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DEVELOPMENT AND EXPERIMENTAL ANALYSIS OF A DOMESTIC PARABOLIC TROUGH COLLECTOR WITH COPPER AND BRASS RECEIVERS

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Abstract

More interest in using solar thermal energy has led to a rise in Parabolic Trough Collectors (PTCs). Using these, sunlight is guided onto a pipe where it can create thermal energy for many purposes. The study describes how to create a domestic PTC system that is both efficient and is mainly built using copper and brass as receivers. Copper is respected for its ability to conduct heat and avoid rust, compared to brass which is strong as well as resistant to heat. The experiments and simulations are used to check the effects of using these materials as solar irradiance, fluids, and ambient temperature levels change. A detailed review of thermal efficiency, the retention of heat, and how temperature changes throughout the receiver tube is performed using key performance indicators. A tracker system on the collector allows it to follow the sun from north to south and from east to west as the seasons and time of day change. Scientists also research the effect of using water, air, silicone oils, or thermal oils to help gather heat and store it. It has been seen that copper receivers work better in direct sunshine for reaching a high efficiency, whereas brass receivers function more effectively than copper in varying weather conditions. They perform well in solar water heating and heating rooms, bringing about savings and a greener solution compared to other energy sources. According to the findings, success in using PTCs at home relies on choosing the proper material, effectively managing heat, and having the tracks aligned.

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Keywords: Studies include PTC, Solar Thermal Energy, Receiver Materials (Copper and Brass, etc.), Domestic Applications, Thermal Efficiency, Performance of Receiver Tubes, Material Selection, Comparing Copper and Brass, Energy Conversion Processes, Type of Heat Transfer Fluids.

I. INTRODUCTION

A. Solar Radiation

Solar energy is made up of heat and light given out by the Sun, which can now be converted into energy by using several types of technology. Among its many positives, solar energy stands out for having a lot to offer, staying sustainable, and causing no further environmental harm. Since the Sun is always giving its energy abundantly, solar energy is considered unlimited as a source of electricity. As a thermal and clean resource, solar radiation offers plenty of upsides for producing solar energy. Through photovoltaic cells, solar radiation helps make electricity, while solar thermal technology turns it into steam or heat for various things. It uses solar radiation in different ways to supply heat or steam for both homes and plants.

In these systems, sunlight is absorbed by solar thermal collectors and is used to warm up a fluid, which is then stored in a tank. The heated fluid could be water, a coolant, or some other form of liquid. Making use of solar energy allows you to save money on both energy consumption and heating costs. They created formulas to help determine pipe coating for different working situations. The main factors it deals with are the inlet fluid temperature, how much fluid flows per unit time, the temperature of the surroundings, the solar beam radiation, and the heat transfer coefficient. As a result, conducting a quick analysis on parabolic collectors and using analytical expressions allows for optimizing solar thermal systems [1]

In every case, solar energy provides the main power and heats up the plant for its thermal needs. Instead of using conventional heating and cooling, modern solar thermal systems can be purposefully used to reduce the amount of greenhouse gases and fossil fuels used.

All of these uses rely on solar radiation to supply the heat needed for their thermal processes. An engineering equation solver (EES) was used to create the model and validate its data for the function of collectors and receivers [2].

B. Concentration Solar Thermal:

This technology makes use of mirrors or lenses to point the sun's rays onto a receiver. A solar collector, or receiver, is designed to capture intense light from the sun and use that energy to heat materials. With different CST configurations, the maximum temperatures in the collector can vary from a number of hundreds to literally thousands of Celsius degrees.

Several heat loss tests for a steady state are carried out, which allows a link to be formed between the receiver and other existing ones, supporting further advancements. It is also important to understand end loss from both a theoretical and practical point of view, regardless of using insulators or heat coils [3]

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Solar thermal systems use different methods to gather light and come in many different forms. Among the typical technology used are dish or Stirling engine systems, solar power towers, and parabolic trough systems. Solar energy in a parabolic trough system is collected by curved mirrors that guide sunshine to a tube running down the focal line instead of using an array of large curved mirrors like in solar towers.

