

# Design, Development and Performance Optimization of a Parabolic Trough Collector for Domestic Solar Water Heating Applications

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## ABSTRACT

The growing demand for sustainable and environmentally friendly energy systems has accelerated the development of solar thermal technologies for domestic applications. This study presents the design, fabrication, and experimental performance evaluation of a parabolic trough collector (PTC) for domestic water heating. The collector employs a line-focus parabolic reflector to concentrate solar radiation onto a receiver tube positioned along the focal line. A prototype PTC was fabricated using a mild steel support structure and polished aluminum reflective sheets. Three receiver tube configurations stainless steel (SS), copper (Cu), and black-coated stainless steel (BC-SS) were experimentally investigated under identical environmental conditions. Key performance parameters, including inlet temperature, outlet temperature, ambient temperature, and solar radiation intensity, were recorded and analyzed.

The experimental results indicate that the copper receiver exhibits the highest thermal efficiency due to its superior thermal conductivity. However, the black-coated stainless steel receiver demonstrates a favorable balance between efficiency, durability, and economic feasibility, making it a suitable choice for domestic-scale applications. The study highlights the critical role of material selection and surface treatment in enhancing the thermal performance of parabolic trough collectors.

**Keywords:** Parabolic Trough Collector, Solar Thermal System, Renewable Energy, Thermal Efficiency, Solar Concentrator, Receiver Optimization, Domestic Water Heating.

## 1. INTRODUCTION

The increasing depletion of conventional fossil fuel resources and the rising environmental concerns associated with greenhouse gas emissions have necessitated the transition toward renewable energy systems. Solar energy, being abundant, clean, and sustainable, has emerged as one of the most promising alternatives for meeting global energy demands.

Solar thermal systems, in particular, offer an efficient means of harnessing solar radiation for thermal applications such as water heating, space heating, drying, and industrial process heating. In countries like India, where solar radiation ranges between 4–7 kWh/m<sup>2</sup>/day, solar thermal systems have significant potential for domestic and small-scale applications.

A parabolic trough collector (PTC) is a line-focus solar concentrator that uses a parabolic reflective surface to focus parallel rays of sunlight onto a receiver tube located at its focal line. The working fluid flowing through the receiver absorbs the concentrated solar energy and converts it into useful heat energy. The fundamental energy balance of a PTC is

expressed as:

$$Q_u = mC_p(T_o - T_i)$$

$$\eta = \frac{Q_u}{I \cdot A}$$

Where  $Q_u$  is useful heat gain,  $I$  is solar intensity, and  $A$  is aperture area.

### Problem Statement

Despite the potential of solar thermal systems for domestic applications, their performance is limited by thermal losses, inefficient receiver material selection, high costs, and lack of optimized small-scale designs. Additionally, most studies focus on large-scale systems, with limited experimental comparison of receiver materials under identical conditions. Therefore, there is a need to systematically evaluate and optimize the thermal performance of stainless steel, copper, and black-coated stainless steel receiver tubes for domestic-scale parabolic trough collectors.

### Objective

The primary objective of this study is to design and experimentally evaluate a domestic-scale PTC and to optimize its performance through comparative analysis of different receiver tube materials:

- Stainless steel (SS)
  - Copper (Cu)
  - Black-coated stainless steel (BC-SS)
1. To design and fabricate a line-focus parabolic trough collector capable of efficiently concentrating solar energy.
  2. To measure key parameters such as inlet temperature, outlet temperature, ambient temperature, and solar intensity during experimental testing.
  3. To analyze and compare the thermal performance and efficiency of each receiver pipe
  4. To determine the most suitable receiver pipe material for domestic solar water heating

Component	Material	Justification
Frame	Mild Steel	High strength And ease of fabrication
Reflector	Polished Aluminum Sheet	High reflectivity for solar concentration
Receiver Tube	SS, Copper, BC-SS	Comparative performance evaluation

Applications based on performance and cost considerations.

To suggest possible improvements and optimization techniques for enhancing the efficiency of the parabolic trough collector.

## Design Methodology

The design methodology of the parabolic trough collector (PTC) involves a systematic approach consisting of geometric design, material selection, fabrication planning, and performance-oriented considerations. The primary objective of the design is to achieve maximum solar energy concentration on the receiver tube while ensuring structural stability, cost-effectiveness, and suitability for domestic applications.

### Conceptual Design Approach

The collector is based on the line-focus concentrating principle, where a parabolic reflector is used to concentrate parallel rays of solar radiation onto a receiver tube positioned along the focal line. The design aims to:

- Maximize solar energy absorption
  - Minimize thermal losses
  - Ensure ease of fabrication and operation
  - Provide compatibility with manual solar tracking
- The geometry of the parabolic reflector is critical to ensure accurate focusing of solar radiation.

