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Design and Thermo-Optical Optimization of a Solar Parabolic Trough Collector

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

خَلَقَ السَّمَاوَاتِ وَالْأَرْضَ بِالْحَقِّ ۖ يُكَوِّرُ اللَّيْلَ عَلَى النَّهَارِ وَيُكَوِّرُ النَّهَارَ
عَلَى اللَّيْلِ ۖ وَسَخَّرَ الشَّمْسَ وَالْقَمَرَ ۖ كُلٌّ يَجْرِي لِأَجَلٍ مُّسَمًّى ۗ أَلَا هُوَ
الْعَزِيزُ الْغَفَّارُ ﴿٥ الزمر﴾

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DEDICATION

First and foremost, I would like to express my deepest love and gratitude to my parents for their unwavering support and belief in me, helping me reach this stage in my academic journey and realize my potential. I am also immensely thankful to my friends for their constant presence and support throughout this endeavor, always there when I needed them without a word of complaint. Finally, I wish to extend my heartfelt thanks to my partner in this work for being an exceptional teammate and an invaluable part of this project.

GUEDRI MOHAMED SERADJ EDDINE

I completed this small effort with the assistance of ALLAH, who has opened my eyes to the paths of knowledge. I dedicate this work to my lovely parents with all of my love, compassion, and respect. For all they have done for me, I will never be able to repay them. God bless you and keep you safe. To my sisters and brother, for all the love and support they have given me. To my entire family. To all my friends for their encouragement. And especially to my partner in this work.

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Abstract

In this graduation project, we focused on the design, construction, and optimization of a Parabolic Trough Collector (PTC). Extensive efforts were made to build the PTC using various materials and innovative techniques. numerous tests were conducted to enhance the PTC performance, experimenting with single tube, double tube, and multi-pass absorber setups. The findings demonstrate a 63% improvement in thermal efficiency, validating the effectiveness of the proposed design for thermal solar energy applications.

Keywords: Parabolic Trough Collector, absorber configuration, thermal efficiency, solar energy, multi-pass tubes

ملخص

في مشروع التخرج، ركزنا على تصميم وبناء وتحسين مجمع الطاقة الشمسية ذو المقطع المكافئ. بذلنا جهودًا كبيرة في بناء المجمع باستخدام مواد وتقنيات مبتكرة مختلفة. أجرينا العديد من الاختبارات لتحسين تكوين الممتص، حيث جربنا إعدادات الأنبوب الواحد، والأنبوبين، والأنابيب متعددة المراحل. تُظهر نتائجنا تحسينات كبيرة في الكفاءة الحرارية، مما يثبت فعالية تصميماتنا المحسنة لتطبيقات الطاقة الشمسية

مجمع الطاقة الشمسية ذو المقطع المكافئ، تكوين الممتص، الكفاءة الحرارية، الطاقة الشمسية، الأنابيب متعددة **:الكلمات الرئيسية**
المراحل

General Introduction

This project investigates the development and optimization of Parabolic Trough Collectors (PTC), a pivotal technology in harnessing solar energy. The study is structured into three comprehensive chapters, each focusing on a crucial aspect of PTCs.

In the first chapter, we conduct a historical review and provide a detailed examination of the components of PTCs. This includes an analysis of different types of solar concentrators and their respective applications, illustrating the evolution and significance of PTC technology in the renewable energy sector.

The second chapter is dedicated to the design and construction of the PTC. Here, we meticulously document the methodologies and processes involved in the manufacturing of the PTC, providing step-by-step details of each stage. This includes material selection, structural design, and the assembly of the various components, highlighting the challenges and solutions encountered during the construction process.

The final chapter presents an experimental study where we conducted extensive tests on the PTC to evaluate its optical and thermal performance. We explored different configurations, including single and double tubes, and introduced innovative tests with a multi-pass absorber. The results of these experiments are analyzed to determine the maximum temperatures achieved under various configurations, demonstrating the efficacy and potential improvements of the multi-pass design. This chapter underscores our contributions to advancing PTC technology and its applications in sustainable energy production.

I.1 History and introduction

Parabolic trough solar collectors (PTC) use curved mirrors to concentrate sunlight on a receiver, generating heat to produce electricity or power other processes. The concept of PTC dates back to antiquity, but their large-scale development began in the late 19th century. Continuous technological advances, such as vacuum tube receivers, have improved their efficiency during the 20th and 21st century. Today, PTC is a mature and competitive technology for renewable electricity generation, offering benefits like energy storage and high efficiency.

Beyond power generation, PTC can be used for green hydrogen production, desalination and various industrial applications. Despite challenges such as high cost and potential environmental impact, PTC represents a promising solution for a sustainable energy future, driven by technological advances, lower costs and political support.

Figure 1: Parabolic cylindrical concentrator

I.2 PTC composition

I.2.1 *The reflector: Capturing solar energy*

The reflector plays a crucial role in the efficiency of the cylindrical parabolic solar concentrator (PTC) by maximizing the reflection of the solar radiation towards the absorbing tube. Its manufacture involves the shaping of a sheet according to a precise parabolic form, described by the equation:

$$y = a \cdot x^2 \qquad \text{Avec} : a = \frac{1}{4 \cdot F} \qquad y = \frac{1}{4 \cdot F} x^2 \tag{1}$$

Allowing the convergence of the sun's rays towards a single focal point following a distance F=1/(4.a) from the axis of symmetry. For optimal reflectivity, the surface material should be highly reflective, like stainless steel with a mirror polished finish.

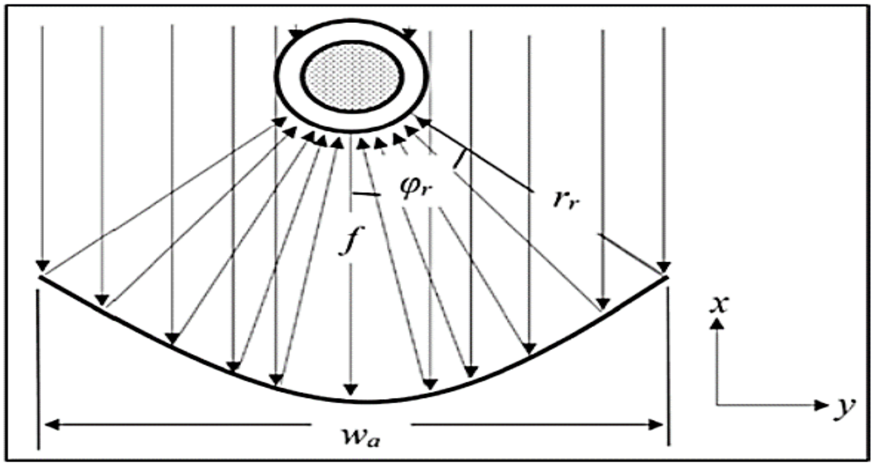


Figure 2: Linear PTC-cross section [1]

I.2.2 The absorber: Converting solar energy into heat [2]

The absorber (Fig.3) is responsible for absorbing concentrated solar radiation and converting it into useful heat. Its design is based on a compromise between the diameter, length and thickness of the tube to minimize heat loss. Generally made of steel or copper for high thermal conductivity, its surface is covered with a matte black paint to maximize the absorption of solar radiation.

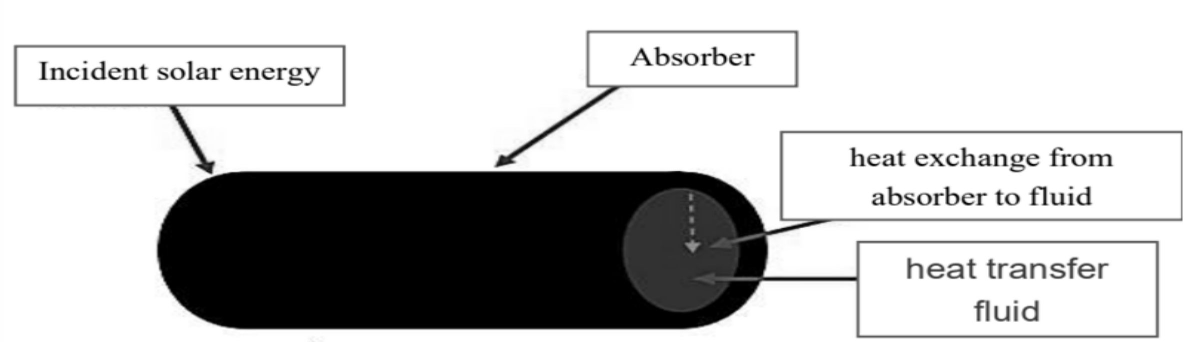


Figure 3: Schematic of an absorber tube [3]

I.2.3 The coolant fluid: Transport of thermal energy [2]

The heat transfer fluid plays an essential role in the PTC system by transporting the heat energy converted by the absorber to its use or storage. To ensure optimal performance, it must meet strict criteria:

- **Low viscosity and low casting point:** Facilitates fluid flow through the system.

- **High boiling point and low freezing point:** Allows use in a wide temperature range.
- **Chemical resistance:** Prevents corrosion and degradation of system materials.
- **Low pressure drops:** Minimizes energy loss during fluid transport.
- **High heat transfer coefficient:** Promotes efficient heat absorption by the fluid.
- **High heat capacity:** Carries a large amount of heat.
- **Low toxicity:** Ensures safety and environmental protection.

I.2.4 Support structure:

The support structure holds the mirrors in place and directs the PTC towards the sun. The structure must be strong enough to support the weight of the mirrors and withstand winds and snow loads.

I.2.5 Solar Tracking System:

The solar tracking system (Fig.4) allows the PTC to be directed towards the sun throughout the day. This ensures that the sun's rays are always focused on the receiver with maximum efficiency.

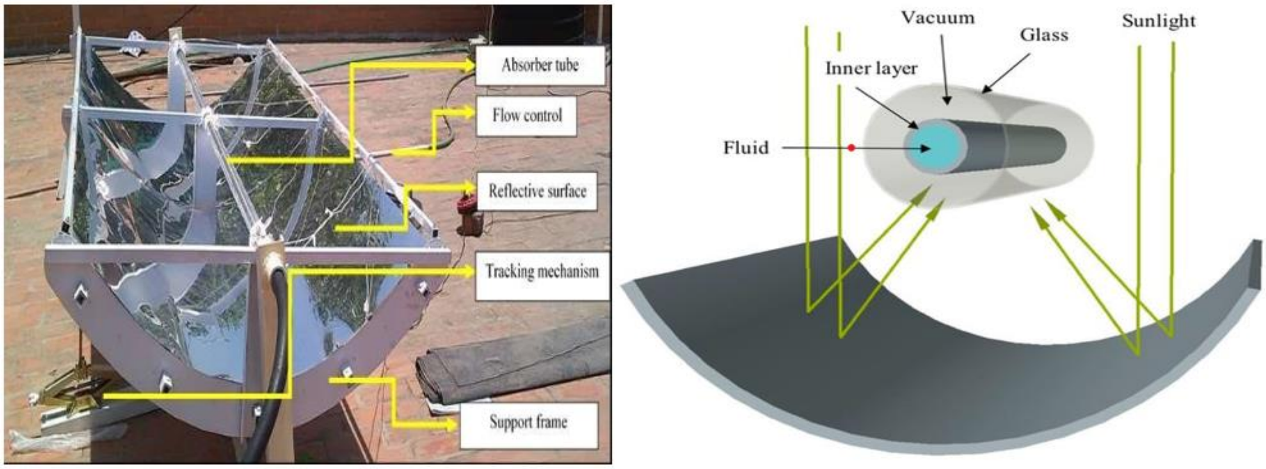


Figure 4: Detail of parabolic trough solar collector

I.3 Types of solar concentrators:

The types of solar concentrators vary depending on their ability to concentrate sunlight to produce heat or electricity. These types include point concentrators, such as tower plants, linear concentrators, such as solar collectors with vacuum tubes, and non-concentration or low temperature concentrators, like flat solar collectors. Each of these types has specific characteristics in terms of design and applications in solar thermal and photovoltaic systems and there are more types:

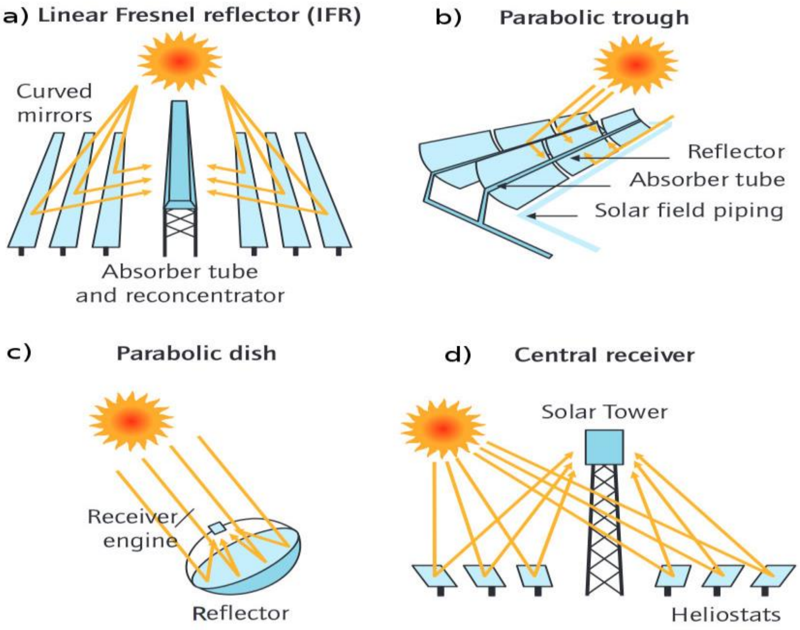


Figure 5: Types of solar concentrators [1]

I.3.1 Comparison of PTC with other solar concentrators

PTC solar concentrators are distinguished by their ability to generate an extremely high heat flow, placing them at the top of the list in this category. However, their main disadvantage lies in their lack of uniformity on the absorber, Although PTC have the highest solar flux, their uniformity on the absorber is relatively low, with a uniformity coefficient of about 0.32% [4].which can impact their performance. Despite this, PTCs have the advantage of being able to produce high temperature ranges by efficiently harnessing available solar energy. It is essential to note that the effectiveness of PTC can be subject to various factors, including the concentration ratio and the specific design of the solar collector. These elements play a crucial role in maximizing the performance of these systems.

I.4 Factors influencing PTC performance

The performance of PTC solar concentrators depends on several key factors, including the specific type of PTC used, as well as its composition and structure. In addition, operating conditions play a crucial role in their effectiveness. Aspects such as volume flow, receiver design, concentration ratio and the overall configuration of the solar collector are also determining factors that significantly impact PTC performance. It is therefore essential to take these different factors into account when designing and operating these systems to ensure optimal performance.

I.5 Application domain

- **Electricity generation** In concentrated solar power plants, parabolic troughs concentrators (PTC) are commonly used. Sunlight, concentrated by PTC, heats a fluid which is then used to generate steam. This steam feeds a turbine that is connected to an electricity generator. [5]
- **Water desalination** PTCs can be used in the water desalination process. The heat produced by the concentrators is used to evaporate seawater. The steam produced is then condensed to produce fresh water. [5] [6]
- **Heating and cooling systems** PTCs can be used to heat water and air in residential and institutional environments. They can also be integrated into solar cooling systems. [5] [6]
- **Industrial processes** Various industrial processes requiring high temperatures, such as glass and metal melting, can use PTC. [5]
- **Solar drying** PTCs can be used to dry agricultural products and other items. [6]

I.6 Enhancement Technique

I.6.1 Use of Nanofluids

Using nanofluids as a heat transfer fluid can increase efficiency by up to 10% [7]Nanofluids have better thermal properties than conventional fluids, which can improve heat transfer.

I.6.2 Tubular Receiver with Insertion

The use of a tubular receptor with insertion can increase the overall efficiency up to 10% [7]. Insertion can increase the turbulence of the fluid flow, thus improving heat transfer.

I.6.3 Optimization of Geometry and Optical Properties

The geometry and optical properties of PTC can be optimized to improve its performance [8]. This may involve adjusting the shape and size of the reflector or using different materials for the reflective surface.

I.6.4 Collision Reduction and Mirror Protection

Collision reduction and mirror protection can help maintain PTC performance [6]. This may involve using protective coatings or implementing systems to reduce dust and debris.

I.6.5 Minimization of Heat Transfer Fluid Pipeline Length

Minimizing the length of coolant lines in PTC systems is a key strategy to reduce heat loss and optimize system energy efficiency by maintaining high circuit temperatures. Efficient pipe design and management is essential to maximize the performance of PTC solar concentrators [6].

Chapter.II Design Methodology and Implementation Steps

II.1 The PTC holder design

II.1.1 Introduction

The holder of a Parabolic Trough Collector (PTC) is a critical component that ensures the proper alignment and stability of the reflective surface and the receiver tube. This section outlines the key steps and considerations in designing and sizing the holder for optimal performance and durability. Creating the holder for our Parabolic Trough Collector involved extensive work and precision. We meticulously performed numerous tasks, including cutting, drilling holes for secure connections (Fig.6), and aligning parts to ensure structural integrity. Each step required careful attention to detail to maintain the precise parabolic shape and ensure the stability of the holder. The culmination of these efforts resulted in a robust and reliable structure capable of supporting the PTC effectively.

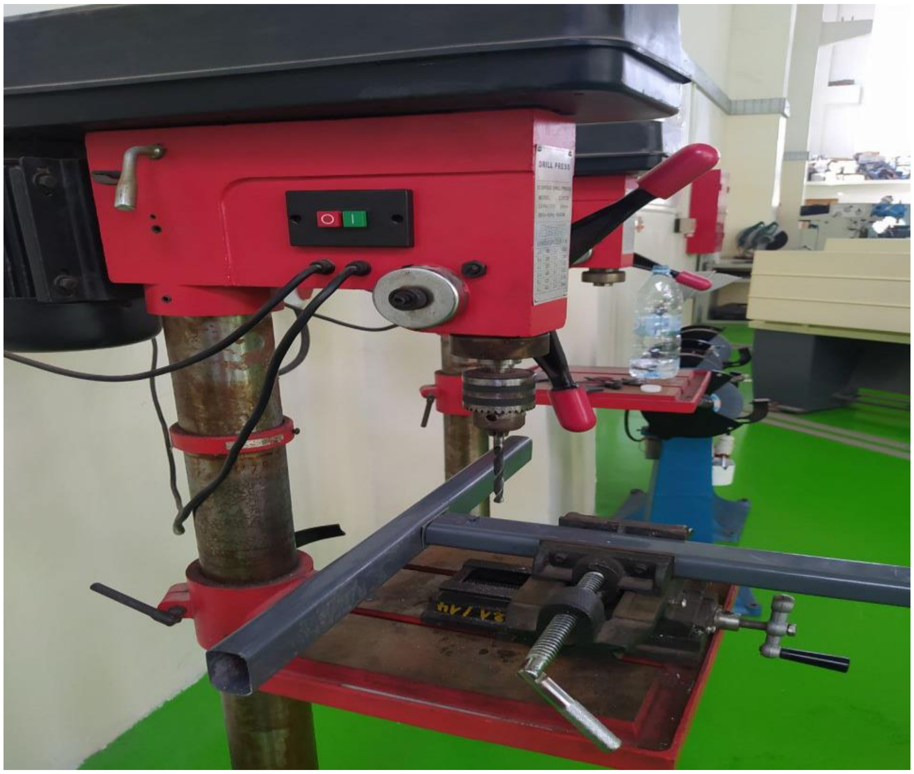


Figure 6:Holder drilling

II.1.2 The holder's contents

II.1.2.1 Receiver Holder Piece

This component is designed to securely hold the receiver tube in place. Ensuring that the receiver is precisely aligned with the focal point of the parabolic trough which is crucial for maximizing the concentration of sunlight. The precise alignment allows the system to efficiently convert solar energy into heat and it represents the number (1) in the **figure 7**.

II.1.2.2Parabola Holder Piece

The parabola holder piece is responsible for supporting the reflective parabolic surface. It maintains the correct curvature and alignment of the parabola, which is essential for focusing sunlight onto the receiver tube. The accuracy of this piece directly impacts the efficiency of the solar energy collection process, it also plays a role in stabilizing the holder, and it represents the number (2) in the **figure 7**.

II.1.2.3Equilibrium Piece

The equilibrium piece is designed to stabilize the entire holder structure. It ensures that the holder remains balanced and steady, maintaining structural integrity and alignment. This stability is vital for the consistent performance of the Parabolic Trough Collector over time and it represents the number (3) in the **figure 7**.

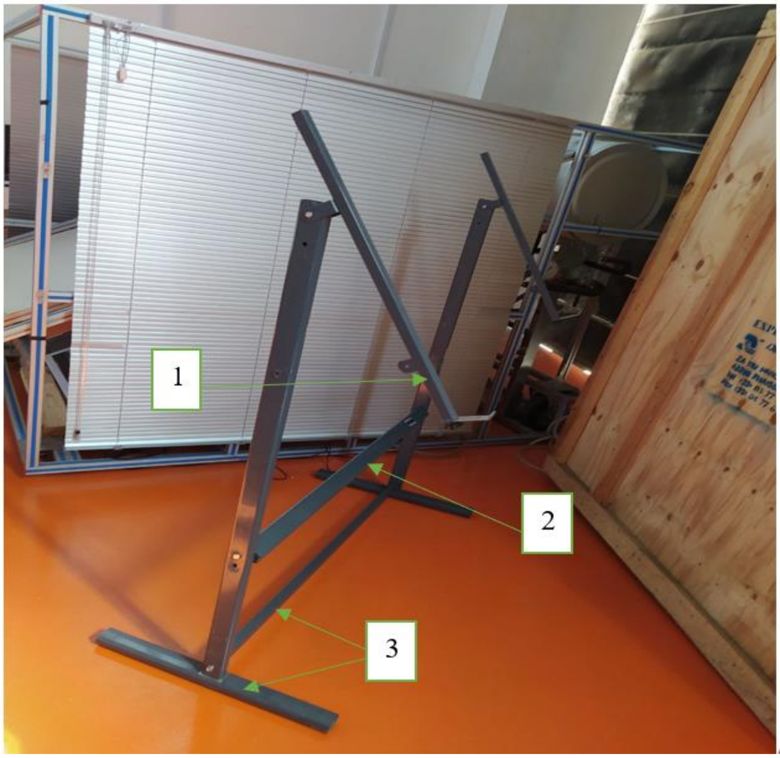


Figure 7: The PTC's holder

II.2 Sizing of the parabola

The rim angle (φr) is the angle between the collector's center line and the line drawn from the focal point to the edge of the collector (Fig.2). The design of the reflector includes an optimal rim angle, which ranges between 70° and 110° [9].Given a fixed rim angle of 80 degrees (φr = 80°) and the width of stainless steel foil used (S=2m) for our PTC, we can now determine the aperture width (Wa) of the parabolic using equation II-1: [10]

$$W_a = \frac{2S\tan\left(\frac{\varphi_r}{2}\right)}{\left(\sec\left(\frac{\varphi_r}{2}\right)\tan\left(\frac{\varphi_r}{2}\right) + \ln\left(\sec\left(\frac{\varphi_r}{2}\right) + \tan\left(\frac{\varphi_r}{2}\right)\right)\right)} \quad \text{(II-2)}$$