Concentrated solar thermal systems are available in different forms, each concentrating light differently. The receiver and its cover break the data into several small bit segment. All the hydrogen and oxygen fluids are counted and matched for each stage separately. In order to solve these partial differential equations, they are converted to nonlinear algebraic equations in discrete form. The model was compared to the actual results obtained during the experiments [4]. The technique allows secure and eco-friendly energy creation by using the best traits of solar power and storing them for later use. The Parabolic trough collector, Linear Fresnel reflector, Heliostat field collector, and Parabolic dish reflector can be seen on Figure 1.

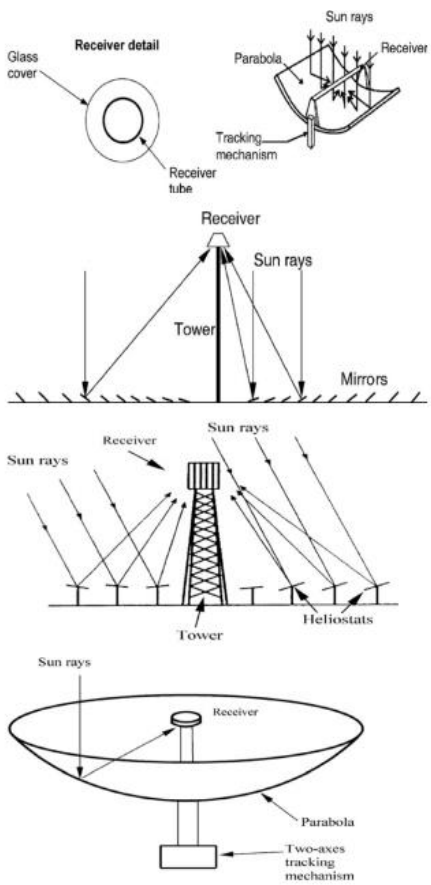

Figure 1: Parabolic trough collector, Linear Fresnel reflector, Heliostat field collector, Parabolic dish reflector.

C. Parabolic Trough Collector:

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Solar thermal power technology known as a parabolic trough collector uses the energy from the sun to create electricity or heat. This technology is commonly used and well accepted in concentrated solar power (CSP).

The shape of the parabolic trough collector is based on a parabola, allowing the receiver tube to catch concentrated sunlight at the focal point on its parabolic curve. Most of the time, inside the receiver tube, molten salt or synthetic oil is used as the heat transfer fluid, which becomes very hot as it absorbs the solar heat.

As a further example, heat energy might be put to use for various industrial processes or to heat residential and industrial areas. Using MATLAB, the E-plane and H-plane radiation patterns can be made. Beam width, efficiency charts for various center frequencies, focals, and diameters, were all determined [5].

Solar flux is gathered and distributed in concentrated solar power. The energy flux is different in each of the four dedicated solar power collection techniques called parabolic trough, linear Fresnel, solar power towers, and parabolic dish collectors. Issues related to CSP like materials, heat causing stress, and deformation [6].

There are many advantages to using parabolic trough creditors. They have been operating well for a long period and consistently deliver high performance. They work well at higher temperatures, which helps with green power generation and the storage of heat. It also means that energy can be produced from solar panels, even when the sky isn't clear.

Figure 2 a) represents the Trough mode and Figure 2 b) shows the Recirculation mode of direct steam. They keep finding use in large solar thermal power plants internationally, helping increase the use of renewable and clean electricity.

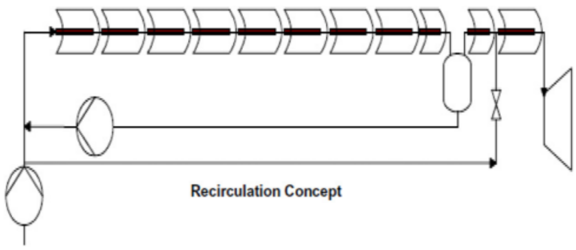

Figure 2: a) Trough mode of operation of direct steam generation.

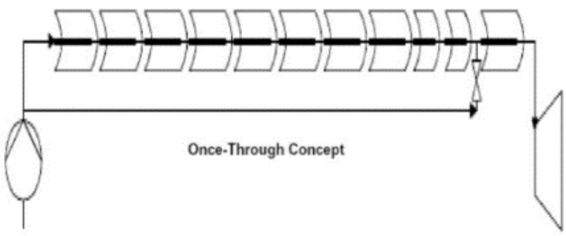

Figure 2: b) Recirculation mode of operation of direct steam.

