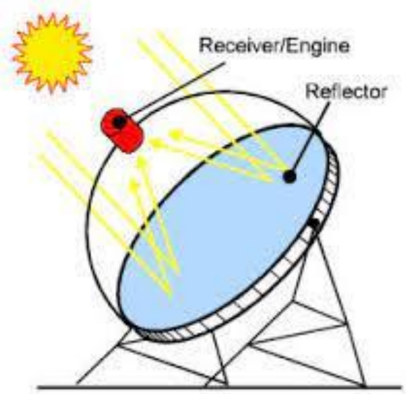

Figure 4: Parabolic Dish

SOLAR COLLECTOR:

The selection of a solar collector type is based on the total radiation transmitted to the reception area compared to the radiation received in the collection area. Solar concentration is achieved through the reflection or refraction of solar radiation from a large collection area to a smaller receiver area using mirrors or lenses. The concentration factor is a dimensionless geometric factor that represents the ratio between the collection area and the receiver area. It is greater than 1 for concentrating technologies and is a crucial factor in determining the effectiveness of solar concentration.
Several materials can be used for constructing solar collectors, each with its own advantages and disadvantages.

- **Steel:**

Steel is a commonly used material for parabolic trough solar collectors due to its strength, durability, and cost-effectiveness. It is easy to manufacture and has a long lifespan. However, steel has low thermal conductivity, which can lead to heat loss, and its weight can make installation and maintenance challenging.

- **Aluminum:**

Aluminum is another popular material for parabolic trough solar collectors. It is lightweight, has high thermal conductivity, and is corrosion resistant. Aluminum is also easy to manufacture and has a long lifespan. However, it is more expensive than steel, and it has lower strength and durability.

- **Glass:**

Glass is used as the reflector material in some parabolic trough systems. It has excellent optical properties and high reflectivity, which makes it an attractive choice. However, glass is fragile and can be expensive to manufacture and maintain.

- **Polymers:**

Polymers are lightweight, flexible, and can be molded into different shapes, making them a popular material for parabolic trough reflectors. They are also cost-effective and easy to manufacture. However, they have a shorter lifespan than other materials and can degrade quickly under high temperatures.

In summary, the choice of material for a parabolic trough solar collector depends on factors such as cost, durability, thermal conductivity, and optical properties. Steel is a cost-effective option, while aluminum is lightweight and corrosion resistant. Glass has excellent optical properties but is fragile, and polymers are flexible and easy to mold but have a shorter lifespan.

RECIEVER TUBE:

The receiver in a solar thermal system has the critical function of efficiently absorbing solar radiation and transferring the energy to the heat transfer fluid (HTF). Depending on the application, the receiver can be made of metal (for heating) or glass (for solar disinfection). For heating applications, the receiver comprises three primary components: the pipe receiver, the cover glass, and the solar selective coating (SC). The cover glass minimizes heat losses on the pipe and protects it from degradation. The SC is applied to the external surface of the pipe to increase solar heat flux absorption. In evacuated receivers, a vacuum is applied in the annular region between the glass and the tube to minimize heat losses, and the receiver is sealed to prevent vacuum losses. Bellows allow thermal expansion of the pipe and glass cover without losing vacuum in the annulus. Hydrogen getters are used to adsorb residual hydrogen that can be formed due to thermal degradation of the HTF. The glass-to-metal seal reduces mechanical stresses due to differences in thermal expansion.

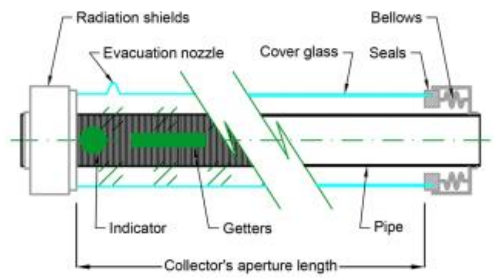

Figure 5: Receiver for heating applications.

Stainless steel is the most used material for pipe receivers, as it has high resistance to corrosion, low thermal expansion, and high thermal conductivity. However, it has low thermal conductivity, which can lead to heat loss. The cover glass should be made of a material with high transmittance, low reflectance, and low refractive index to transmit the highest possible amount of incident radiation reflected from the mirrors. Small-aperture collectors and prototypes usually have non-evacuated receivers.

1. **Evacuated Receiver Tubes**

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.

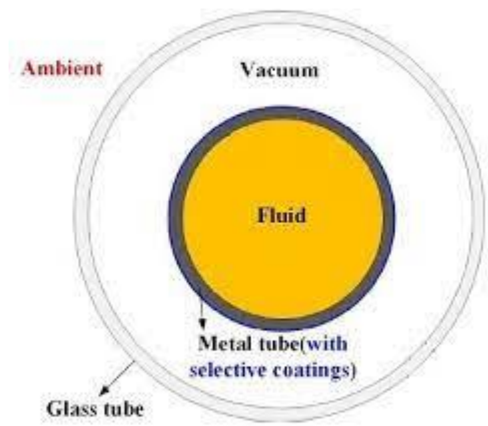

Figure 6: Evacuated Receiver Tubes

Advantages:

- High efficiency
- Low heat loss
- Long lifespan

Disadvantages:

- High cost
- Maintenance requirements
- Vulnerability to damage

Applications:

- Large-scale power generation plants
- Industrial processes that require high-temperature heat transfer

2. **Non-Evacuated Receiver Tubes**

Non-evacuated receiver tubes are designed for low-temperature applications where high-temperature resistance is not required. They are made of materials such as copper, aluminum, or plastic and are not evacuated. Their design is simpler than that of evacuated receiver tubes, consisting of a metal pipe with an absorber coating.

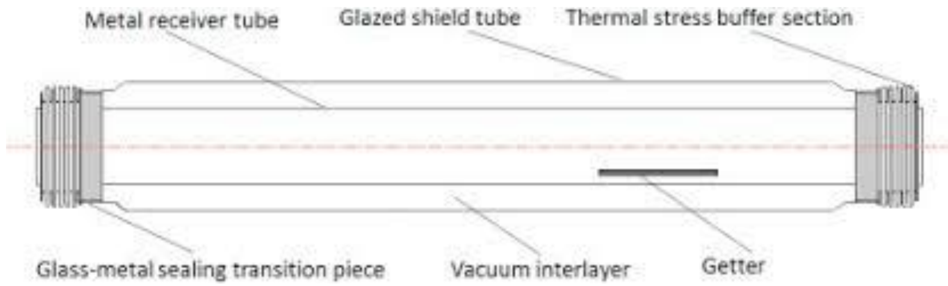

Figure 7: Non-Evacuated Receiver Tubes

Advantages:

- Lower cost
- Ease of maintenance
- Flexibility in design

Disadvantages:

- Lower efficiency
- Higher heat loss compared to evacuated tubes.

Applications:

Small-scale applications such as residential solar water heaters, solar dryers, and solar cookers

In summary, the choice of receiver tubes in parabolic trough solar collectors depends on the application, temperature requirements, and cost considerations. Evacuated tubes are suitable for high-temperature applications that require high efficiency and long lifespan, while non-evacuated tubes are suitable for low-temperature applications that require lower cost and flexibility in design.

1. Bare Tube Receivers

Bare tube receiver tubes are a type of non-evacuated receiver tube used in parabolic trough solar collectors. They are made of a metal pipe with an absorber coating, and no cover glass or vacuum insulation is used. The metal pipe is usually made of copper, aluminum, or steel, and the absorber coating is a selective surface that absorbs solar radiation and converts it into heat.

Advantages:

- Low cost.
- Simple design.
- Easy maintenance.
- More flexible in design.
- Can be made in different sizes and shapes to fit specific applications.
- Lower risk of damage from thermal stress compared to evacuated tubes.

Disadvantages:

- Lower efficiency.
- Higher heat loss compared to evacuated tubes.
- Shorter lifespan due to corrosion.
- Thermal degradation.

Applications:

- Solar water heating systems.
- Small-scale solar thermal applications.
- Experimental and research projects due to their flexibility in design.
- Low cost.

