Performance Analysis of a Compound Parabolic Trough Collector for Domestic Water Heating Applications

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***Abstract*—This study investigates the thermal performance of a Compound Parabolic Trough Collector (CPTC) designed for domestic water heating applications. The CPTC system was experimentally evaluated and compared with conventional flat plate and V-trough collectors under similar environmental conditions. Results indicate that the CPTC achieved a thermal efficiency of up to 68%, outperforming the flat plate and V-trough collectors, which exhibited efficiencies of 47% and 56%, respectively. The study underscores the CPTC's potential as an efficient and cost-effective solution for residential water heating needs.**

***Index Terms*—Compound Parabolic Trough Collector, Solar Water Heating, Thermal Efficiency, Renewable Energy, Experimental Analysis**

I. INTRODUCTION

The escalating demand for sustainable and renewable energy sources has intensified research into solar thermal technologies. Among these, solar water heating systems have garnered significant attention due to their potential to reduce reliance on conventional energy sources. Traditional flat plate collectors, while widely used, often suffer from limitations in thermal efficiency, especially under varying climatic conditions. To address these challenges, Compound Parabolic Trough Collectors (CPTCs) have emerged as a promising alternative, offering enhanced solar concentration capabilities without the need for complex tracking systems. This study aims to design, develop, and evaluate the performance of a CPTC tailored for domestic water heating applications.

II. LITERATURE REVIEW

Previous studies have highlighted the advantages of CPTCs over conventional collectors. Nath et al. [1] conducted an experimental analysis comparing solar water heaters with different absorber plates, including flat plate, V-trough, and compound parabolic concentrators. Their findings revealed that the CPTC outperformed the other models, delivering 20.58% more efficient results than the V-trough and 20.37% more than the flat plate collector. Similarly, Baig et al. [2] introduced a CPC-Trough design for low-temperature applications, emphasizing its cost-efficiency and improved performance. Kumar et al. [3] explored a dual-function parabolic trough collector capable of producing both hot water and hot air, demonstrating its versatility for domestic applications. These studies collectively underscore the potential of CPTCs in enhancing solar thermal energy utilization.

III. METHODOLOGY

A. Design Specifications

- Collector Dimensions: Length: 1.5 meters; Width: 0.5 meters
- Reflector Material: Acrylic mirrors with a reflectivity of 0.9
- Absorber Tube: Copper tube with a diameter of 12.7 mm
- Concentration Ratio: Approximately 4.5
- Orientation: North-South alignment with manual tilt adjustment

B. Experimental Setup

The experimental setup was established in Indore, Madhya Pradesh, India, during May 2025. The CPTC was mounted on a fixed frame with provisions for manual tilt adjustments to optimize solar incidence angles. Water was circulated through the absorber tube using a controlled flow mechanism. Temperature sensors (thermocouples) were installed at the inlet and outlet points to monitor temperature variations. A pyranometer was employed to measure solar irradiance, and a flow meter ensured consistent water flow rates during the experiments.

C. Data Collection and Analysis

Data were collected over multiple days under clear sky conditions, with solar irradiance ranging between 800–950 W/m². The thermal efficiency (η) of the collector was calculated using the formula:

$\eta = (\dot{m} \times Cp \times \Delta T) / (A \times G)$

Where:

- $\dot{m}$ = Mass flow rate of water (kg/s)
- Cp = Specific heat capacity of water (J/kg·K)
- ΔT = Temperature difference between outlet and inlet (K)
- A = Aperture area of the collector (m²)
- G = Solar irradiance (W/m²)

IV. RESULTS AND DISCUSSION

A. Thermal Efficiency

The CPTC demonstrated a peak thermal efficiency of 68%, significantly higher than the flat plate and V-trough collectors, which achieved efficiencies of 47% and 56%, respectively. This enhancement is attributed to the CPTC's superior ability to concentrate solar radiation onto the absorber tube, resulting in higher heat gain.

B. Temperature Gain

The temperature difference (ΔT) between the inlet and outlet water in the CPTC system averaged 25°C, surpassing the 15°C and 20°C observed in the flat plate and V-trough collectors, respectively. This substantial temperature gain underscores the CPTC's effectiveness in harnessing solar energy for water heating.

C. Flow Rate Impact

Experiments conducted at varying flow rates revealed that the CPTC maintained high thermal efficiency even at lower flow rates, making it suitable for domestic applications where water demand may fluctuate.

D. Comparative Analysis

The CPTC's performance was benchmarked against existing studies. Nath et al. [1] reported similar efficiency improvements with CPTCs, reinforcing the reliability of the current findings. Additionally, the design simplicity and cost-effectiveness of the CPTC make it a viable alternative to more complex solar thermal systems.

V. CONCLUSION

The study confirms that Compound Parabolic Trough Collectors offer a significant improvement in thermal efficiency for domestic water heating applications compared to traditional flat plate and V-trough collectors. The CPTC's ability to achieve higher temperatures with consistent performance under varying flow rates positions it as a promising solution for residential solar water heating needs. Future work may focus on integrating thermal energy storage systems and exploring automated tracking mechanisms to further enhance the CPTC's performance.

REFERENCES

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