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II. PROPOSED SYSTEM

A general flow diagram of the CSP is shown in Figure 3. As the heat transfer fluid is heated as it goes through the collectors' receivers, CSP helps make steam. There is a production of high-pressure steam due to the heat exchange process. The steam within a typical turbine circulates within its own system. Condensed steam coming from the turbine goes back to the steam generator to be heated further as part of the cycle. Solar energy is converted into heat using the technique known as concentrating solar thermal technology. Eventually, the heat can be used for various high-temperature activities such as cooling, heating, process heat, working with materials, producing power, and chemical reactions.

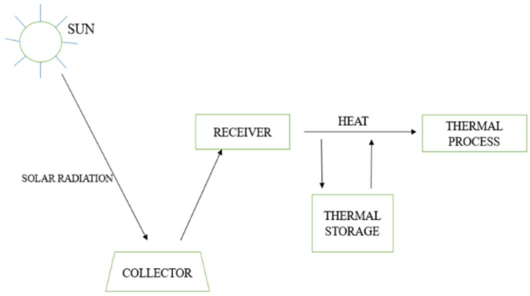

Figure 3: General flowchart for the CSP.

The aim of the work is to make a parabolic collector, which is built from copper and bronze. A range of experiments will be undertaken with different collector components, including those with receiver diameters between 60 and 180 mm. Rivers also vary in widths from 1 to 6 m. and have concentration ratios from 10 to 80. Race cars are fitted with wheels that vary from 700 to 1200 in rim angle. Using simulation to predict how concentrating solar power plants would work for direct steam generation technology for direct steam generation [7].

When CSP is used alongside biomass, wind, geothermal, coal, and natural gas, it is called a hybrid. The result will be improved performance, and hybrids are grouped as low, medium, and high renewable hybrids. Parameters considered for comparison are energy efficiency, conversion of solar power to electricity, how much electricity is produced, and costs [8]. Solar thermal systems transfer heat from the receiver and the heat exchanger to the heat storage tank using heat transfer fluids. There are six basic groups of solar heat transfer fluids, including oil, water, air, refrigerants, silicon, and molten salts. By using knowledge about two-phase flow, steam generation, and operational strategy and benefits, the authors created the model for the linear solar concentration system [9]. By using this method, it produces hot steam at ambient pressure [10]. In solar ocean water desalination, water is processed through evacuated tubes in a series of steps for double evaporation and recuperation. Temperature in the steam, the amount of solar energy, and the state of the surrounding space are all factors [11].

III. PERFORMANCE ANALYSIS OF PARABOLIC TROUGH COLLECTOR

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The analysis of the parabolic trough collector is done by considering the following factors. Picture a parabolic dish that is W wide, L long, and has edge at tangent with a circle with radius Φr. The receiver tube has an inner diameter of Di and an outer diameter.

A fluid flows into the receiver tube m at temperature Ti, leaves at To, and has a mean temperature Tm .

The collector's concentration ratio is defined as

$C = Effective\ aperture\ area$

$receiver\ tube\ area$, C = L(W − Do) L πDo

Since the surface area is ibrb, the specular reflectance ρ, the intercept factor ϒint, and (τα)b all contribute, the total absorbed flux is given by,

S = Ibrbρ(γint)(τα)b + Ibrb(τα)b(Do W−Do)

A useful expression for the Nussult number (Nu) is used to determine the heat transfer co-efficient for convective heat transfer hf in fluid film.

Nu = 0.3 + 0.62Re0.5Pr0.33 + 0.25 [1 + (0.4Pr2 4) 7 3] 4/ 5

Overall heat loss per length (q) depends of the following components.

If we divide q by h = (hwπmπ) and apply σ, we have: Do (Tf − Ti) + σ∈o (To 4 − Ti 4)

hw stands for the convective coefficient that occurs at the wall.

The overall heat loss of a room is given by

UL = q L⁄πDo(To−Ti) 1.6

Collector efficiency F1 is calculated using the following formula:

Solving for F 1, we have F 1 = 1 UL + Do Dihm.