There are several materials that can be used for parabolic trough solar receiver tubes, depending on the desired operating temperature, cost, and efficiency requirements.

- **Stainless steel:**

This is the most used material for receiver tubes due to its high resistance to corrosion, low thermal expansion, and high thermal conductivity. Stainless steel can withstand high temperatures and is malleable, making it easy to fabricate into tubes.

- **Copper:**

Copper is another popular material for receiver tubes, especially for non-evacuated tubes used in low-temperature applications. Copper has high thermal conductivity, which means it can transfer heat efficiently. However, copper is more susceptible to corrosion than stainless steel, and its higher cost may make it less economical for some applications.

- **Aluminum:**

Aluminum is lightweight and has a high thermal conductivity, making it a suitable material for receiver tubes. However, it is also more vulnerable to corrosion and requires a protective coating to prevent degradation.

- **Glass:**

Glass can be used as a material for the receiver tube, especially in solar disinfection applications. Glass is transparent and can allow radiation to pass through while protecting the water from contamination. However, glass is brittle and may be more prone to breakage than other materials.

- **Ceramics:**

Ceramics can withstand high temperatures and are highly resistant to corrosion. They can be used for receiver tubes in high-temperature applications, but their brittleness may make them less suitable for some applications.

The selection of material for the receiver tube in a parabolic trough solar collector depends on various factors, such as the desired operating temperature, cost-effectiveness, efficiency, and maintenance requirements. Among the materials used, stainless steel is the most used material owing to its durability and cost-effectiveness. Copper and aluminum are used for non-evacuated tubes for low-temperature applications. Glass and ceramics are used for specialized applications such as solar disinfection or high-temperature processes.

HEAT TRANSFER FLUID:

An essential component in many heat transfer systems is the working fluid, also referred to as the HTF. The primary function of the HTF is to absorb heat from the receiver and utilize it as process energy. To perform this function effectively, the HTF should possess certain desirable properties such as high thermal capacity and conductivity, low thermal expansion, low viscosity, minimal corrosive activity, low toxicity, and thermal and chemical stability over its entire operating temperature range.

Liquids are the most commonly used type of HTFs due to their excellent heat transfer properties. For researchers conducting a literature review on this topic, it is essential to explore the various types of HTFs available and their properties to identify the most suitable HTF for their specific application. Moreover, the literature review should also highlight recent advancements in HTF technology and their impact on heat transfer efficiency and system performance.

Parabolic trough solar collectors utilize a heat transfer fluid (HTF) to absorb solar radiation and transfer the heat to a thermal storage system or power generation unit. The choice of

HTF is a critical factor in the overall efficiency and cost-effectiveness of a parabolic trough system.

Synthetic oils such as Therminol VP-1, Dowtherm A, and Syltherm XLT are the most used HTFs in parabolic troughs due to their high thermal stability and ability to operate at temperatures up to 400°C.

Another class of HTFs that have gained popularity in recent years are molten salts, particularly a mixture of sodium nitrate and potassium nitrate, commonly referred to as Solar Salt. Molten salts can store thermal energy at high temperatures and can operate at temperatures up to 565°C.

Water is a potential HTF for parabolic troughs but is limited to vacuum systems operating at low pressures due to its low boiling point. In general, water is mostly used in low enthalpy and direct steam generation applications.

Table 2: Comparison of various HTF

Fluid	Working temperature (°C)	General properties	Advantages	Disadvantages
Water	Up to 100	Odorless, relative low viscosity, nontoxic	- No environmental risks (pollution or fire) - Low operational pressures. - Simple plant design	- Only for low enthalpy applications - Requires water treatment
Glycols	−50–300	High heat transfer properties (with combined with water), low viscosity, toxic (depending on the preparation)	- Antifreezing properties (with the proper concentration)	- Environmental risks (toxicity) - Used only in low enthalpy applications (when mixed with water) - Degradation with long-term operation
Steam	Up to 500	High pressure and temperature applications	- Higher working temperature - Secondary HTF no needed - No environmental risks (pollution or fire) - Easier plant design	- Evaporation (two-phase flow, heat losses in flashing) - Higher operational pressures - Requires water treatment - More complex solar field control - Lack of suitable TES system
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 be dehumidified (air)	- Higher steam temperature - Thermal storage enhancement - No environmental risks (pollution or fire) - Nontoxic - Chemically inert - Minimum corrosion	- Poor heat transfer in the receiver - More complex solar field control - Higher operational pressures
Supercritical CO_2	–	A supercritical gas works as a single-phase liquid with the filling property of a gas, higher temperature operation, abundant	- Gas with liquid-like properties - Higher thermal performance when compared with subcritical CO_2	- Challenging operation (leakage, pressure, etc.) - Thermal fatigue of pipes - Corrosion - Under investigation
Synthetic oils	−90–400	High thermal capacity, low flow properties (compared with water), flammable, toxic	- Higher thermal efficiencies are achieved (compared with others) - Relative low operational pressures	- Requires fire protection system - Environmental risk (toxicity) - Heat exchangers required (for power generation)
Mineral oils	−10–300	Stability against thermal degradation and oxidation, relatively inexpensive, noncorrosive and nontoxic, flammable	- Relative lower power consumption (due to its low viscosity and density compared with others)	

Vegetable oil has emerged as a viable alternative to conventional synthetic oils as a heat transfer fluid due to its renewable and environmentally friendly properties. It has gained significant attention in recent years due to its high thermal stability, low toxicity, and biodegradability.

Several types of vegetable oils can be used as HTFs, including sunflower oil, rapeseed oil, soybean oil, and palm oil. Sunflower oil and rapeseed oil are particularly suitable for high-temperature applications, as they have high flash points and can operate at temperatures up to 350°C. Soybean oil and palm oil, on the other hand, have lower flash points and are typically used in low-temperature applications.

The use of vegetable oil as an HTF offers a significant advantage in terms of sustainability and renewability. Unlike conventional synthetic oils, vegetable oils are derived from renewable sources and do not contribute to the depletion of finite resources. Furthermore, vegetable oils have lower carbon footprints than conventional oils, making them a more environmentally friendly option.

However, vegetable oils also have some limitations as HTFs. They may experience oxidative degradation over time, and their higher viscosity compared to synthetic oils may affect their performance. To optimize the performance of vegetable oils as HTFs, further research is needed, and new technologies should be explored to overcome these limitations.

In conclusion, vegetable oils have the potential to be a promising alternative to conventional synthetic oils as HTFs. The choice of vegetable oil will depend on the specific application and temperature range required. The use of vegetable oil as an HTF may contribute to a more sustainable and environmentally friendly future for the industry.

Table 3: Comparison of various HTF

Oil Type	**T_f (Flash Point)**	**Thermal Conductivity (W/mk)**	**Biodegradability**	**Cost**	**Specific Heat Capacity (j/gk)**
Mineral Oil	100-170	0.11-0.16	Slow to degrade	(~Rs. 1600 Per litre)	1.6-2.0
Synthetic Oil (Silicone Fluids)	300-310	0.15	Very slow to degrade	(~Rs. 6000 Per litre)	1.5

Vegetable Oil	275-328	0.16-0.17	Readily Biodegradable	(~Rs. 500 Per litre)	1.2-2.1

SUPPORT STRUCTURE:

The supporting structure plays a crucial role in the performance and stability of a solar collector system. It is responsible for fixing the components of the collector, providing rigidity and stability to the entire system. Typically, the structure is made of strong, durable materials such as steel or aluminum to ensure it can withstand the environmental stresses and loads placed upon it.

The PTC supporting structure comprises three main components from a structural perspective: the main support, the frame, and the receiver brackets. The main support serves as the primary anchor for the collector and holds it in place. This component must have the capacity to withstand the wind loads that the collector will encounter, as the collector's aperture is typically exposed to the wind.