And the Focal length is given as: [10]

$$f = \frac{W_a}{4\tan\left(\frac{\varphi_r}{2}\right)} \quad \text{(II-2)}$$

The vertical height of parabola is calculated by: [11]

$$H_p = \frac{W_a^2}{16f} \quad \text{(II-3)}$$

Rim radius of parabola calculated by: [11]

$$r_r = \frac{2f}{1 + \cos\ \varphi_r} \quad \text{(II-4)}$$

II.2.1 *Enhancing PTC Efficiency with Optimal Arc Length*

we have meticulously chosen a shiny stainless-steel sheet with dimensions of 2/1 meter. The decision to utilize the 2-meter length as the arc length of the parabola stems from our aim to maximize the concentration ratio, which is critical for enhancing the efficiency of solar energy collection. The increased arc length of 2 meters offers a superior concentration ratio compared to a 1-meter arc, thereby capturing and focusing more solar energy onto the receiver tube. This choice is complemented by our holder, which is designed to support a 1-meter length, ensuring structural stability and ease of integration into the overall system. By optimizing the arc length, we achieve a balance between enhanced performance and practical design considerations, paving the way for an efficient and effective parabolic trough collector.

To understand the efficiency of this design, we calculate the geometric concentration ratio using equqtion II-5 :

$$C = \frac{Effective\ aperture\ area}{Absorber\ tube\ surface\ area} = \frac{(W_a - D_o) \times L}{\pi D_o L} \quad \text{(II-5)}$$

In comparison to the aperture width, the tube's diameter is being disregarded:

$$C = \frac{W_a}{\pi D_o} \quad \text{(II-6)}$$

Table 1: parameters of the parabola

Parameters	Dimensions
Rim angle (φr)	80°
Aperture width (Wa)	1.806 m
Length (L)	1m
Focal length (f)	0.536m
Concentration ratio (C)	35.929
Rim radius (r_r)	0.913m
vertical height (H_p)	0.380m

II.2.2 *Focal point experimental verification*

For the verification of the focal point, we began by drawing the x and y axes on a wooden table, providing a clear reference framework for our measurements. Using these axes, we carefully plotted the points to define the parabolic curve. To create the parabolic shape, we utilized a tube, bending it precisely according to the plotted points. This meticulous process involved precise calculations to ensure the correct shape and focal point, crucial for the efficiency of the Parabolic Trough Collector. The wooden table served as a stable and durable surface, allowing us to accurately mark and adjust the parabola as we needed.

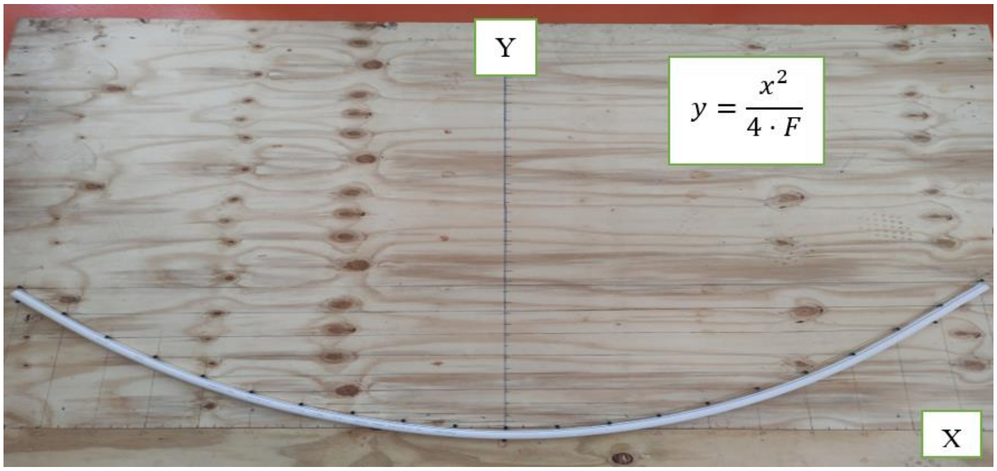


Figure 8:the parabolic curve

After shaping the tube to match the parabolic curve, we covered it with aluminum to enhance its reflective properties. To determine the focal point, we utilized a laser light. However, instead of forming a precise point, the laser projection resulted a line. To address this, we used a mirror, which allowed us to accurately pinpoint the focal point. This indicated that adjustments were necessary to refine the alignment and ensure that the parabolic curve correctly focuses sunlight onto a single point on the receiver tube for optimal efficiency. To accurately locate the focal point, we needed to ensure the laser was positioned perpendicular to the parabolic surface, at a 90-degree angle (Fig.9). This precise alignment was crucial for determining the exact focal point.

Figure 9:Locating the focal point

II.2.3 Optimization of the parabolic shape

Upon measuring, we found that the practical results matched our theoretical calculations perfectly for the focal point. However, we discovered that only 60% of the sunrays were reflecting to our focal point. This indicated that our parabola was not accurately drawn, resulting in suboptimal reflection efficiency. To address this issue, we concluded that a new method was necessary to optimize the parabolic shape. This led us to research and implement advanced techniques to ensure a more precise parabolic curve, thereby improving the concentration of sunlight onto the receiver tube and enhancing the overall efficiency of our Parabolic Trough Collector.

To improve our design, we adopted a new method, which provided a more precise approach to optimizing the parabolic shape. The new method we adopted relied on our already established focal point and utilized a square tool to draw the parabola. First, we needed to make our square tool, ensuring it was precisely constructed to aid in accurate plotting as shown in **Figure 10**.

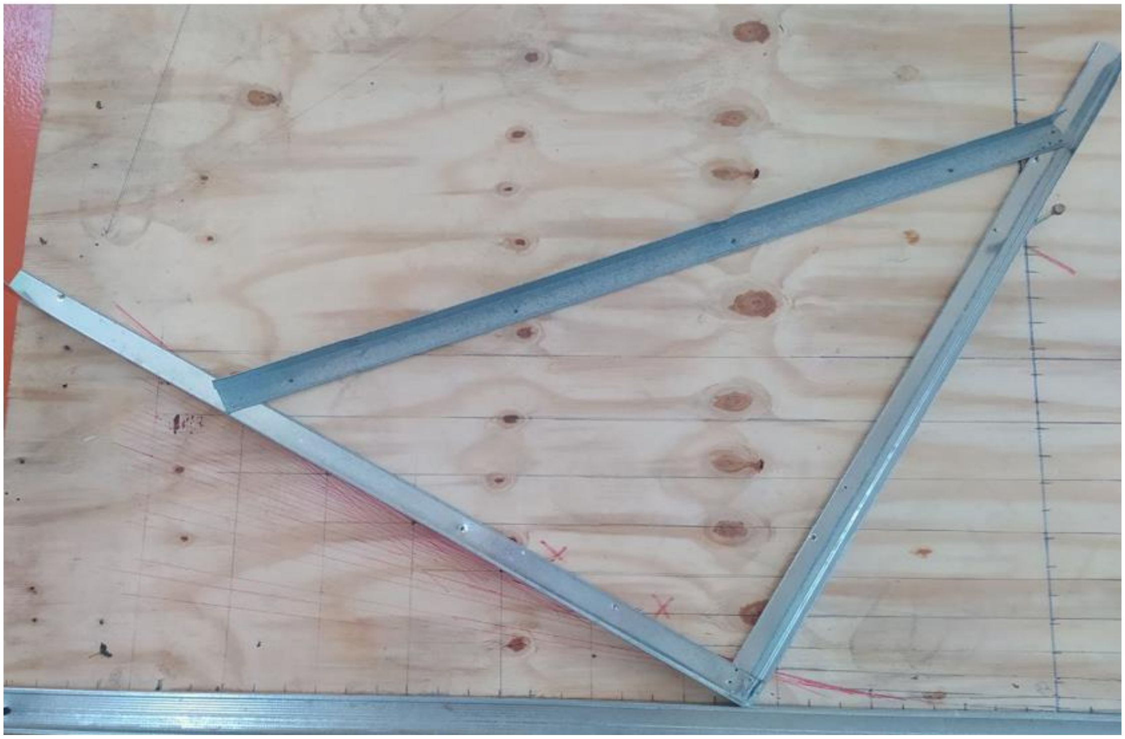


Figure 10: square tool manufactured for the parabola drawing

By aligning the square tool with the focal point and ensuring the 90-degree angle of the tool intersected each point along the x-axis, we were able to systematically and accurately mark the parabolic curve, as shown in **Figure 11**. This technique ensured a more precise shape for our parabola. The new method provided us with a perfect shape for our parabola, resulting in an impressive 95% of reflective sunrays converging to the focal point. This precision enhanced the efficiency, maximizes the concentration of sunlight onto the receiver tube and significantly boost the system's overall performance.

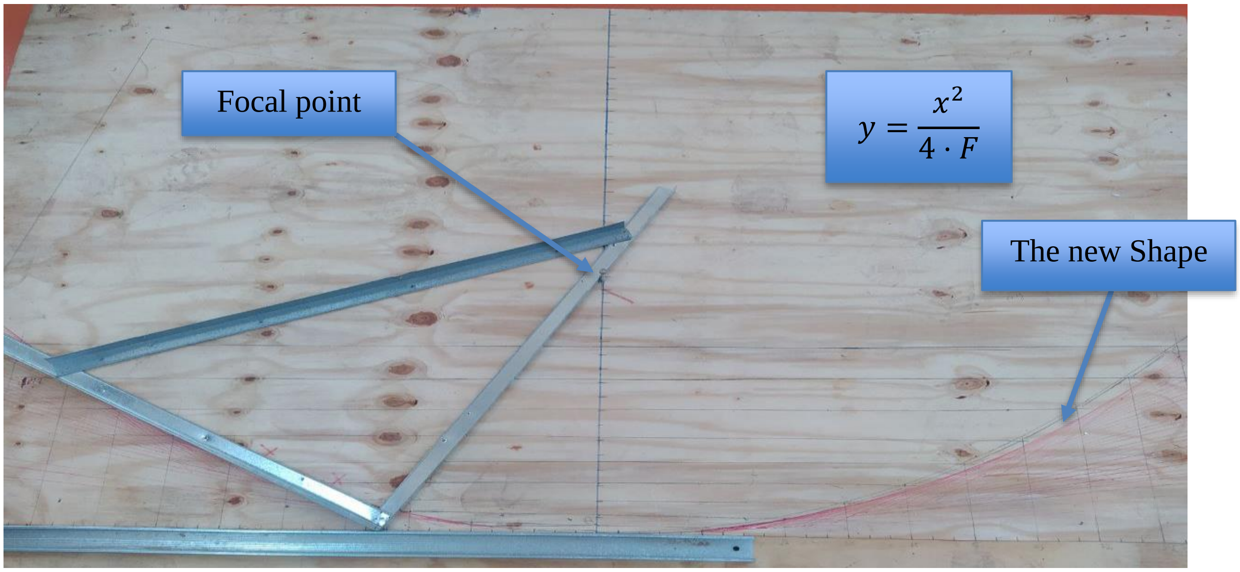


Figure 11: The new parabola shape

After achieving the exact shape of the parabola, we proceeded to shape two pieces of flat iron steel, each measuring 2 meters in length, to match the parabolic curve. To accomplish this, we used a folding machine. This meticulous process ensured that the steel components conformed perfectly to our parabolic design, providing a robust and accurate structure for the Parabolic Trough Collector.