The heat removal factor FR can be calculated as

FR = mCp πDoULL [1 − exp [−F 1πDoULL mCp]]

Look at the following expression, which defines the useful heat gain rate qu:

qu = FR(W − Do)L [S − UL C (To − Ti)]

Finally, the efficiency of a parabolic trough collector system is described by

By the definition above: ηb = qu IbrbWL

IV. EXPERIMENTATION

A. Methodology:

The experiment is performed to observe how different solar parabolic receivers affect the efficiency of the collectors. This experiment is mostly about receivers. The whole experiment

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uses the one parabolic collector. They use different receivers to take readings. The experiment is set up at the beginning of the day and allowed to run throughout the day with regular breaks. Tracking is done with the same method throughout the whole experiment.

First, the connections and necessary mods are made to ready the experiment for use. A parabolic collector was set according to the design of the tracking mechanism used. A receiver is then put along the focal line of the parabolic collector. After that, the appropriate input and outlet tubes and valves are connected. All necessary changes to the reservoir and the pump have been done.

Solar light concentrated by the parabolic collector helps to warm up the receiver on its focal axis. The tilt of the parabolic reflector is 10 degrees each hour, from east to west. Because of this, heat is produced as fluid travels through the receiver tube. The parabolic collector's work rate parameters are found by noting the starting and finishing temperatures at the receiver entrance.

East–West Horizontal – EW Tracking Mechanism

The best way to move parabolic trough collectors is with the NS Horizontal – EW Tracking mechanism. Here, the parabolic axis is positioned so that it goes parallel to the NS axis of the planet. The trajectory of tracking in the EW direction is shown in Figure 4. How the parabolic collector follows the movement of the sun.

This mechanism allows the parabolic collector to be tilted so that solar radiation hits the parabola at a right angle, as you can see in Figure 5.

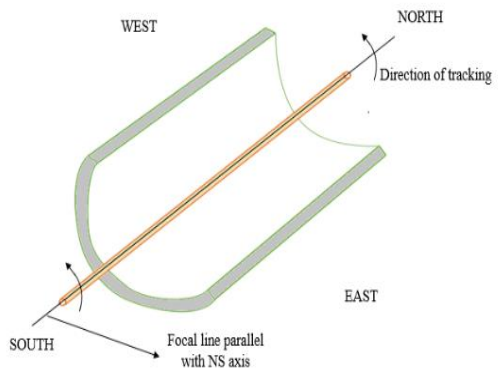

Figure 4: Tracking mechanism of parabolic collector.

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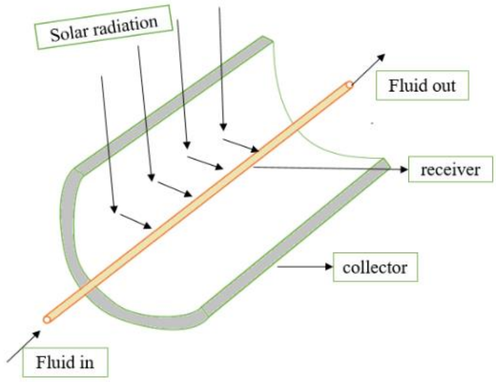

Figure 5: The working flow of the solar collector.

V. WORKING PRINCIPLE OF THE EXPERIMENT

A parabolic collector directs the solar radiation onto its focal line, right where the receiver is set. Because of this, the radiation will build up mainly in the receiver tube. A fluid, which circulates within the concentrated solar radiation, gets heated by it. Thus, the solar energy is used to produce heat that can be used.

Assumptions

- Heat transfer fluids move through the system in a laminar fashion.
- The mean temperature is evenly distributed along the whole length of the receiver.
- Heat is evenly distributed along the receiver length.
- Since force convection is very small, we only consider free convection.
- The radiation flux reaching the receiver tube is evenly spread down the length.

VI. DESIGN AND DEVELOPMENT OF PTC

A. Design Parameters:

- Trough length (l): total length of the parabola.
- Focal length (f): the space between the focal point and the vertex in a parabola. The parameter controls the shape made by the parabola.
- Aperture width (a): It refers to the distance between different vertexes of a parabola.
- Rim angle (Φr): The distance between the optical axis and the straight line joining, where the light rays converge with the mirror's edge.
- Aperture area (Aa): where the sunlight reaching the environment.
- Aperture angle (ϕ): it is how far off the normal of the aperture the incident ray can go before reaching the receiver.
- Receiver or Absorber area (Arec): only the area of the absorber surface is affected by concentrated radiation. It is important for accessing a useful form of energy.