The frame component of the supporting structure provides rigidity to the mirrors, ensuring they maintain their parabolic shape at all times. This is essential to prevent misalignments that could result in performance losses. The frame also transmits the torque of the tracking system, which is critical for maintaining the optimal orientation of the collector towards the sun.

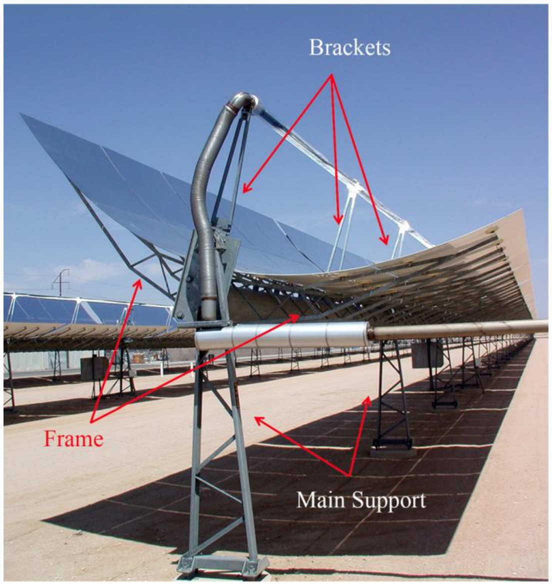

Figure 8: Structural division of a PTC

The brackets, attached to the mirror support, hold the receiver in place at the focal line of the parabola. An insulating material is often used between the receiver and the bracket to reduce heat losses. Proper design and manufacture of the supporting structure framework are crucial to maintaining the parabolic shape of the mirrors and the location of the receiver at the focal line of the parabola. Any misalignments could result in significant performance losses, so the mechanical properties of the framework must be carefully considered during manufacturing. Bending and torsion of the framework, produced by self-weight and wind forces, are two critical parameters that must be taken into account when designing the supporting structure. A well-designed structure will ensure optimal performance and longevity of the solar collector system.

Types of Support Structures for Parabolic Trough Solar Collectors:

- **Ground-Mounted Structure**

Description: Most common type of support structure for parabolic trough solar collectors, made of steel or aluminum, consisting of columns or piles and a box or frame.

Ideal for: flat, level terrain.

Benefits: easy to install and maintain.

- **Roof-Mounted Structure**

Description: Mounted on the rooftop of a building.

Ideal for: urban areas with limited land and available rooftops.

Benefits: less expensive than ground-mounted structures, requires fewer materials.

- **Pole-Mounted Structure**

Description: Main support consists of a single pole instead of columns or piles.
Ideal for: sites with sloping terrain.

Benefits: can be adjusted to maintain collector's orientation.

- **Tension Structure**

Description: Uses cables to support the collector's mirrors instead of a frame or box.

Ideal for: locations with high wind loads.

Benefits: lightweight, requires less material, can withstand wind gusts.

- **Truss Structure**

Description: Lightweight structure that uses triangular units to distribute loads.

Ideal for: locations with low wind loads. Benefits: easy to install and maintain.

TRACKING SYSTEM:

Solar tracking systems are crucial for maximizing the performance of solar collectors that work with direct beam radiation, such as PTCs. These systems align the collector with the sun to optimize its efficiency in one-axis rotation. There are two types of solar trackers - passive and active. Passive trackers use the thermosiphon effect to align the collector, while active trackers rely on electronic signal conversion. However, passive trackers are not widely used in PTCs due to the risk of misalignment caused by wind forces during operation.

Types of Tracking Systems

- Hybrid-Loop Tracking

Combining Algorithm and Sensors for Optimal Tracking

Typical Hybrid-Loop Tracking Process

- Active Closed-Loop Trackers

Components: Light Sensor, Control System, and Drive System

Light Sensor's Role in Aligning the Collector

Advantages and Disadvantages of Closed-Loop Tracking

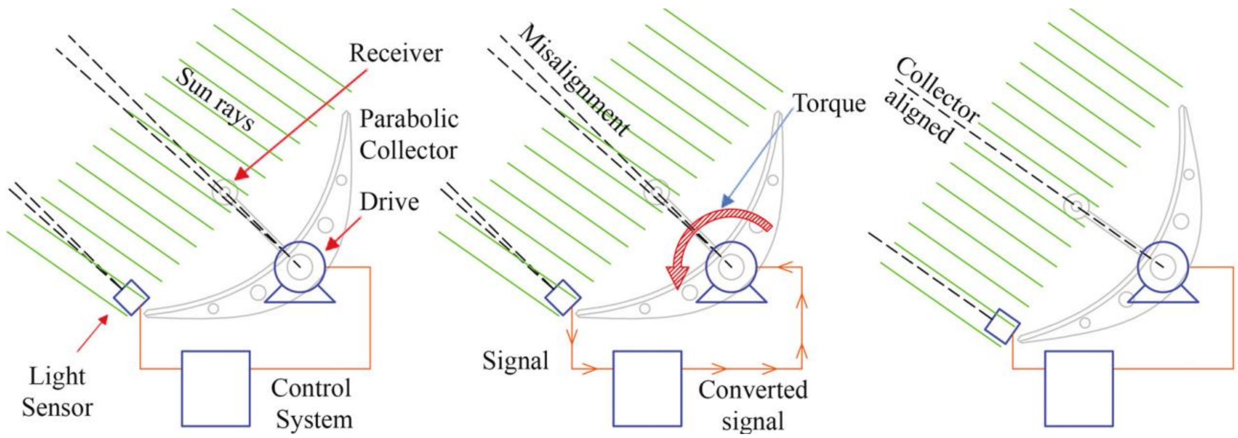

Figure 9: Active Closed-Loop Trackers

- Active Open-Loop Trackers

Components: Controller and Drive

Timed Trackers

Altitude/Azimuth Trackers

Disadvantages of Open-Loop Tracking

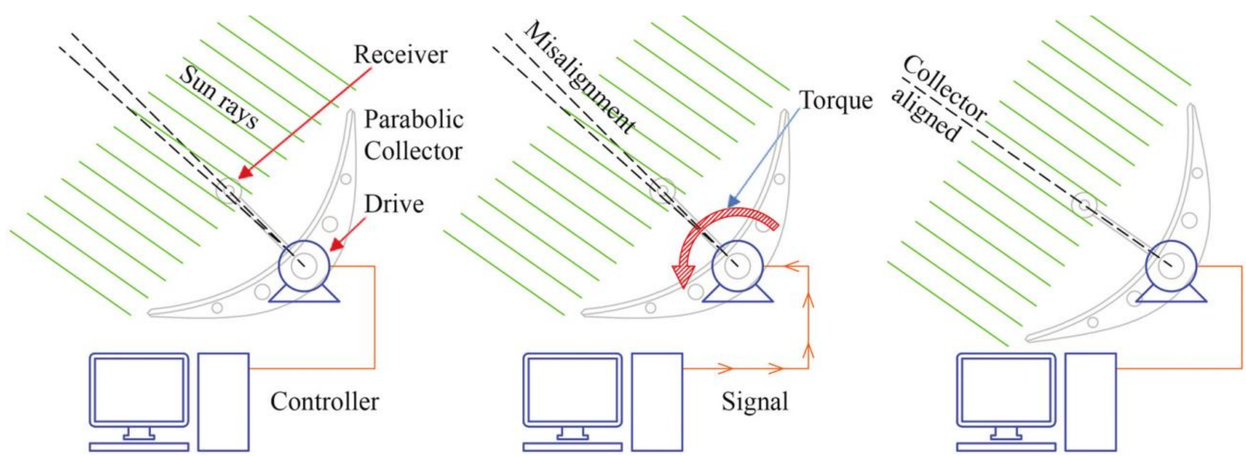

Figure 10: Active Opened-Loop Trackers

Parabolic trough solar collectors (PTCs) are a type of concentrated solar power technology that uses curved mirrors to focus sunlight onto a receiver tube that runs along the focal line of the parabolic shape. To maximize the efficiency of PTCs, solar tracking systems are used to ensure that the mirrors are aligned with the sun as it moves across the sky. There are three main types of tracking systems used in PTCs: single-axis, two-axis, and seasonal.