Unfortunately, the machine and the operator did not produce the exact shape according to the data we provided. This discrepancy required us to undertake significant manual adjustments. We meticulously re-measured and manually bent the steel pieces (Fig.12), using various tools to correct the errors and align them with the precise parabolic curve. This painstaking process demanded precision and patience, as even slight deviations could affect the efficiency of the Parabolic Trough Collector. Despite the initial setbacks, our dedicated efforts ensured that the steel components ultimately conformed perfectly to our parabolic design, providing a robust and accurate structure for optimal sunlight concentration.

Figure 12:Manual Parabolic Shaping Adjustment of the Steel bars

After we adjusted the steel pieces to achieve the exact parabolic shape, we proceeded to drill precise holes for assembly. Carefully aligning the pieces, we then assembled them into the parabola holder piece of our holder. This step was crucial in securing the structure and ensuring the stability and accuracy of the Parabolic Trough Collector, setting the foundation for an efficient solar energy system.

Figure 13: parabola holder assembly

After finishing the holder, it was time to install the stainless-steel foil that would serve as our reflective surface. With the steel pieces already drilled, we carefully positioned the stainless-steel foil, securing it tightly to ensure a smooth and continuous reflective surface and to ensure the structural integrity of our design and prevent the steel pieces from gradually opening and losing their precise parabolic shape over time, we secured the ends of each steel piece with sturdy cables. These cables (Fig.14) provided additional stability and maintained the correct curvature of the reflective surface

Figure 14:Reflective Surface Installation Complete

Once the foil was in place, we meticulously adjusted the position of the focal point and the receiver tube, utilizing the actual sunrays to fine-tune their alignment. This practical alignment confirmed the accuracy of our theoretical calculations, ensuring that the concentrated sunlight would effectively target the receiver. This step was crucial in optimizing the efficiency of our Parabolic Trough Collector, guaranteeing maximum solar energy capture and conversion.

Figure 15:Precise Focal Point Adjustment Using Sunrays

II.3 Fluid circuit design

The water circuit is a crucial element in the functionality of a Parabolic Trough Collector (PTC). It serves as the medium through which the captured solar energy is transformed into usable thermal energy. By circulating water through a network of pipes and a receiver tube located at the focal point of the parabolic mirror, the system harnesses the concentrated solar energy to heat the water. This heated water can then be utilized for various applications such as electricity generation, industrial processes, and residential heating. The design and construction of the water circuit must ensure efficient heat transfer, minimal energy loss, and durability under high temperatures.

II.3.1 Circuit Components

- **Absorber Tube**

For our absorber tube, we utilize a copper tube, which significantly enhances the efficiency and performance of the Parabolic Trough Collector (PTC). Copper is an excellent conductor of heat, ensuring rapid and uniform heat transfer from the concentrated solar energy to the water circulating through the tube. Additionally, copper's durability and resistance to high temperatures and corrosion ensure a long-lasting and reliable operation of the PTC system.

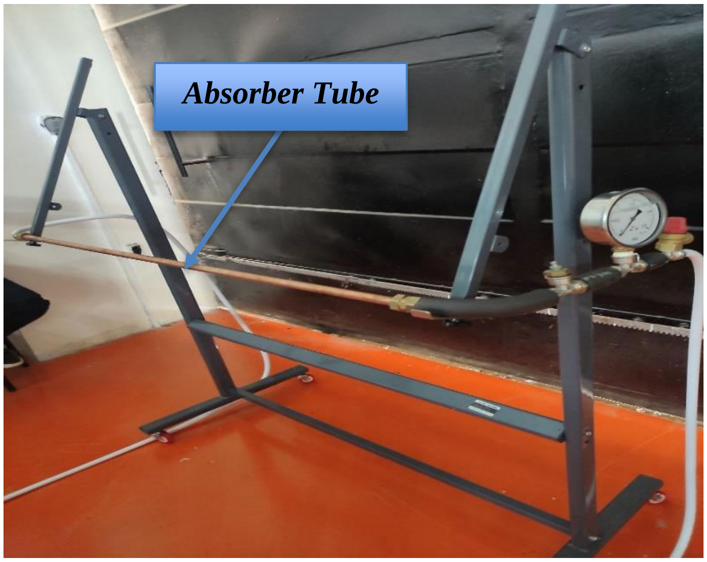


Figure 16:Absorber Tube

Table 2:Characteristics of the absorber tube

Absorber length	**1m**
Outer diameter of the absorber	0.016m
Internal diameter of the absorber	0.015m

- **Water Pump**

The water pump is an essential component of the Parabolic Trough Collector (PTC) system, responsible for ensuring the continuous circulation of water through the copper absorber tube. By maintaining a steady flow, the pump facilitates effective heat absorption and transfer, optimizing the system's efficiency. This continuous movement of water helps prevent overheating and ensures uniform temperature distribution throughout the network of pipes.

Figure 17: Water Pump

- **Safety Valve**

The safety valve is designed to release excess pressure and prevent potential damage or accidents. It ensures the system operates within safe pressure limits, protecting both the equipment and users. By automatically venting pressure, when necessary, the safety valve maintains the integrity and safety of the entire system.

Figure 18: Safety Valve

- **pressure gauge (Fig.19)**
- **inlet and outlet Thermocouple (Fig.19-20)**

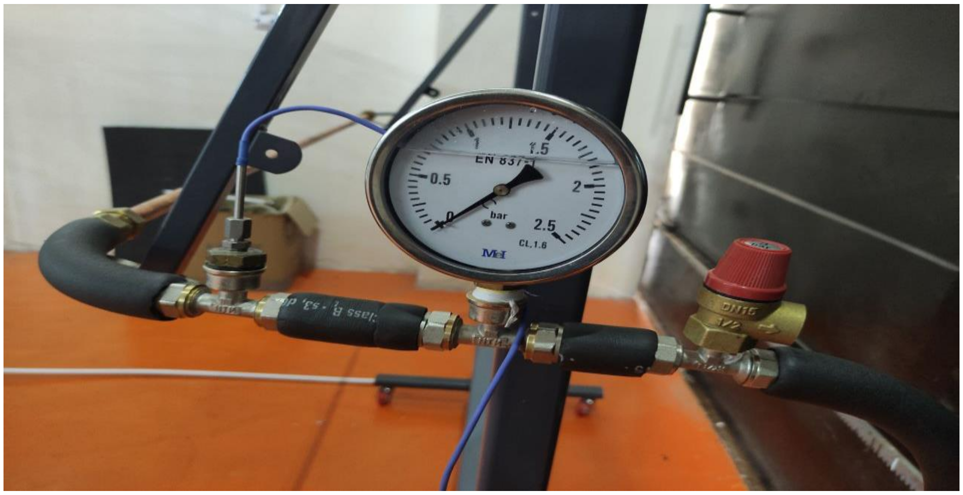


Figure 19: pressure gauge

Figure 20: inlet Thermocouple

- **Flow meter**

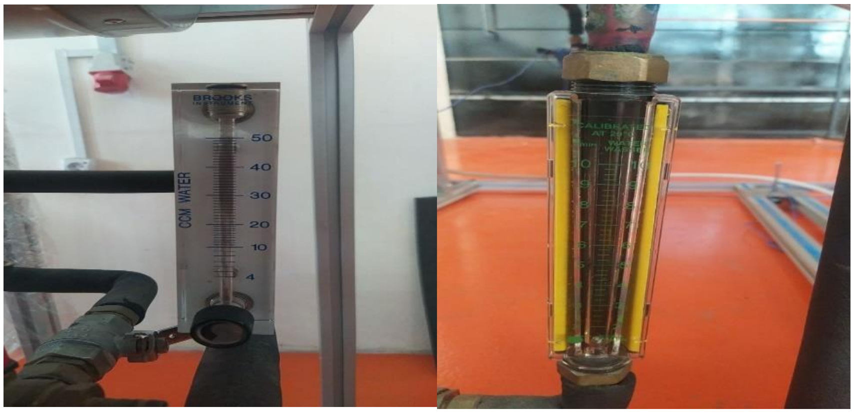


Figure 21:The float flow meter

- **Other Connections**

In constructing the Parabolic Trough Collector (PTC) water circuit, careful consideration was given to the placement of T-junctions, valves, and various junction points (Fig.22). These components are strategically integrated (Fig.23) to ensure efficient water flow control and distribution throughout the system. Materials selected for these elements prioritize durability and reliability under high temperatures, adhering to stringent construction standards to maintain operational integrity and optimize thermal efficiency.

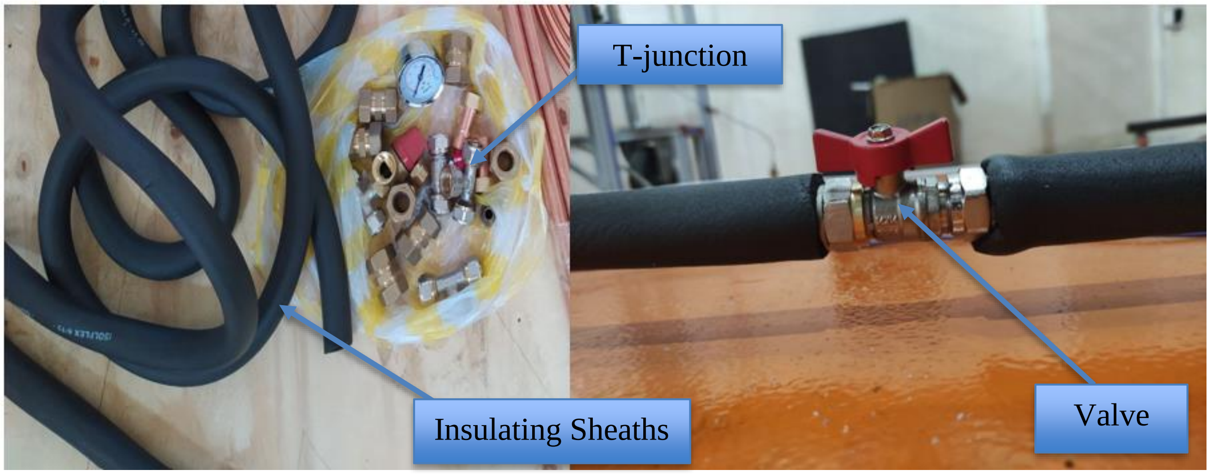


Figure 22: Some Connections

Figure 23: Implementation and Construction of the Circuit

- **Thermal storage tank**

The storage tank of the solar unit EEST was used. This device is intended to store heat created by solar radiation during the day for use during periods of low solar radiation or at night, increasing the overall efficiency and availability of the solar power.

Our thermal storage device with a capacity of 50 liters features an integrated heat exchanger, which efficiently captures and stores excess thermal energy from the Parabolic Trough Collector (PTC) system. Inside, the heat exchanger transfers heat from the circulating water to a storage medium, such as molten salts or thermal oils, allowing for high-temperature retention.