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- Concentration ratio (C): It describes the relationship between the aperture and the area through which the radio signal goes. The figure 6 shows the design for the parabolic collector.

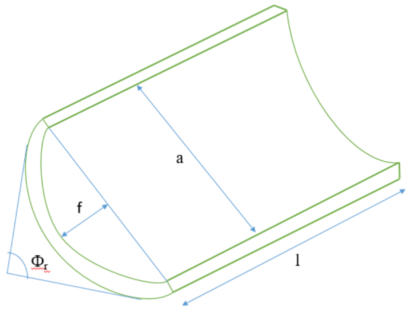

Figure 6: Design Parameters of PTC

Table 1: Dimensions for Parabola

Parameter	**Symbol**	**Value**	**Unit**	**Remarks**
Aperture Width	W	40	cm	Distance across the opening of the parabola
Half Aperture Width	W/2	20	cm	Half of the full aperture width
Focal Length	f	8.81 ≈ 9.0	cm (≈ 0.09 m)	Calculated using W/2 = 2.72 × f
Depth of Parabola (Height)	h	16.65	cm (≈ 0.1665 m)	Using h = 1.85 × f
Total Trough Length	L	1.2	m	Length along the axis of the parabola
Aperture Area	A	0.048	m^2	Calculated using A = W × L = 0.4 m × 1.2 m
Focal Ratio	f/#	0.225	–	Ratio of focal length to aperture width, f/W

A. Receiver Specifications

- Copper Receiver

One reason copper was picked for use is its high thermal conductivity, which is around 386 W/m·K, and its melting point, which is around 1000°C. Because of its unique properties,

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copper is a good choice for using in solar thermal systems. Furthermore, a metallic layer is added to the inside of the copper tubes, helping the material reflect more of the light and heat. Because of this coating, the receiver is able to pick up and send solar energy from the focal line much more efficiently.

- Brass Receiver

Scientists choose brass for researching receivers because its strong, resistant to corrosion, and can be found easily. It is important to mention that the malleability of brass comes from the zinc inside it. White brasses have less than the suitable level of workability because they have more than 45% zinc. Typically, they are used for tasks such as brazing and die-casting. In this process, an appropriate brass is picked to ensure that the zinc in the material can withstand thermal stress.

B. Receiver and Collector Arrangement

The collector's main axis runs in the NS direction, because it goes along with the axis of the planet. The collector is built to follow the sun from East to West, so it stays well illuminated all day long. The receiver tube, which is made from copper or brass, is set perfectly on the focal line of the parabolic reflector to help collect and retain the maximum amount of solar energy. The length of the receiver is the same as the parabola's trough, or 1.2 meters. An extra 10 cm is added to both ends to ensure that fittings are secure, so the effective length of the rod is 1.3 meters. The tube's outer diameter is selected by looking at what sizes are offered in the market, settling on 1.27 cm. The receiver is usually built using metals and metal alloys as they are good conductors of heat, sturdy, and resist corrosion. For the coating to last and maintain its integrity in different temperatures, these traits are very important.

Table 2: Radiative Properties of Copper and Brass at Room Temperature

Material	**Transmissivity (τ)**	**Absorptivity (α)**
Copper	0.85	0.85
Brass	0.72	0.72

VII. RESULTS AND DISCUSSIONS

Arrangements: In this experiment trail, the collector is mounted on the metal frame. The axis of the parabolic collector is placed parallel with the NS axis of the earth. The copper tube receiver tube is fitted at the focal point of the parabolic collector. The collector will move in from east to west direction to track solar radiation.

A. Temperature and Location Data

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Temperature: 28°C - 31°C

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Weather Type: Partly Cloudy
Precipitation: 11%
Humidity: 61%
Wind: 18 km/h
Location: Bangalore South, Karnataka, India

Figure 7 and 8 illustrate the performance of the copper-based parabolic trough collectors with respect to temperature variations and solar radiation levels.