- **Single Axis Tracking Systems:**

Single axis tracking systems are the simplest and most common type of tracking system used in PTCs. They allow the mirrors to rotate around a single horizontal axis, which is usually oriented along an east-west axis. This allows the mirrors to track the sun as it moves across the sky from east to west, maximizing the amount of sunlight that is reflected onto the receiver tube.

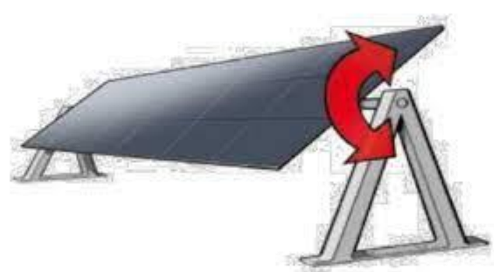

Figure 11: Single axis tracking systems.

- **Dual Axis Tracking Systems:**

Two-axis tracking systems are more complex and allow the mirrors to rotate around both horizontal and vertical axes. This allows the mirrors to track the sun as it moves both horizontally and vertically across the sky, further optimizing the amount of sunlight that is reflected onto the receiver tube. Two-axis tracking systems are more expensive and require more maintenance than single-axis systems, but they can achieve higher levels of efficiency.

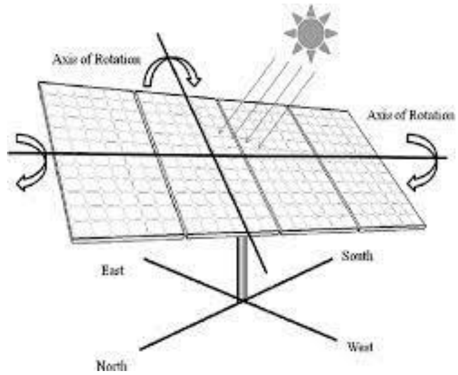

Figure 12: Two-axis tracking systems.

- **Seasonal Tracking Systems:**

Seasonal tracking systems are designed to optimize the performance of PTCs over an entire year. 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.

HEAT EXCHANGERS:

Heat exchangers are essential components of parabolic trough solar cookers, enabling the transfer of heat from concentrated sunlight to water or other fluids. Here we discuss the different types of heat exchangers used for this purpose.

- **Shell and Tube Heat Exchangers:**

The shell and tube heat exchanger is a popular choice for parabolic trough solar cookers due to its high efficiency and heat transfer rate. The exchanger comprises a shell and a bundle of tubes. The water to be heated flows through the tubes, while the shell is heated by the concentrated sunlight. The heat is transferred from the shell to the tubes and then to the fluid inside. However, shell and tube heat exchangers can be costly to manufacture and maintain.

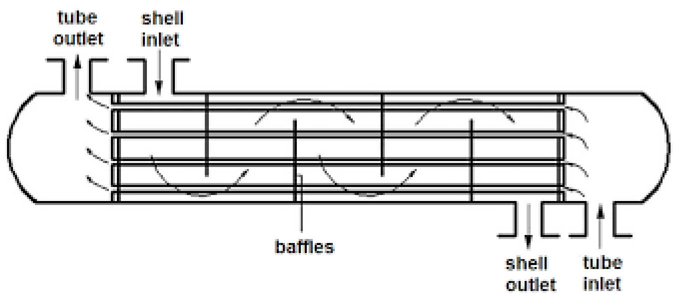

Figure 13: shell and tube heat exchanger

- **Plate Heat Exchangers:**

Plate heat exchangers consist of a series of plates with small gaps between them, allowing water to flow through the gaps while the concentrated sunlight heats the plates. The heat is then transferred from the plates to the water. Plate heat exchangers are compact, efficient, and easy to maintain, but may not be suitable for fluids that are prone to fouling or scaling.

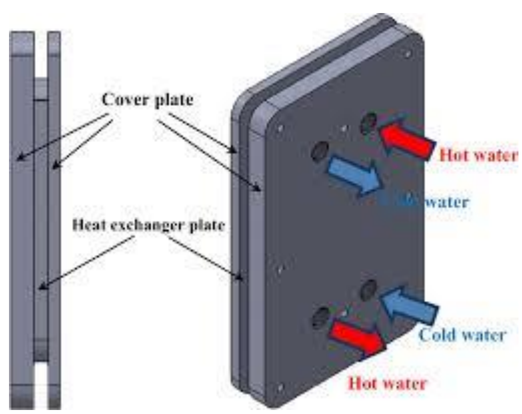

Figure 14: Plate heat exchangers

- **Direct Contact Heat Exchangers:**

In direct contact heat exchangers, water is directly exposed to concentrated sunlight, which heats it up. This type of heat exchanger is simple, efficient, and has a high heat transfer rate. However, it may not be suitable for fluids sensitive to high temperatures, and controlling the temperature of the water can be challenging.

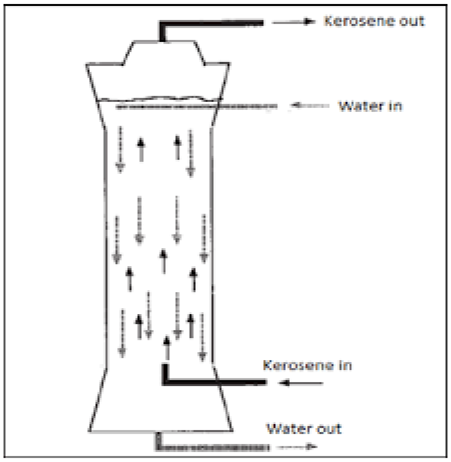

Figure 15: direct contact heat exchangers

- **Immersed Coil Heat Exchangers:**

An immersed coil heat exchanger is a simple, efficient, and inexpensive option. It consists of a coil of tubing immersed in the water to be heated. The concentrated sunlight heats the tubing, which in turn heats the water. However, immersed coil heat exchangers may not be suitable for fluids that are prone to fouling or scaling.

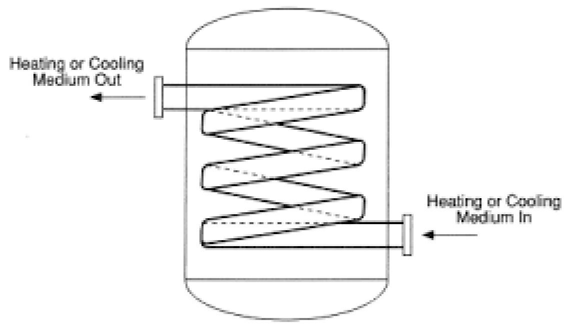

Figure 16: Immersed coil heat exchanger

- **Helically Coiled Heat Exchangers:**

Helically coiled heat exchangers are a type of heat exchanger used in parabolic trough solar cookers for water heating. They consist of a coiled tube that maximizes the surface area available for heat transfer. Helically coiled heat exchangers can be used in large-scale parabolic trough solar cookers for water heating, as well as in industrial heating applications and experimental systems for research and development of solar thermal technologies.

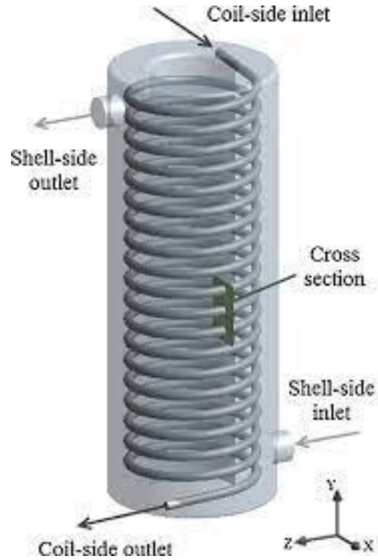

Figure 17: Helically coiled heat exchangers

- With Core and Without Core Helically Coiled Heat Exchangers:

There are two types of helically coiled heat exchangers: with core and without core. With core helically coiled heat exchangers have a core that runs through the center of the coil to maintain its shape and stability.