Figure 24: Thermal storage device

- **Pipe circuit**

We have utilized multilayer pipes in our Parabolic Trough Collector (PTC) system, which are made up of an aluminum core placed between two layers of cross-linked polyethylene (PEX) joined together with a high-performance adhesive. This design combines the strength and thermal conductivity of aluminum with the flexibility and durability of PEX, resulting in a highly efficient and robust piping solution. The multilayer construction ensures excellent pressure resistance and long-term reliability, even under high-temperature conditions. In our circulation system, we have designated two sides: the hot side and the cold side. To minimize heat losses on the hot side, the pipes are covered with insulating pipe sheaths. These sheaths are designed to retain heat within the pipes, enhancing the system's overall thermal efficiency. By reducing heat loss, the insulation ensures that the maximum amount of captured solar energy is utilized for its intended applications, whether for electricity generation, industrial processes, or residential heating.

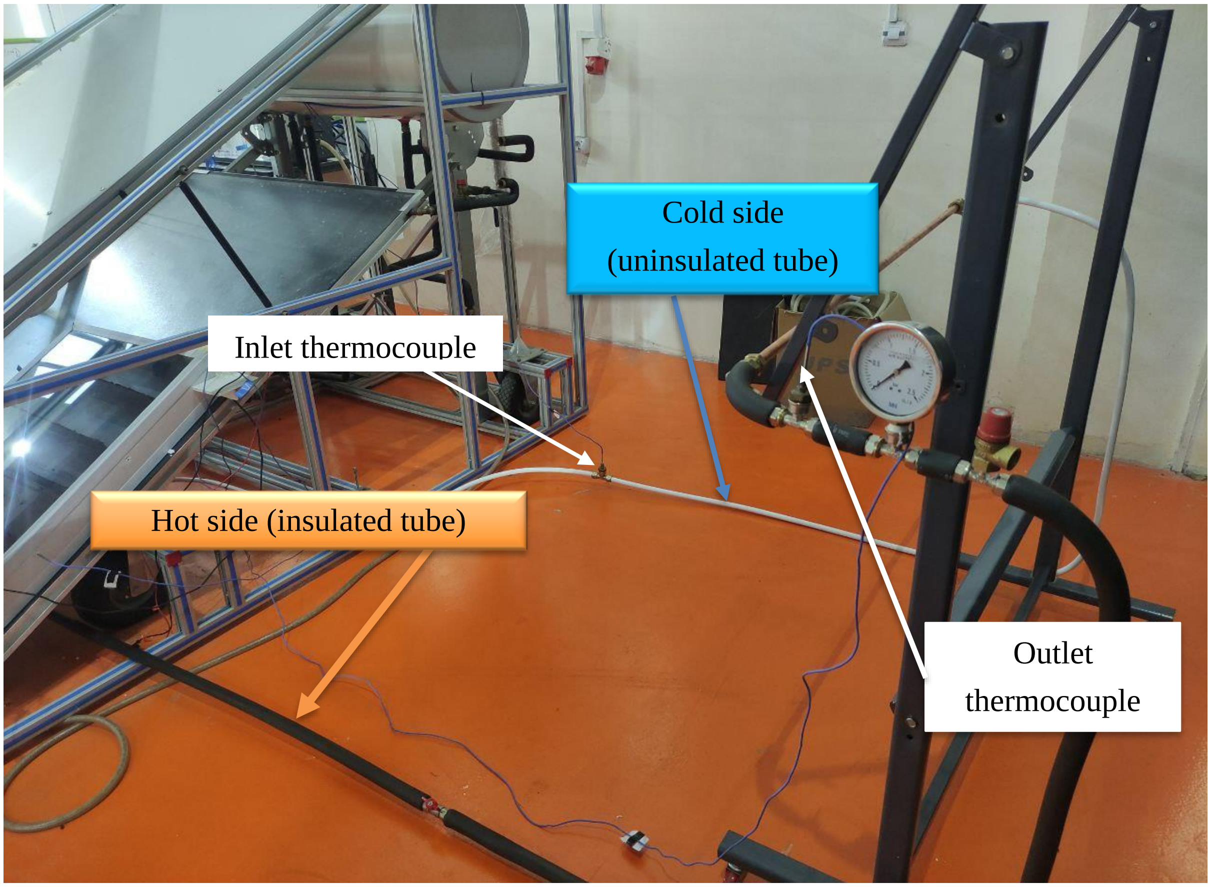


Figure 25: The Experimental setup of Circuit

II.3.2 Water Circulation System

The synoptic of the hydraulic circuit shown in **Figure 26**, created using **EdrawMax**, showcases the comprehensive water circulation system for our Parabolic Trough Collector (PTC). This detailed illustration includes all key components.

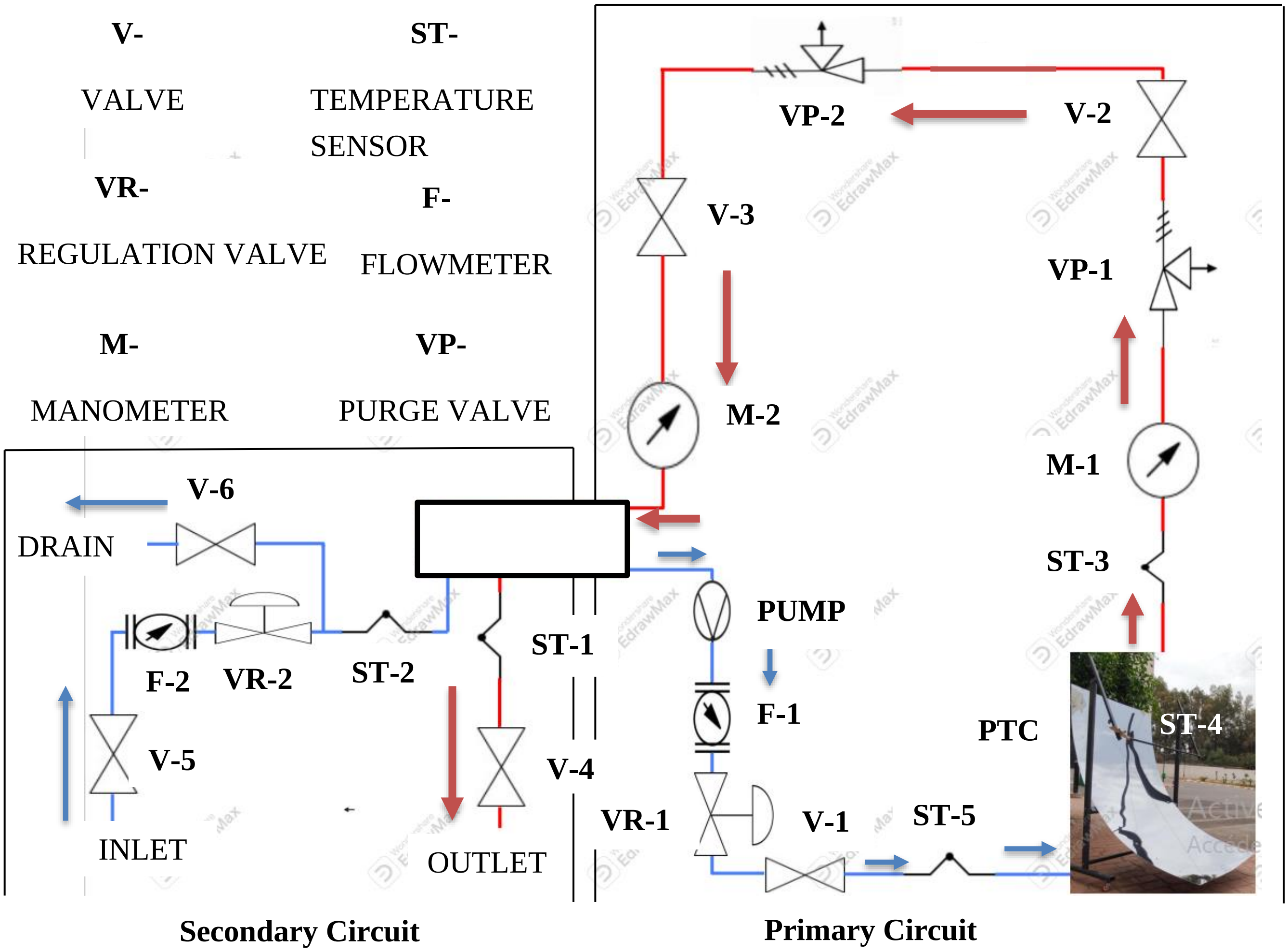


Figure 26: Synoptic of the hydraulic circuit

Chapter.III Experimental Investigation for Efficiency Enhancement

III.1 Introduction

In this chapter, we present and discuss our practical experiments conducted on the parabolic trough collectors. Through a series of detailed tests and measurements, we aim to evaluate the performance, efficiency, and potential improvements of the system. This analysis provides a critical understanding of the practical challenges and successes encountered during our study, offering valuable insights into the real-world application of parabolic trough technology.

III.2 Optical Analysis

The optical efficiency, η_o, is defined as the ratio of the energy used by the heating element to the energy received at the collector's opening, and it is represented by: [1]

$$\eta_o(\theta = 0) = \rho\tau\alpha\gamma \qquad \text{(IIII-1)}$$

Where (ρ) represents the reflectivity of the mirror, (τ) indicates the transmittance of the glass envelope, (α) indicates the absorptivity of the coating on the absorber surface, and (γ) is the capture factor of the mirror and heating element. The maximum optical efficiency of a typical PTC is around 75% [12].

Table 3:The Optical Efficiency and the Geometric Parameters of the PTC.

Parameters	Value
α	0,94
γ	0,72
τ	1
ρ	0,65
$\boldsymbol{\eta_o}$	0,44

III.3 Thermal Performance

The thermal efficiency of the PTC is calculated using: [1]

$$\eta_{\mathrm{th}} = \frac{Q_u}{A_{ap} I_D} \qquad \text{(IIII-2)}$$

$A_{ap}$is the aperture area of collector, and I_D is the direct solar irradiance component in the aperture plane of the collector. Where $Q_u$represents the useful energy transferred to the working fluid: [1]

$$Q_u = \dot{m} C_{p,f} (T_{\mathrm{out}} - T_{\mathrm{in}}) \qquad \text{(IIII-3)}$$

Table 4: The thermal Efficiency and the Parameters of the PTC.

Parameters	Value
A_{ap}	1,8 m²
I_D(Experimental measure)	584,81w/m²
Q_u	154,33kJ 200 w 4246 w/m2
η_{th}	0,19

Although acceptable optical performance was achieved, thermal performance was found to be very low. To address this issue, different absorber configurations were tested in order to enhance the thermal efficiency.

III.4 Optimization Study

In our tests, we evaluated various absorbers configurations, measuring the temperature under different conditions. This approach allowed us to compare performance and identify the most efficient absorber designs.

No-load tests were carried out to determine the best configuration which will afterward be tested under load. During no-load tests, the receivers were exposed to sunlight without water inside, while thermocouples were inserted into the tubes to monitor temperature variations. This setup allows us to isolate and analyze the thermal performance of the absorbers, providing clear insights into their efficiency.

III.4.1 Configuration 1: single copper tube without coating

The **Figure 27** illustrates the temperature and solar radiation graph for a single copper tube over time. It reveals that the tube's temperature rises from an initial 32 degrees Celsius to a peak of 61 degrees Celsius. This temperature increase occurred under solar radiation levels ranging between 240 and 300 W/m².