#### 1.2 Geometric Design of Parabolic Reflector:

The parabolic profile was designed using the standard equation:

$$y^2 = 4fx$$

where  $f$  is the focal length of the parabola. The focal length was determined using:

$$W^2$$

$$f =$$

$$16d$$

where:

- $W$  = aperture width (1.0 m)
- $d$  = depth of parabola (0.355 m)

$$f = 0.176 \text{ m}$$

The receiver tube was positioned precisely at this focal distance to ensure maximum concentration of reflected solar radiation.

#### 1.3 Design Parameters:

The key design parameters considered are:

- Aperture width = 1.0 m
- Parabolic depth = 0.355 m
- Collector length = 1.405 m
- Focal length = 0.176 m

These parameters were selected to achieve an optimal balance between energy concentration and structural feasibility for domestic-scale applications.

## Material Selection

The selection of materials was based on thermal performance, durability, cost, and availability.

Copper was selected for its high thermal conductivity, stainless steel for durability, and black-coated stainless steel for improved absorptivity.

## Receiver Tube Design Considerations

The receiver tube is the most critical component in the PTC system. The following factors were considered:

- Thermal conductivity of material
- Surface absorptivity
- Resistance to corrosion

- Heat loss minimization

To reduce heat losses, insulation was provided around the receiver tube.

### **Structural Design and Support**

A rigid frame structure was designed using mild steel to support the parabolic reflector and receiver tube. The design ensures:

- Proper alignment of reflector and receiver
- Stability under outdoor conditions
- Ease of installation and maintenance

Adjustable supports were provided to position the receiver tube accurately along the focal line.

### **Solar Tracking Mechanism**

A manual tracking system was incorporated to align the collector with the sun's position throughout the day. The system allows:

- Rotation along a horizontal axis
- Adjustment at regular intervals (30–60 minutes)

This approach ensures adequate solar concentration while maintaining simplicity and low cost.

### **Design Considerations for Efficiency Improvement**

The following design aspects were incorporated to enhance system efficiency:

- Use of reflective aluminum sheets to maximize incident radiation
- Accurate focal alignment to reduce optical losses
- Black coating on receiver to improve absorptivity
- Insulation to reduce convective and radiative heat losses

### **Testing Procedure**

Each receiver tube was tested under identical conditions. Data was recorded at 15-minute intervals.

Thermal efficiency was calculated as:

$$mC_p(T_o - T_i)$$

$$\eta = I \cdot A \times 100$$

### **Experimental Setup and Observations**

The experimental study was conducted using water as the working fluid. Thermocouples were used to measure inlet and outlet temperatures, and a solar intensity meter was used to record solar radiation. The collector was manually adjusted every 30–60 minutes for proper alignment.

The performance of stainless steel (SS), copper (Cu), and black-coated stainless steel (BC-SS) receiver tubes was evaluated, as shown in Table I.



Fig.1 View of Parabolic Trough Collector

Table 1. Performance Comparison of Receiver Materials

RECEIVER MATERIAL	AVERAGE TEMPERATURE RISE (°C)	AVERAGE EFFICIENCY (%)
STAINLESS STEEL (SS)	31.7	47.7
COPPER (CU)	39.0	57.3
BLACK- COATED STAINLESS STEEL (BC-SS)	36.7	54.7

## 2. CONCLUSION

This study presented the design, fabrication, and experimental evaluation of a domestic-scale parabolic trough collector for solar water heating applications. The thermal performance of stainless steel, copper, and black-coated stainless steel receiver tubes was systematically compared under similar operating conditions.

The experimental results show that the copper receiver tube achieved the highest thermal efficiency of 57.3%, followed by black-coated stainless steel with 54.7%, and stainless steel with 47.7%. The superior performance of copper is attributed to its high thermal conductivity, while the improved efficiency of black-coated stainless steel is due to enhanced absorptivity and reduced heat losses, as also reported in recent studies.

From a practical perspective, black-coated stainless steel offers an optimal balance between efficiency, durability, and cost, making it a suitable choice for domestic applications. The findings are consistent with previous research highlighting the importance of material selection and surface coating in improving the performance of solar thermal collectors.

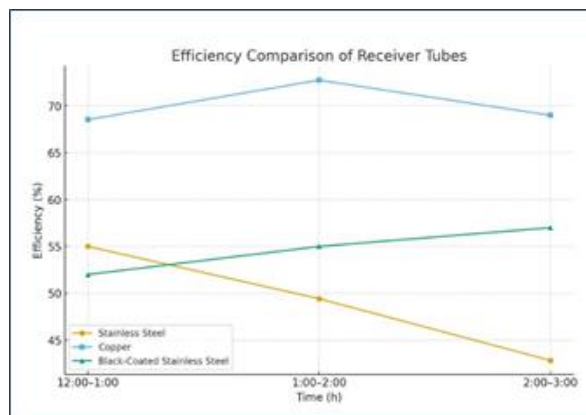


Fig 2. Time Vs Efficiency graph

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