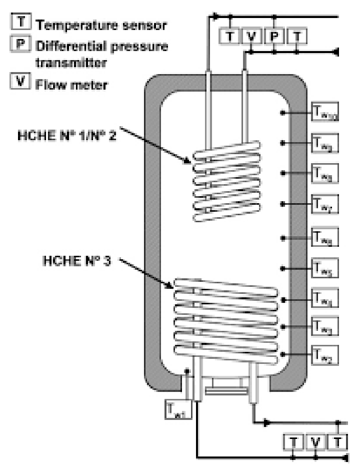

Figure 18: With core helically coiled heat exchangers

Without core helically coiled heat exchangers do not have a core, and the coil is supported by the fluid flowing through it.

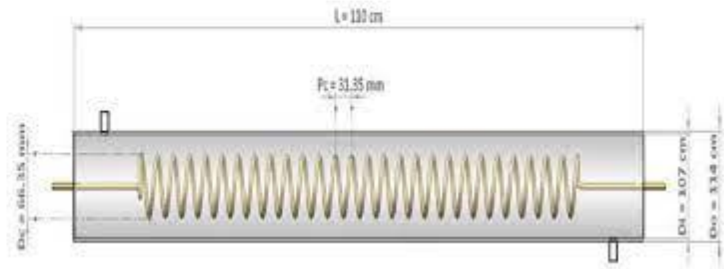

Figure 19: Without core helically coiled heat exchangers

- Advantages of Helically Coiled Heat Exchangers:

Helically coiled heat exchangers have a high heat transfer rate due to their large surface area, making them efficient and effective at heating fluids to high temperatures. They are also relatively easy to manufacture and maintain and can be used with a variety of fluids.

- **Disadvantages of Helically Coiled Heat Exchangers:**

Helically coiled heat exchangers can be expensive to manufacture, especially if a core is required. They may not be suitable for use with fluids that are prone to fouling or scaling and can be difficult to clean if fouling or scaling occurs.

- **Applications of Helically Coiled Heat Exchangers:**

Helically coiled heat exchangers are commonly used in large-scale parabolic trough solar cookers for water heating, as well as in industrial heating applications and experimental systems for research and development of solar thermal technologies.

- **Applications of Heat Exchangers in Parabolic Trough Solar Cookers:**

Shell and tube heat exchangers and plate heat exchangers are commonly used in large-scale parabolic trough solar cookers for water heating. Direct contact heat exchangers and immersed coil heat exchangers are typically used in smaller-scale or experimental systems.

The choice of heat exchanger depends on factors such as the fluid being heated, system size, and budget constraints.

CHAPTER 3: METHODOLOGY

Design Considerations

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

- **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 include a parabola reflector made from GI sheet. Several experiments were carried out which involved assessing the existing hot water system and identifying any necessary upgrades or modifications.

- **Data Collection**

We were to Collect data on the hot water usage patterns of the average households, including the number of occupants, daily hot water demand, and peak usage times. This involved using a water meter or other measuring devices to record water consumption over a period. The results are below:

Table 4: Average water Requirement.

10min shower	20 gallons
Average daily toilet flush	19-22 gallons
Washing machine	15 gallons
Dishwasher	7 gallons
Face and handwash	3 gallons
Handwashing dishes	18 gallons
Total (for a family of five people, excluding the toilet flush water)	155 gallons

From the data available to us by the weather stations, the direct normal irradiance of Islamabad during the cloudy months of November to February, in which our device will face the least favorable conditions, were extracted. The average of each month is mentioned below:

Table 5: The average DNI of Islamabad in the past 5 years

Month	*DNI (W/m^2)*
November	**54.4**
December	**66.3**
January	**58.7**
February	**62.6**

- **Design Parameters**

Determining the design parameters for the solar water heating system, 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 several software tools and simulations to model the performance of different system configurations:

i. *TRNSYS:* It has a solar thermal module that can be used to model and simulate the performance of parabolic trough collectors in a solar water heating system.
ii. *ProE:* The software enables users to create precise 3D models of parts and assemblies, which can be used to develop and refine product designs.
iii. *Parabola Calculator:* This software calculates the focal point of a parabola using the sheet dimensions and input prompts provided by the user.

- **Economic Analysis**

Conducting an economic analysis to evaluate the cost-effectiveness of the solar water heating system. This involved estimating the installation and maintenance costs, as well as the expected energy savings and payback period.

Design:

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

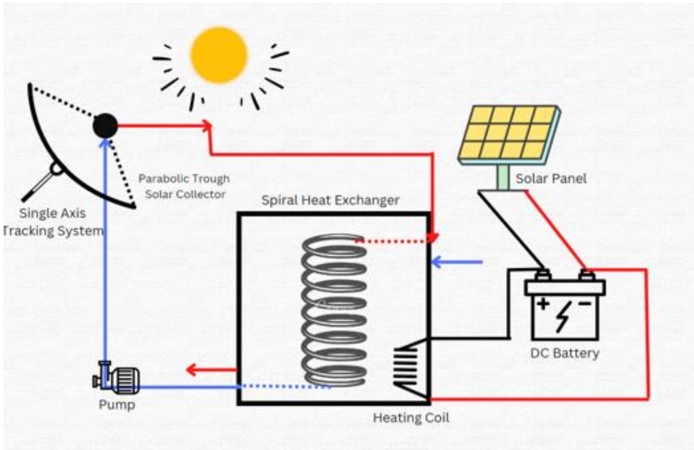

Figure 20: Systematic Diagram of the system

Components:

i. Solar Collector

In our design, we used parabolic trough collector as our solar collector. The reason we preferred parabolic trough collector over flat plate collector was due to 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 collectors are better at capturing sunlight in low light conditions, such as during cloudy or overcast weather. This is because the mirrors are designed to concentrate light, rather than simply absorbing it like flat plate collectors.
- Parabolic trough collectors can be more compact than flat plate collectors, making them easier to install in small spaces. This can be particularly important for domestic heating applications where space is limited.
- Parabolic trough collectors tend to have a longer lifespan than flat plate collectors because they are made from materials that are more resistant to degradation from exposure to sunlight and heat.

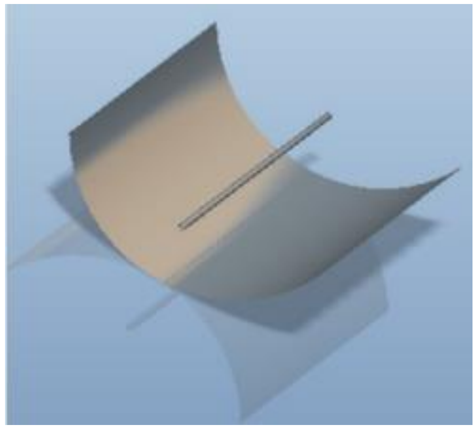

Figure 21: CAD model of parabolic trough

The material that was used in constructing a parabolic trough collector was galvanized steel. The reason why GI sheet was preferred over other materials was:

- Galvanized steel is highly resistant to corrosion, which makes it an ideal material for use in outdoor environments where the collector is exposed to moisture and sunlight. This means that galvanized steel parabolic trough collectors can last for many years without requiring frequent maintenance or replacement.
- Galvanized steel is a strong and durable material that can withstand high temperatures and mechanical stress. This makes it ideal for use in parabolic trough collectors, which require materials that can withstand the weight of the support structure.
- Galvanized steel is a relatively low-cost material compared to other metals such as aluminum or stainless steel, which makes it an attractive option for parabolic trough collectors.
- Galvanized steel is widely available and easy to source, which makes it a convenient material.

- Galvanized steel is a highly recyclable material, which means that it can be reused or repurposed at the end of its useful life, reducing waste, and minimizing the environmental impact of the parabolic trough collector.

Figure 22: GI Sheet

ii. Supporting Structure

The main purpose of the supporting structure is to fix the components of the collector, which provides rigidity and stability to the whole system. It should also be able to resist shocks and wind tension forces in strong and windy environments. The material used for constructing the support was steel.