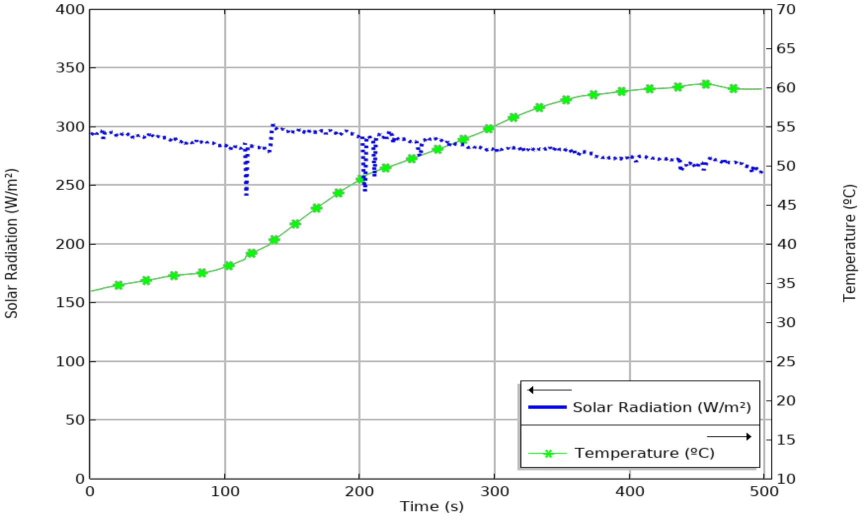


Figure 27:Temporal Variation of Temperature and Solar Radiation in copper tube

III.4.2 Configuration 2: Case of a copper tube with black coating

Figure 28 illustrates the temperature and solar radiation graph for a single black copper tube over time. It reveals that the tube's temperature rises from an initial 40 degrees Celsius to a peak of 69 degrees Celsius. This significant temperature increase occurred under solar radiation levels ranging between 215 and 250 W/m². The data underscores the black copper tube's superior ability to absorb and convert solar energy into heat.

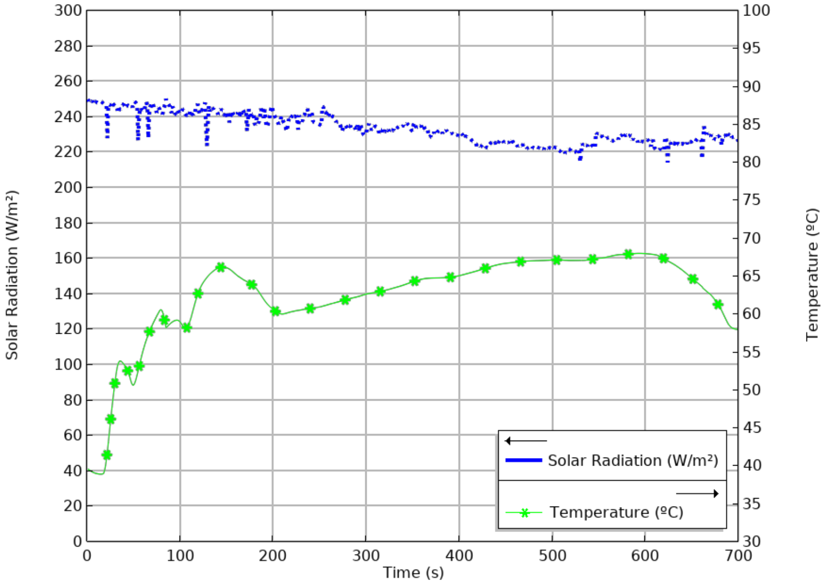


Figure 28:Temporal Variation of Temperature and Solar Radiation in black copper tube

III.4.3 Configuration 3: Case of two black copper tubes " bypass"

Figure 29 reveals that the temperatures of the tubes rise from initially low values to a peak of 100 degrees Celsius. This temperature increase occurred under solar radiation levels ranging between 530 and 590 W/m².

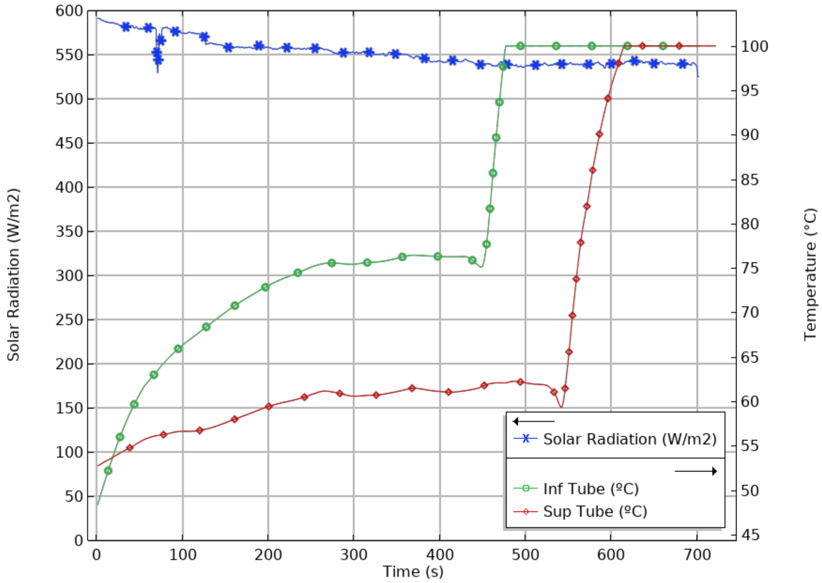


Figure 29:Temporal Variation of Temperature and Solar Radiation in two black tubes

Notably, the figure shows that the inferior tube reached 100 degrees Celsius in just 450 seconds, while the superior tube took longer, reaching the same temperature in 550 seconds. This data highlights the differing thermal response times of the tubes under identical solar radiation conditions, emphasizing the efficiency and rapid heating capability of the inferior tube.

III.4.4 Configuration 4: Case of three black copper tubes "tri-pass"

In this study, we applied a multi-pass absorber configuration consisting of three black copper tubes, as depicted in the **figure 30**. This setup allows us to investigate the collective thermal performance of the tubes under varying solar radiation levels and operational conditions. By analyzing the temperature and solar radiation graphs over time, we aim to assess how the multi-pass design enhances heat absorption and efficiency compared to single-tube configurations. This approach provides valuable insights into optimizing solar thermal collectors for increased energy capture and utilization efficiency in renewable energy applications.

III.4.4.1 Case of one a centralized tube

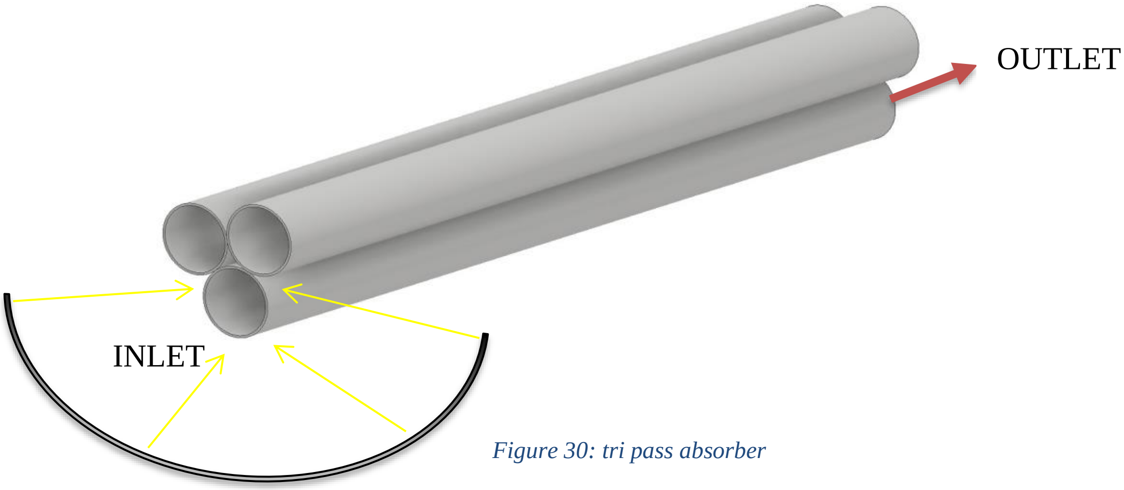


Figure 30: tri pass absorber

Figure 31 illustrates the temperature and solar radiation graph for a configuration with three black copper tubes, including one centralized tube (Fig.30), over time. The graph reveals that the temperatures of the tubes rise from initial values to significantly higher values under solar radiation levels ranging between 440 and 490 W/m². The figure shows that the centralized tube **(T3)** quickly reached 90 degrees Celsius, rising from an initial 44 degrees. In contrast, the inferior of the two peripheral tubes **(T2)** reached 86 degrees Celsius from an initial 57 degrees, and the superior tube **(T1)** reached 84 degrees Celsius from an initial 66 degrees. This difference is because the two peripheral tubes are less exposed to the sun's rays compared to the centralized one which is more exposed, with the inferior tube being more exposed than the superior. Notably, the initial temperature for each tube started at 32 degrees Celsius. This data highlights the impact of tube positioning on heat absorption and efficiency in solar thermal systems.

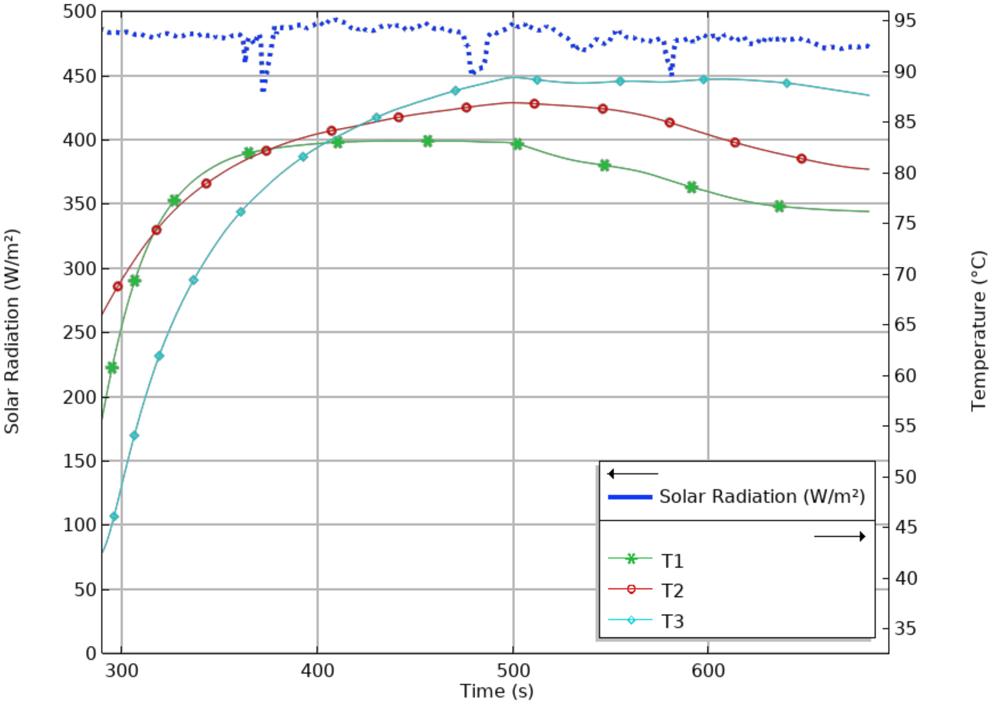


Figure 31:Temporal Variation of Temperature and Solar Radiation in centralized tube

III.4.4.2 Case of two centralized tubes

Figure 32 illustrates the temperature and solar radiation graph for a configuration with three black copper tubes, including two centralized tubes, over time. The graph reveals that the temperatures of the tubes rise from initial low values to significantly higher degrees Celsius under solar radiation levels ranging between 320 and 390 W/m². Specifically, the inferior centralized tube (T3) reached 94 degrees Celsius rapidly, starting from an initial temperature of 32 degrees. Meanwhile, the superior centralized tube (T2) attained 87 degrees Celsius, also from an initial 31 degrees. The third tube (T1), which is less exposed to direct sunlight compared to the centralized tubes, reached 71 degrees Celsius from an initial 32 degrees.