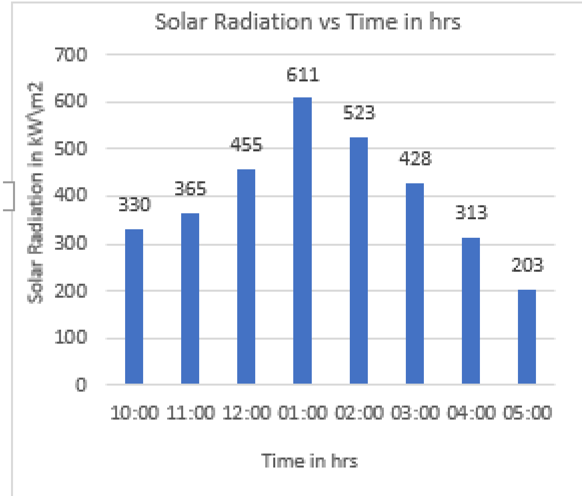

Figure 7: Solar Radiation (Wh/m²) vs. Time (hrs)

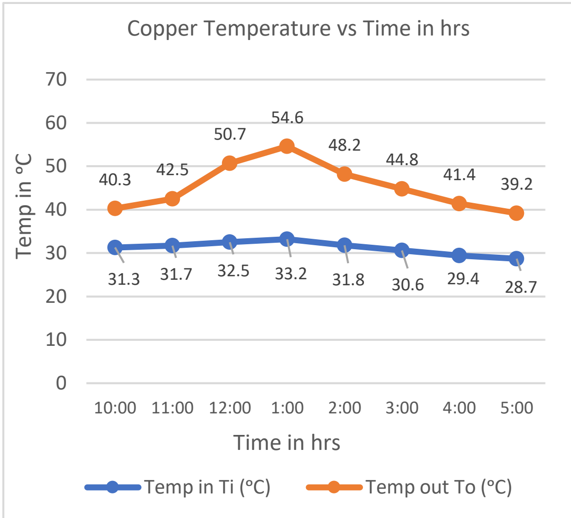

Figure 8: Temperature (°C) vs. Time (hrs)

Based on the experimental data collected, the maximum temperature differential for each receiver is recorded for performance comparison.

B. Data for Calculation

1. Inner diameter of the receiver (Di)	0.0124 m
2. Outer diameter of the receiver (Do)	0.0127 m
3. Length of the receiver (L)	1.2 m
4. Width of the collector (W)	0.40 m
5. Rim angle (Φ)	1200
6. Mass flow rate of water (m)	0.17 Kg/sec
7. Specific heat (Cp)	4.178 kJ/kg·K

C. Concentration Ratio of the Collector

Using the formula:

$C = (W - D_o) / (\pi \times D_o)$

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Substituting values:
C = (0.4 - 0.0127) / (π × 0.0127)
C ≈ 9.71

Therefore, the concentration ratio (C) of the parabolic trough collector is approximately 9.71.

Table 3. shows the reading of the copper receiver on trial day 1 at 1 p.m. for the highest solar radiation on that day.

Table 3: Copper Tube Receiver

Time in hour	Solar radiation in W/m^2	Temperature of Inlet water in °C	Temperature of outlet water in °C
1:00 pm	611	33.2	54.6

Mean temperature T_m is given by.

$$T_m = \frac{T_o - T_i}{2}$$

$$T_m = \frac{54.6 + 33.2}{2}$$

T_m = 43.9 °C

Table 4. shows the reading of the brass receiver on trial day 1 at 2 p.m. for the highest solar radiation on that day.

Table 4: Brass Tube Receiver

Time in hour	Solar radiation in W/m^2	Temperature of Inlet water in °C	Temperature of outlet water in °C
2:00 pm	523	34.4	47.6

Mean temperature T_m is given by.

$$T_m = \frac{T_o + T_i}{2}$$

$$T_m = \frac{47.6 + 34.4}{2}$$

T_m = 41 °C

Taking physical properties at mean temperature,

1. Reflectivity; Density, ρ = 996 kg/m^3

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2. Specific heat, C_p = 4.178 KJ/kg K,
3. Kinematic viscosity, υ = 0.657*10-6 m2/s
4. Prandtl number; Pr = 4.340
5. Extinction Coefficient, K = 0.6280

A. Performance Analysis of Receivers.

The Output temperature of the Copper and Brass Receiver is shown in Table 5, The graph of copper vs. brass output temperature is shown in Figure 9, we can observe that the copper receiver gains the higher output temperature. Brass is more malleable than bronze or zinc. The relatively low melting point of brass (900 to 940 °C; 1,650 to 1,720 °F, depending on composition) and its flow characteristics make it a relatively easy material to cast. Because brass is not ferromagnetic, ferrous scrap can be separated from it by passing the scrap near a powerful magnet. Brass scrap is melted and recast into that are extruded into the desired form and size.