Figure 23: Support Structure

iii. Receiver tube

Bare tube receiver was preferred over other types in solar water heating for domestic use. The material used was copper and the length of the tube was 6ft while the diameter is 1 inch. It was then fit into the parabola trough through the wooden side frames, to give us the following layout:

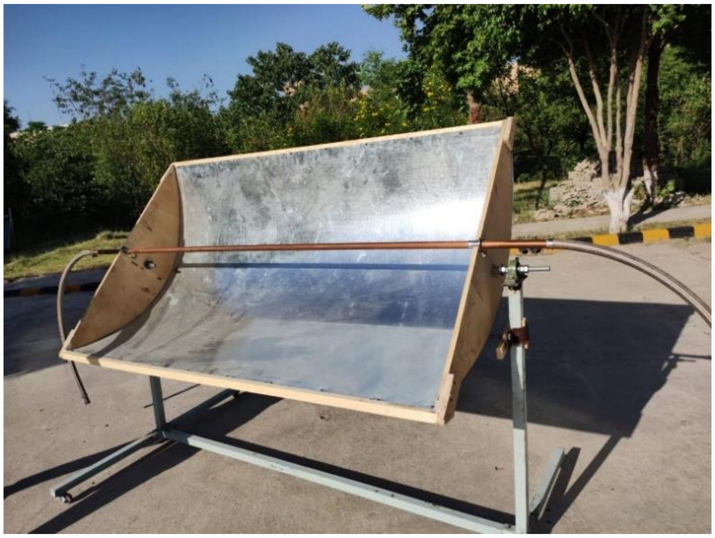

Figure 24: Bare Tube Receiver fitted along the parabolic trough.

Bare tube receiver was chosen, instead of an evacuated tube, for the following reasons:

- **High Efficiency**: Bare tube receivers have a high efficiency in absorbing solar radiation, which makes them more effective at heating the water that flows through them. This means that they can produce hot water more quickly and efficiently than other types of receivers.
- **Low Cost**: Bare tube receivers are relatively low-cost compared to other types of receivers, such as evacuated tube or flat plate receivers. This makes them an

attractive option for domestic solar water heating systems, where cost is an important consideration.

- **Easy Maintenance**: Bare tube receivers are relatively easy to maintain, as they do not have complex vacuum or insulation systems that require regular upkeep. This means that they can be serviced quickly and easily, reducing downtime and maintenance costs.
- **Durability:** Bare tube receivers are durable and long-lasting, as they are not as prone to damage from hail or other environmental factors as other types of receivers. This means that they can provide reliable hot water for many years with minimal maintenance.

iv. Working fluid

We have chosen *vegetable 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 vegetable oil is above the operating temperature of our working fluid, which is 110°C.
- Vegetable 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.
- Vegetable 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.
- Vegetable oil has good heat transfer properties, which means it can efficiently transfer heat from the solar collectors to the heat exchanger or storage tank.

v. **Heat exchanger:**

After thorough literature review regarding different types of heat exchangers, helical coil heat exchanger was considered as the most suitable type of heat exchanger for project.

Figure 25: Helical Coil Heat Exchanger

- Helical coil heat exchangers typically provide more efficient heat transfer than straight tube heat exchangers because the fluid flow is more turbulent. The helical design of the coil creates vortices that promote mixing and turbulence, which enhances heat transfer.

- Helical coil heat exchangers can be more compact than straight tube heat exchangers because the helical design allows for a longer heat transfer surface area to be packed into a smaller
- The helical design of the coil can also help to prevent fouling and clogging, as any particles or sediment that may accumulate in the coil are more likely to be carried along by the turbulent flow and flushed out of the system. Due to this, less maintenance will be required, reducing the overall costs.
- Helical coil heat exchangers typically have a lower pressure drop than straight tube heat exchangers due to the more efficient fluid flow. This can be beneficial in applications where a low-pressure drop is desired to minimize energy consumption.
- Helical coil heat exchangers can handle higher flow rates than straight tube heat exchangers due to the more efficient fluid flow. This can be beneficial in applications where a high flow rate is necessary to meet process requirements.

Heat exchangers with a core are often preferred over heat exchangers without a core because the core can provide several benefits, which include:

- The core can increase the heat transfer efficiency of the heat exchanger by creating turbulence in the fluid flow. This helps to promote better heat transfer between the two fluids by increasing the contact time between them.
- The core can also help to improve the distribution of heat across the heat exchanger, which can help to prevent hot spots and ensure that the heat is evenly distributed.
- A core can also help to increase the flow rate of the fluids through the heat exchanger by reducing the pressure drop. This is because the core can help to create a more uniform flow and prevent any stagnation zones from forming.

- The presence of a core can also help to reduce fouling and scaling in the heat exchanger by creating turbulence in the fluid flow. This can help to prevent any particles or sediment from settling on the heat transfer surfaces and reduce the likelihood of blockages.

The reason why copper was preferred as the ideal material for the tubes was:

- Copper has excellent thermal conductivity, which means it can efficiently transfer heat from one fluid to another. This makes copper tubes a good choice for heat exchangers where efficient heat transfer is important.
- Copper is highly resistant to corrosion, which means it can withstand exposure to different fluids without deteriorating or degrading over time. This is important in heat exchangers where different fluids are in contact with each other and can potentially cause corrosion.
- Copper is a ductile and malleable metal, which means it can be easily shaped and formed into different configurations. This makes it an ideal material for the helical coil design of heat exchangers.
- Copper has good thermal expansion properties, which means it can withstand changes in temperature without deforming or cracking. This is important in heat exchangers where temperature fluctuations can occur.
- Copper is a widely available and relatively inexpensive material, which makes it an attractive choice for use in heat exchangers.

vi. Backup system

A solar-based DC backup system can be useful in domestic water heating applications that use parabolic trough collectors for several reasons:

- The use of solar energy for water heating depends on the availability of sunlight. However, in situations where there is insufficient sunlight or during cloudy weather, the hot water supply may be interrupted. A solar-based DC backup system can help to ensure continuous hot water supply by providing backup power when sunlight is not sufficient.
- Domestic water heating using parabolic trough collectors can help to reduce dependence on the grid, but it still requires electricity to operate pumps and other components. A solar-based DC backup system can provide a self-sufficient backup power source, reducing the reliance on the grid and potentially reducing electricity bills.
- A solar-based DC backup system can increase the energy efficiency of the water heating system by providing power directly to the DC components, such as pumps and controllers, without the need for an AC to DC converter. This can help to reduce energy losses during the conversion process and improve overall system efficiency.
- The use of a solar-based DC backup system can increase the reliability of the water heating system by providing a backup power source in the event of power outages or other disruptions. This can help to ensure that the system continues to operate as intended and reduce the risk of system downtime.

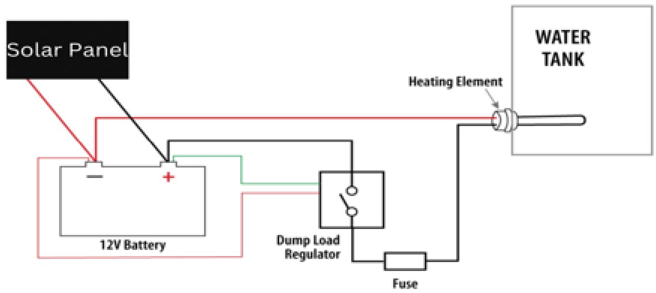

Figure 26: Backup system scheme

Construction & assembly:

i. Solar Collector:

For constructing a PTC, bending operation was performed on a *rectangular GI sheet* of dimensions *6 x 4 ft* and *22-gauge* thickness in order to form a parabola shape. A sheet of GI was bended and set in a parabola profile.

Figure 27: Assembling of Solar Collector

With the help of a wooden structure at its ends, this profile was kept as accurate as possible as defined to us by the parabola calculator tool.