This difference in temperature rise is attributed to the varying exposure levels to solar radiation among the tubes. The centralized tubes, being more directly exposed to the sun's rays, demonstrated a faster and higher temperature increase. Among these, the inferior centralized tube (T3) showed the highest temperature, indicating it received the most direct sunlight. In contrast, the third tube (T1) had a more gradual and lower temperature rise due to its position, which limits its exposure to sunlight. This no-load test helped us determine the fluid optimal circuit for a load test (Fig.32: preheating then heating of the fluid).

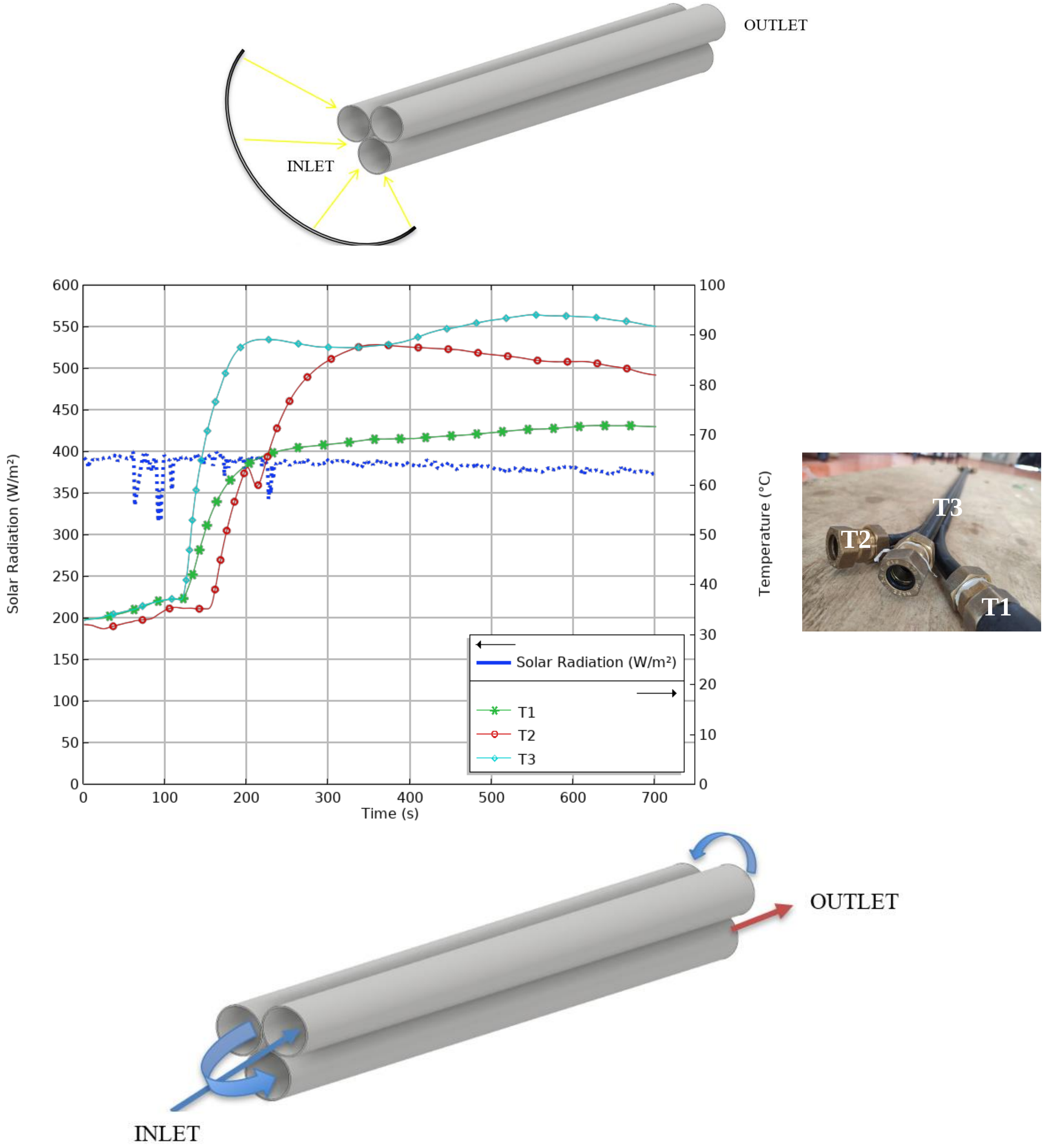


Figure 32:Time dependent Variation of Temperature and Solar Radiation for two centralized tubes and water circuit from the colder to the hotter tube: preheating then heating

III.4.5 Cases studied Comparison

The **Figure 34** shows the average temperature variation with the average solar radiation for each tube configuration. It reveals that the copper tube reaches 49 degrees Celsius at a solar radiation level of 280 W/m², while the black tube, due to its higher absorptivity from the coating, reaches 63 degrees Celsius at a lower radiation level of 220 W/m². The multi-pass configuration with one centered tube achieves the highest temperature on the graph, reaching 75 degrees Celsius at 480 W/m². Slightly lower, at 74 degrees Celsius, are the two tubes configuration which requires a higher radiation level of 550 W/m². The multi-pass with two centered tubes reaches 71 degrees Celsius at 370 W/m², suggesting that this setup is highly efficient.

The previous results led us to further investigate the tri-pass two centralized tubes configuration, which reached 73 degrees Celsius at 570 W/m² (Fig.33). This final configuration validated our previous findings, confirming the effectiveness of the tri-pass design with centralized tubes in maximizing thermal efficiency. Figure 34 illustrates the temperature and solar radiation graph for a configuration with three black copper tubes charged with water, including two centralized tubes, over time. The graph reveals that the temperatures of the tubes rise from initial low values to significantly higher temperature under solar radiation levels ranging between 510 and 600 W/m². Initially, the inlet temperature of the multi-pass system began at 35 degrees Celsius and remained stable for a brief period. Subsequently, the outlet temperature of the multi-pass system increased from 40 to 100 degrees Celsius. The temperature of the tubes themselves rise rapidly from an initial 29 degrees Celsius to 100 degrees Celsius.

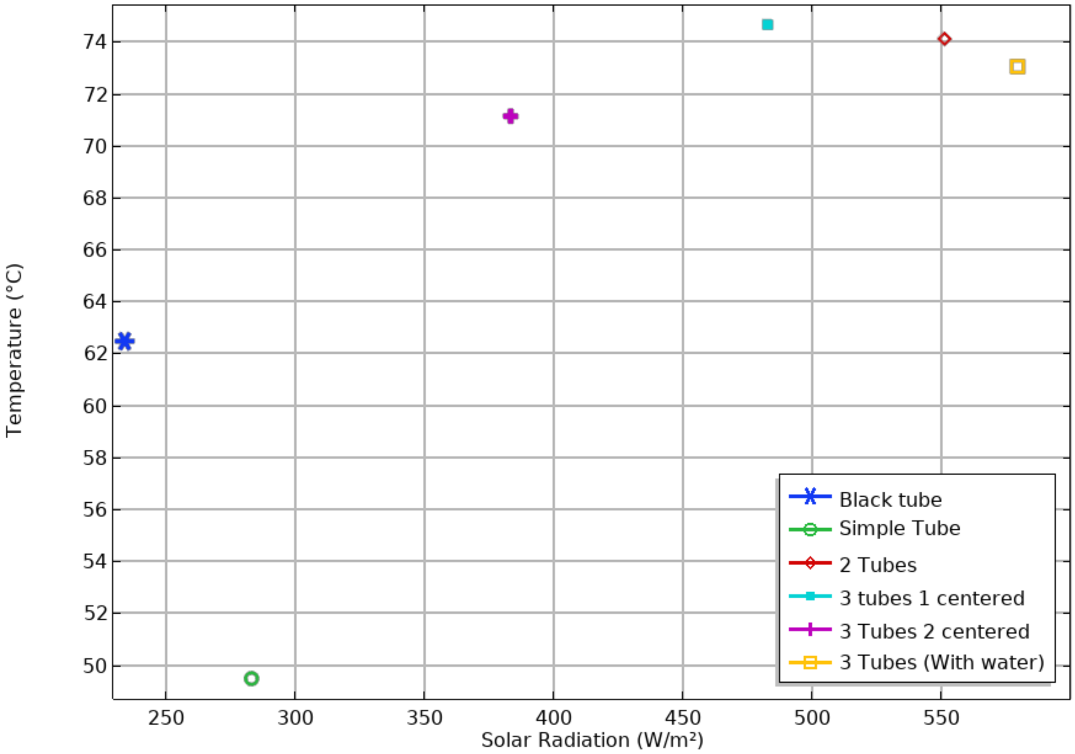


Figure 33: Average Temperature Variation with Solar Radiation for Each Tube Configuration

This data underscores the multi-pass design's effectiveness in maximizing heat absorption and thermal energy conversion. The stable initial inlet temperature indicates efficient input management, while the rapid rise in tube temperatures, especially in the centralized tubes, demonstrates their high exposure and absorption efficiency. The dramatic increase in outlet temperature, reaching boiling point and causing water evaporation, showcases the system's ability to effectively transfer and utilize heat, achieving significant thermal gains. The configuration's performance under high solar radiation highlights the importance of tube positioning and multi-pass design in optimizing thermal efficiency, emphasizing its potential for high thermal output applications.

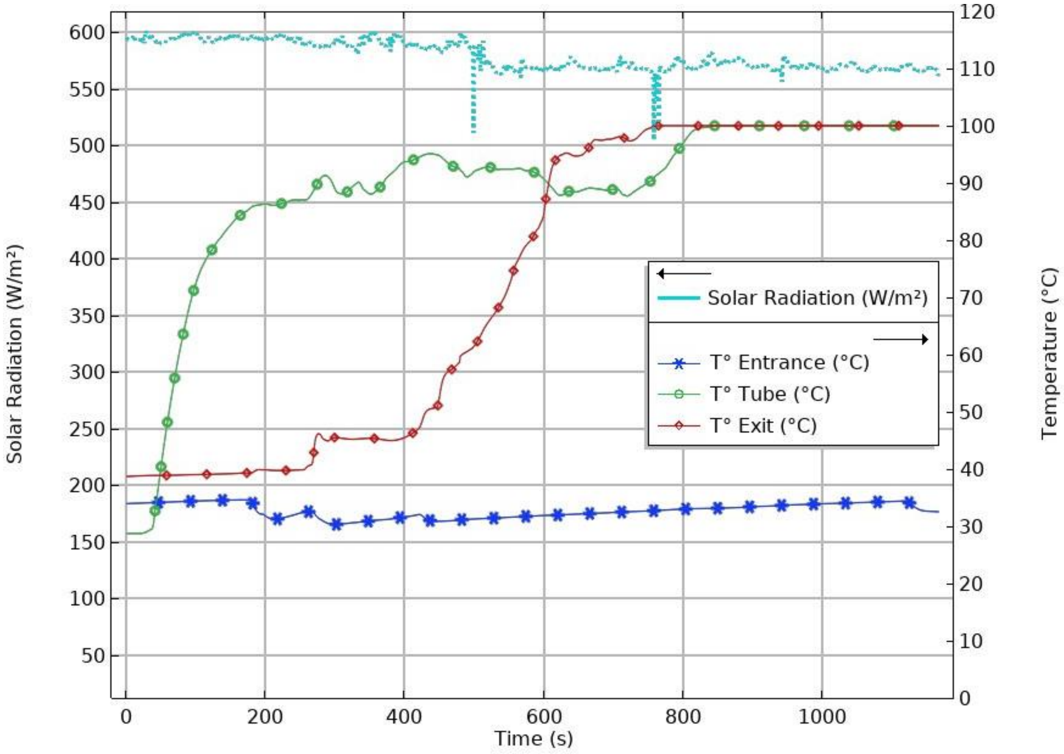


Figure 34:Temporal Variation of Temperature and Solar Radiation in two centralized tubes with water

General Conclusion

The design and construction of a PTC were meticulously demonstrated, detailing the methodologies and processes involved, including material selection, structural design, and component assembly. The challenges encountered during construction and the solutions implemented were thoroughly outlined.