Table 5: Copper vs. Brass output temperature

Time in Hrs (AM)	**Brass**	**Copper**
	Temp out To (°C)	**Temp out To (°C)**
10:00	42.3	42.3
11:00	44.1	44.1
12:00	45.7	51
01:00	46.2	49.5
02:00	47.6	44.6
03:00	46.8	43.8
04:00	42.1	40.1
05:00	38.4	38.6

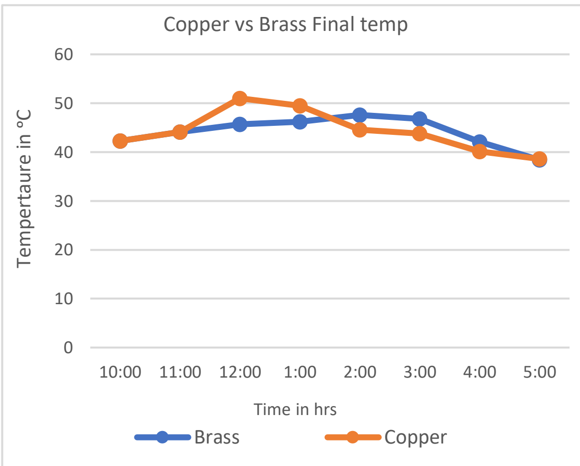

Figure 9: Copper vs. Brass output temperature

In Table 6 the performance analysis of the Copper receiver is shown for the different parameters, and in Table 7 the brass receiver performance analysis is shown for different parameters

Table 6: Copper Receiver Performance Analysis

Sl No.	**Time in hour**	**Temperature output (T_o) in °C**	**Solar radiation (I_b) in W/m²**	**Absorbed flux(S) in W/m²**	**Useful heat gain(q_u) in W**	**Efficiency (η) in %**
1	10:00	40.3	330	203.21	38.88	24.2
2	11:00	42.5	365	224.76	46.67	26.2

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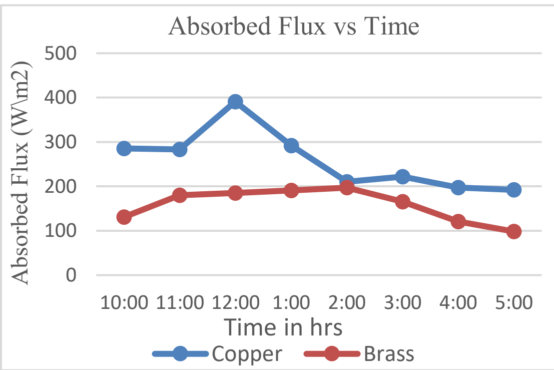
3	12:00	50.7	455	280.18	78.69	35.5
4	1:00	54.6	611	376.24	92.53	31.1
5	2:00	48.2	523	322.05	70.90	27.8
6	3:00	44.8	428	263.55	61.38	29.4
7	4:00	38.3	313	192.74	38.45	25.2
8	5:00	34.2	203	125.01	23.74	24

Table 7. Brass Receiver Performance Analysis

Sl No.	**Time in hour**	**Temperature output (T_o) in °C**	**Solar radiation (I_b) in W/m²**	**Absorbed flux(S) in W/m²**	**Useful heat gain(q_u) in W**	**Efficiency(η) in %**
1	10:00	42.3	348	131.16	43.21	25.5
2	11:00	44.1	478	180.15	50.56	21.7
3	12:00	45.7	492	185.43	51.86	21.6
4	1:00	46.2	507	191.08	56.19	22.7
5	2:00	47.6	523	197.11	57.05	22.4
6	3:00	46.8	439	165.45	61.38	28.7
7	4:00	42.1	321	120.98	45.80	28.3
8	5:00	38.4	261	98.37	34.12	26.8

Table 8: Copper vs Brass Absorbed flux.