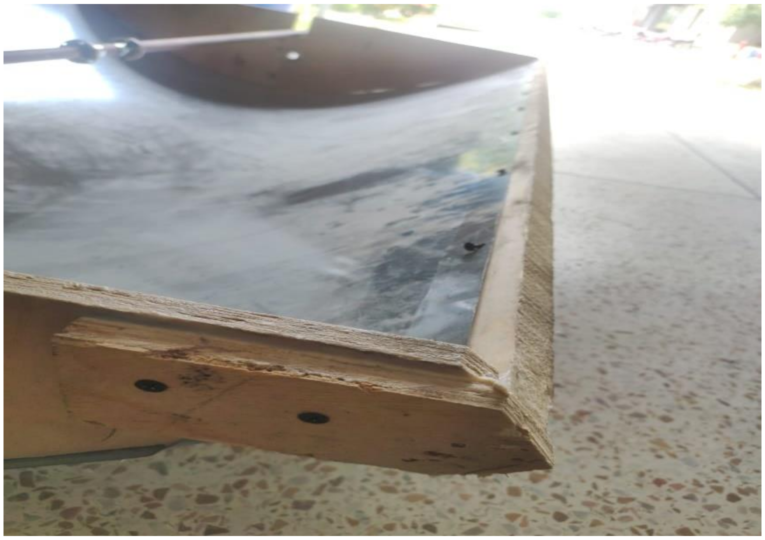

Figure 28: Wooden Supports for PSC

The wooden structure gives the parabola support and make sure that it stays in a perfect parabolic profile, have the same constant focal line.

ii. Supporting structure:

The supporting structure, made up of steel, was welded in accordance with our parabolic size. To combine and set the parabola in place, we used power bearings, that can also be adjusted to change and modify the angle a bit, in accordance to where we get the light most incident on the parabola surface.

Figure 29: Power Bearing Assembly

iii. Heat exchanger:

We procured a heat exchanger, that is composed of a storage tank made of *GI sheet* of *3.5ft height* & *2ft dia*.

- On the base of the storage tank, a core of *1ft dia* was welded.

For designing the helical coil, *copper* tube of *length 80ft* and *outer diameter of 13mm* was wrapped around the core in the shape of a coil. *21 turns* were provided to the coil.

Figure 30: Spiral copper tubes for helical coil heat exchanger

iv. Pipe assembly:

To carry our working fluid through the receiver tube, into the coil and back in the receiver tube (with the aid of a hot oil pump), we used various mechanical tools:

- Flaring nipples were used to connect the different diameter tubes and coils together and give us a closed loop system.

Figure 31: Flaring Nipple assembly for copper tubes

- Mechanical washers were also used along with epoxy chemical and Teflon tape to make sure that the chances of any water leak are minimized.
- Valves were used to control the fluid flow.
- An oil reservoir was used in line with the pump to make sure that the pump doesn't dry out and subsequently break down.

Figure 32: Oil Reservoir for pump

v. Backup system:

The equipment's used in our backup system have the following ratings:

Table 6: Backup system specifications

Name of equipment	Quantity	Ratings
Solar PV panel	5	90 W each
Heating element	2	150 W per piece with a 12 V DC.
DC Battery	1	12 V, 100 Ah

CHAPTER 4: RESULTS AND DISCUSSIONS

The system was manufactured, assembled, and tested in the workshop of USPCAS-E, the energy department of NUST. The experiment for the testing of the parabolic trough solar geyser was conducted on 3rd June 2023.

Testing Conditions:

Due to unpredictable weather patterns in Pakistan and sudden wave of rains in Islamabad, the testing was delayed but as soon as the rains stopped, we performed the experiment to test our system.

The weather was partly cloudy with average ambient temperature around 20 degrees Celsius. The parabola along with the storage tank was placed in the garden beside the workshop.

The main points of the experiment are follows:

- The experiment was day long from 9 AM to 5 PM.
- Thermocouples were attached to the inlets and outlets of both the hot fluid and water.
- Real time data logging was used to record temperature readings after each 10 mins interval.
- The inlet temperature of water was kept constant at around 20 degrees Celsius.
- The parabola was manually rotated throughout the experiment to provide maximum exposure to sunlight.

Results:

Following is the result obtained after a day of testing the solar geyser:

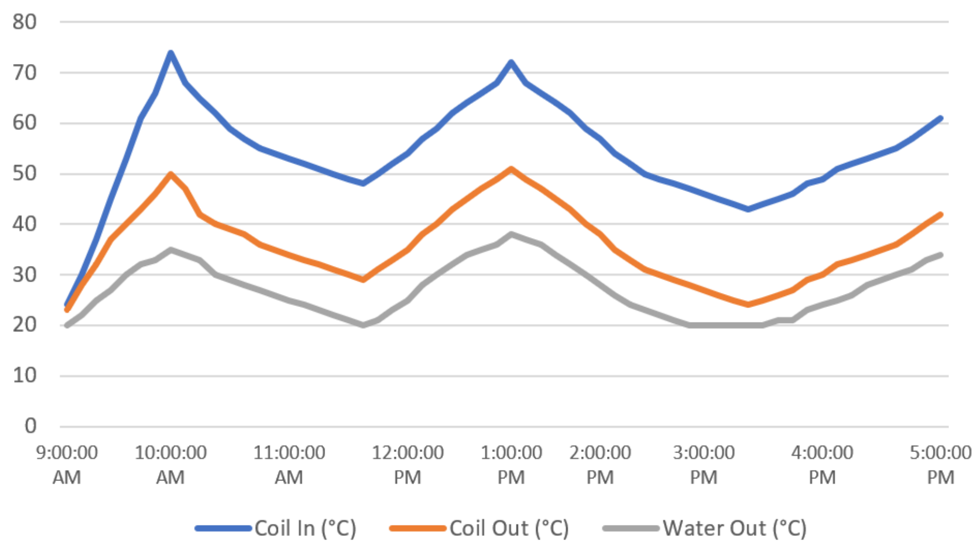

Figure 33: Time Stamp vs Temperature graph

Highlights of the experiment are as follows:

- We obtained a temperature gradient in the range of 15-25 degrees Celsius.
- The water was artificially taken out at intervals to mimic the use of a household at planned intervals to match the cloudy weather which also lowered the temperatures of hot fluid as well.
- The hot fluid reached maximum temperatures as high as 75 degrees Celsius.
- The water reached maximum temperature of around 38 degrees Celsius.

DISCUSSION

The repeated flushing of water at cloudy intervals was to test the reliability of our heat exchanging system at peak water usage hours, which proved to be very high and accurate.

We were expecting maximum temperatures of hot water around 40-45 degrees Celsius but due to the factor of heat losses and unpredictable weather, having achieved a temperature gradient of around 15-25 degrees Celsius was an achievement given that we had limited funding and resources to manufacture this system.

We also need to keep in mind that we did not deploy the system on a roof but in a garden due to logistical and space issues.

Projection of these results are impressive suggesting that we can achieve our desired results of peak water usage conditions in peak winter weather of Islamabad if following improvements are introduced in this system:

- Enhanced Heat Absorption: The efficiency of the system will improve by using advanced coatings on the surface of the collector tubes to enhance solar energy absorption. This can increase the heat transfer from the sun to the working fluid.
- Tracking Mechanism: Implementing a solar tracking system that adjusts the position of the parabolic trough throughout the day to maximize solar exposure. This allows the collector to constantly face the sun, increasing its efficiency and energy capture.
- Improved Insulation: Enhancing the insulation of the water storage tank and the piping system to minimize heat loss. Insulating materials with high thermal resistance will help maintain water temperature for longer periods, especially during nights or cloudy days.

- Optimized Fluid Flow: Optimizing the flow of the working fluid inside the collector tubes to maximize heat transfer. This can be achieved by using flow-enhancing devices or improving the design of the fluid flow channels to reduce resistance and increase thermal efficiency.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Conclusions:

In conclusion, the project demonstrated significant potential for harnessing solar energy to meet residential water heating needs. The project successfully designed and implemented various components, including a helical coil heat exchanger, parabolic trough collector, supporting structure, tracking system, and thermostat system. However, the absence of a tracking system due to time constraints hindered the system's overall efficiency.