An extensive experimental study was carried out to evaluate the optical and thermal performance of the PTC. While the optical performance was satisfactory, the thermal performance was notably low. To resolve this issue, various absorber configurations were tested to improve thermal efficiency.

Various configurations, including single, double, and triple-pass receiver were tested. The experiments aimed to determine the maximum temperatures achieved under different conditions, demonstrating the potential improvements of the multi-pass design. The final proposed configuration significantly improved the thermal efficiency by **63% (Fig.35),** demonstrating the efficacy of the multi-pass design.

Future studies can further optimize the PTC design to enhance efficiency. Additionally, the designed PTC can be used as teaching equipment for practical academic work, contributing to educational advancements in renewable energy technologies.

Overall, this study contributes to advancing PTC technology and its applications in sustainable energy production. The insights gained and improvements achieved pave the way for further research and development in this vital field.

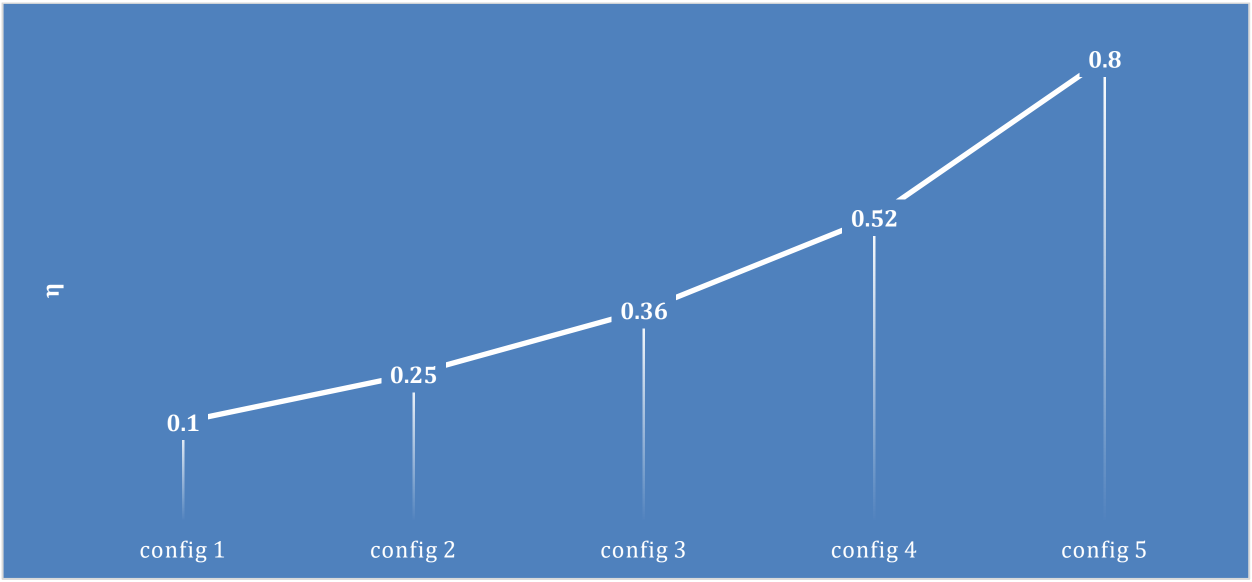


Figure 35 Thermal Efficiency improvement

References

[1] H. A. Mohammed, Hari B. Vuthaluru and Shaomin Liu, Parabolic Trough Solar, 2022.

[2] A. K. M. Sayeh and L. A. Abbas, *Etude expérimentale d'un concentrateur cylindro-parabolique,* 2019.

[3] A. Gama, M. Haddadi and M. Ali, "Étude et réalisation d'un concentrateur cylindro Parabolique avec poursuite solaire aveugle," *Revue des Énergies Renouvelables,* vol. 11, no. 3, p. 437 – 451., Janvier 2008.

[4] Fei Cao, Jiarui Pang, Xianzhe Gu, Miaomiao Wang and Yanqin Shangguan, "Performance Simulation of Solar Trough Concentrators: Optical and Thermal Comparisons," *College of Mechanical and Electrical Engineering, Hohai University, Changzhou 213022, China,* vol. 16, no. 4, p. 1673, 2023.

[5] V. M. Bindu and H. G. M. Josline, Advances in Automation, Signal Processing, Instrumentation, and Control, Singapore: springer nature Singapore, 2021, pp. 361-370.

[6] "Parabolic Trough Solar Collectors (Ultimate Guide)," [Online]. Available: https://solartechadvisor.com/parabolic-trough-solar-collectors/. [Accessed 21 4 2024].

[7] "Thermal efficiency enhancement of parabolic trough collectors: a review," *Journal of Thermal Analysis and Calorimetry,* p. 10923–10942, 2022.

[8] "Parabolic Trough Optical Performance Analysis Techniques," *Journal of Solar Energy Engineering,* pp. 147-152, 2006.

[9] M. Gunther, M. Joemann and S. Csambor, Parabolic Trough Technology, Advanced CSP Teaching Materials, 2010, pp. 1-106.

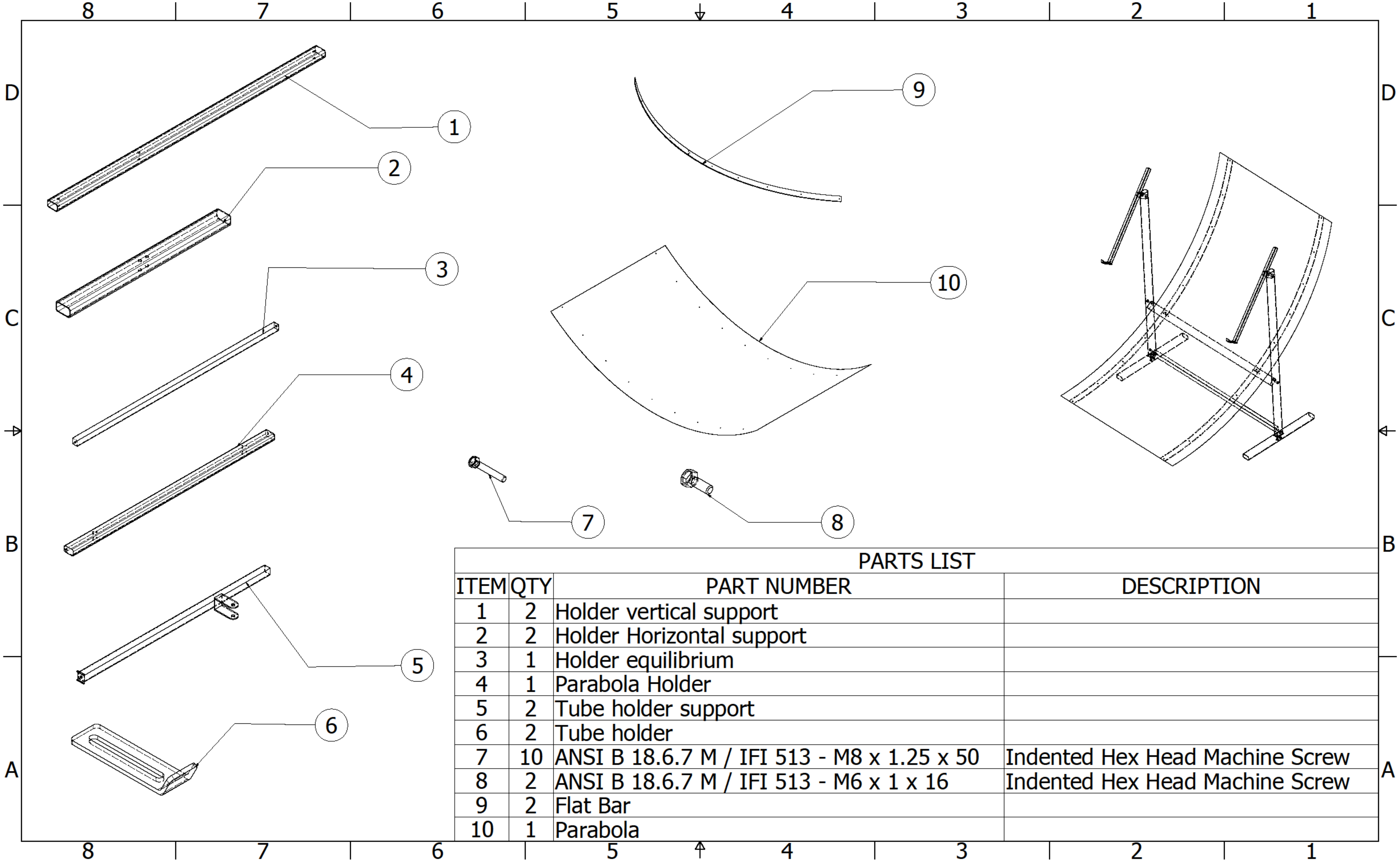
[10] E. Venegas-Reyes, O. A. Jaramillo, R. Castrejón-García, J. O. Aguilar and F. Sosa-Montemayor, "Design, construction, and testing of a parabolic trough solar concentrator," *Renewable and Sustainable Energy,* september 2012.

[11] Alka Bharti and Bireswar Paul, "Design of solar parabolic trough collector," February 2017.

[12] E. Bellos, C. Tzivanidis and D. Tsimpoukis, " Multi-criteria evaluation of parabolic trough collector with internally finned absorbers.," *Appl Energy* , vol. 61, p. 205, 2017.

[13] M. Fedkin and J. A, "Types and Elements of Concentrating Collectors," Dutton e-Education Institute, College of Earth and Mineral Sciences, Penn State University., [Online]. Available: https://www.e-education.psu.edu/eme812/node/7. [Accessed 21 4 2024].

Appendix



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Holder vertical support	
2	2	Holder Horizontal support	
3	1	Holder equilibrium	
4	1	Parabola Holder	
5	2	Tube holder support	
6	2	Tube holder	
7	10	ANSI B 18.6.7 M / IFI 513 - M8 x 1.25 x 50	Indented Hex Head Machine Screw
8	2	ANSI B 18.6.7 M / IFI 513 - M6 x 1 x 16	Indented Hex Head Machine Screw
9	2	Flat Bar	
10	1	Parabola	