Time in Hrs (AM)	**Copper**	**Brass**
	Absorbed Flux (W\m2)	**Absorbed Flux (W\m2)**
10:00	285.727	131.161
11:00	283.264	180.157
12:00	391.028	185.434
01:00	291.885	191.087



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02:00	210.601	197.118
03:00	221.685	165.458
04:00	197.669	120.984
05:00	192.127	98.37

Figure 10: Absorbed Flux (W\m2) vs Time (hrs)

The Table 8. Shows the comparison of absorbed flux between the copper and brass receivers, and Figure 10, shows the comparison between the copper and brass receivers absorbed flux with respect to time in hrs, it is observed that the copper receiver has higher absorbed flux compared to the brass receiver.

Table 9 shows the useful heat gain of copper and brass receivers, Figure 11, shows the useful heat gain vs. time of copper and brass receivers, it is observed that the copper receiver has higher heat gain compared to the brass receiver.

Table 9: Copper vs Brass Useful heat gain

Time in Hrs (AM)	Copper	Brass
	Useful Heat Gain (W)	Useful Heat Gain (W)
10:00	43.64	43.21
11:00	57.92	50.56
12:00	73.93	51.86
01:00	79.12	56.19
02:00	61.38	57.05
03:00	57.05	61.38
04:00	45.8	45.8
05:00	41.04	34.12

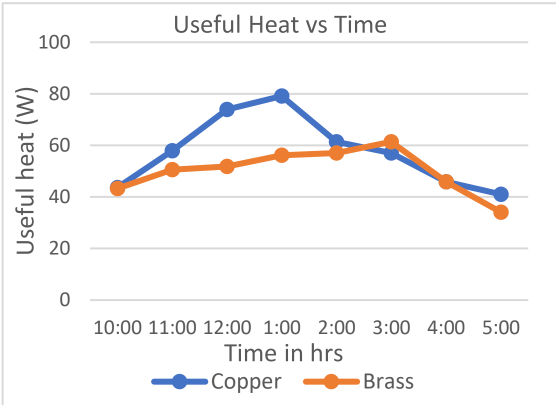
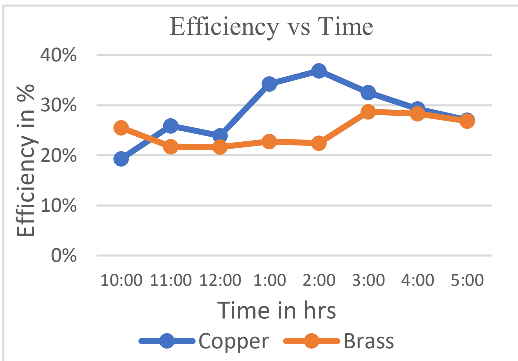


Figure 11: Useful heat vs. Time

The efficiency of copper and brass receivers is shown in 10 and the Figure 12 shows the efficiency of copper and brass with respect to time in hours. It is observed that the copper receiver has more efficiency compared to the brass receiver.

Table 10: Copper vs. Brass Efficiency

Time in Hrs (AM)	Copper Efficiency	Brass Efficiency
10:00	19.32%	25.50%
11:00	25.86%	21.73%
12:00	23.91%	21.65%
01:00	34.28%	22.76%



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02:00	36.86%	22.41%
03:00	32.55%	28.72%
04:00	29.30%	28.31%
05:00	27.02%	26.85%

Figure 12: Efficiency vs Time

VIII. CONCLUSION

The findings showed that the highest absorbed solar radiation, heat entering the system, and top receiver temperature take place during high solar radiation. The way the receiver works depends strongly on its material's heat traits. As a result of this project, several major consequences have come about. First and foremost, it describes in detail the main features of a parabolic trough collector used for home purposes. A thorough thermal model was built to understand the system's function and how well it works in different working conditions. Attention was also given to how much heat the parabolic collector absorbed, how it was spread around, and how well it kept the heat. In addition, the way copper receivers handle heat was studied and put up against other types of receiver material. The investigation proves that the design of the collector system leads to better results for the receiver. The modified copper receiver was found to be both more practical and efficient, supporting the fact that it is more useful than other receivers in use. Furthermore, the design of the parabolic collector and the decision to use easy-to-produce copper and brass receivers make the system both cheap and scalable, making it possible for domestic use by many. Based on the findings of this project, solar thermal energy systems for homes can be improved in the future.

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