Despite this limitation, the project yielded valuable insights into the design, implementation, and performance of the domestic water heating system. The parabolic trough collector efficiently concentrated solar radiation, while the helical coil heat exchanger facilitated effective heat transfer to the water. The supporting structure provided stability, and the thermostat system ensured optimal temperature control.

Moving forward, it is recommended to prioritize the integration of a tracking system to enhance the system's efficiency. The tracking system would allow the parabolic trough collector to actively follow the sun's movement, maximizing solar radiation collection throughout the day. This improvement alone has the potential to significantly increase the system's performance and overall energy utilization.

In addition to the tracking system, optimizing the system's components is essential for maximizing efficiency. Careful material selection for the helical coil heat exchanger, improving heat transfer efficiency, and reducing thermal losses will contribute to better overall performance. Moreover, reviewing and refining the design of the parabolic trough collector and supporting structure for durability, ease of installation, and maintenance are crucial.

Automation and control mechanisms should also be considered to enhance the system's efficiency and user experience. The integration of advanced sensors, actuators, and a programmable logic controller (PLC) can automate the tracking system, optimize water temperature control, and facilitate remote monitoring and control. These enhancements will streamline operation, reduce human intervention, and improve energy utilization.

To ensure the economic viability of the system, conducting a comprehensive cost-effectiveness analysis is recommended. This analysis should compare the initial investment, maintenance costs, energy savings, and payback period of the proposed system with conventional water heating systems. Highlighting the economic benefits and environmental advantages of the proposed system will aid in decision-making for stakeholders.

Furthermore, the project opens avenues for further research and development. Exploring the integration of additional renewable energy sources, such as photovoltaic panels or wind turbines, to create a hybrid system could enhance energy generation. Investigating alternative heat exchange mechanisms and innovative designs for parabolic trough collectors would also contribute to system improvements.

In conclusion, the domestic water heating system with a parabolic trough collector demonstrates great potential for utilizing solar energy in residential applications. The project's findings emphasize the importance of a tracking system for maximizing energy collection. By implementing the recommended improvements, such as the integration of a tracking system, optimizing system components, automating control mechanisms, and conducting a cost-effectiveness analysis, the system's efficiency and effectiveness can be significantly enhanced. With further research and development, the system can evolve into a sustainable and economically viable solution for domestic water heating, contributing to a greener and more energy-efficient future.

Limitations:

- One major limitation was the absence of a tracking system. The parabolic trough collector's efficiency was compromised as it could not actively track the sun's movement throughout the day. This limitation resulted in reduced energy collection, particularly during non-optimal solar angles. To overcome this constraint, further improvements are recommended.

- The parabolic trough surface is prone to dust collection if the conditions are windy, which can decrease the efficiency.
- Like every solar heating device, in cloudy conditions the efficiency and output of our system is bound to take a hit.
- The initial set up, with a copper coil, is expensive.

Recommendations:

Based on the project's outcomes and identified constraints, the following recommendations are proposed:

- **Tracking System Integration:** Installing a tracking system is highly recommended to enhance the system's efficiency. The tracking system would enable the parabolic trough collector to follow the sun's trajectory, maximizing solar radiation collection throughout the day. This would significantly increase the overall performance of the domestic water heating system, ensuring efficient energy utilization.
- **Heat Storage System:** Incorporating a heat storage system is a valuable enhancement for the domestic water heating system. During periods of high solar radiation, excess heat can be stored in thermal energy storage tanks or through the use of phase change materials. This stored heat can then be utilized during periods of low solar radiation or at night when the parabolic trough collector is not actively collecting solar energy. By integrating a heat storage system, the domestic water heating system can provide a continuous supply of hot water, ensuring user comfort and convenience.
- **Reflective Coating:** Applying a high-quality reflective coating to the surface of the parabolic trough collector can significantly improve its efficiency. The reflective coating enhances the collector's ability to absorb and reflect solar radiation, increasing the concentration of solar energy onto the helical coil heat exchanger. This, in turn, maximizes the heat transfer to the water passing through the coil, resulting in higher overall system performance and improved energy utilization.

- **Insulation:** Improving the insulation of the helical coil heat exchanger and storage tanks is crucial for minimizing heat losses and optimizing energy efficiency. By using insulation materials with high thermal resistance, such as fiberglass or foam insulation, the heat transfer from the hot water to the surrounding environment can be significantly reduced. This ensures that the heated water retains its temperature for longer periods, minimizing energy wastage and improving the overall system efficiency.
- **Water Quality Monitoring:** Integrating a water quality monitoring system into the domestic water heating system allows for continuous assessment and maintenance of water quality. Monitoring parameters such as pH levels, mineral deposits, and bacterial growth can help detect any potential issues that may negatively impact the system's efficiency and longevity. By promptly addressing these issues, such as scaling or corrosion, the heat transfer process can be optimized, and the system's lifespan can be extended, ensuring consistent and reliable performance.
- **Performance Monitoring and Analysis:** Implementing a comprehensive performance monitoring and analysis system is essential for evaluating the system's efficiency and effectiveness. By measuring and recording key parameters such as solar radiation levels, water flow rates, inlet and outlet temperatures, and energy consumption, it becomes possible to track the system's performance over time. This data can be used to identify any inefficiencies or deviations from expected performance, enabling necessary adjustments and optimizing the system's operation.
- **System Integration with Existing Infrastructure:** To maximize the benefits and minimize installation costs, integrating the domestic water heating system with existing infrastructure is recommended. For instance, connecting the system to the home's plumbing network or utilizing existing water storage tanks can streamline the installation process and reduce overall costs. Similarly, integrating the water heating system with other renewable energy systems, such as a solar photovoltaic system, allows for synergistic energy utilization and greater overall efficiency.
- **Education and Awareness:** Promoting education and awareness about the benefits of solar water heating systems is crucial for their widespread adoption. Organizing

workshops, seminars, or awareness campaigns can help educate homeowners, contractors, and policymakers about the advantages of renewable energy systems, the potential cost savings, and the positive environmental impact. By raising awareness and providing accurate information, the acceptance and support for such systems can be increased, driving their implementation and contributing to a sustainable future.

- **Collaborative Research and Development:** Collaborating with academic institutions, research organizations, and industry experts can provide valuable insights and foster innovation. Engaging in research projects or participating in industry forums focused on renewable energy and water heating systems enables access to new ideas, technologies, and funding opportunities. Collaborative efforts can lead to the development of more efficient components, advanced control systems, and optimized designs, further improving the domestic water heating system's performance and feasibility.

By:

1. **System Optimization:** To maximize the system's performance, optimization techniques should be implemented. This includes careful selection of materials for the helical coil heat exchanger to improve heat transfer efficiency and reduce thermal losses. Additionally, the design of the parabolic trough collector and supporting structure should be reviewed and refined for better durability, ease of installation, and maintenance.
2. **Automation and Control:** Introducing automation and control mechanisms can further enhance the system's efficiency and user experience. This may involve integrating advanced sensors, actuators, and a programmable logic controller (PLC) to automate the tracking system, optimize water temperature control, and facilitate remote monitoring and control. Such enhancements would streamline operation, reduce human intervention, and improve energy utilization.
3. **Cost-Effectiveness Analysis:** Conducting a comprehensive cost-effectiveness analysis is crucial before considering large-scale implementation. Evaluating the initial investment, maintenance costs, energy savings, and payback period will

provide valuable insights for stakeholders. The analysis should include a comparison with conventional water heating systems to highlight the economic viability and environmental benefits of the proposed system.

4. **Further Research and Development:** The project's scope offers ample opportunities for further research and development. Areas of exploration could include integrating additional renewable energy sources, such as photovoltaic panels or wind turbines, to create a hybrid system. Additionally, investigating alternative heat exchange mechanisms and exploring innovative designs for parabolic trough collectors can contribute to system improvements.