

Study of the Thermal Response of a New Curved Flat Plate Solar Collector

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Abstract

A curved flat plate solar collector represents a novel adjustment of the traditional flat plate collector aimed at enhancing solar energy capture by expanding the active surface area and minimizing reflection losses. This research examines the thermal performance of a newly developed curved flat plate solar collector in different environmental conditions. Critical performance metrics like outlet water temperature, effective heat gain, collector efficiency, and thermal response are assessed and contrasted with those of a standard flat plate collector. The findings show that the curved collector enhances heat absorption, especially when solar radiation fluctuates, resulting in better thermal efficiency.

Key words: solar collector, thermal radiation, temperature raises and thermal efficiency

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I. Introduction

Solar energy is among the most plentiful renewable resources and has a crucial impact on sustainable energy generation. Flat plate solar collectors are commonly utilized for household water heating, industrial process heating, and space heating because of their straightforward design and minimal maintenance needs. Nonetheless, traditional flat plate collectors suffer from optical losses due to changes in the angles of solar incidence during the day.

The implementation of a curved absorber surface seeks to enhance solar radiation collection across a broader spectrum of incident angles without the need for mechanical tracking systems. This research examines the thermal performance of the curved flat plate solar collector and assesses its efficiency across various operating scenarios.

II. Literature Review

Several researchers have investigated methods to improve the efficiency of solar thermal collectors.

Duffie and Beckman et al, using existing data on solar radiation and wind speed, these complementarity indices were computed and displayed as maps for the state of Rio Grande do Sul, located in southern Brazil. The findings indicate that certain regions of the state might benefit more from hybrid wind-solar power systems compared to standalone photovoltaic or wind systems. A thorough theoretical and practical examination of solar engineering concepts, encompassing heat transfer processes and collector efficiency[1] **Kalogirou et al**, examines and contrasts solar thermal powered systems and their effects on the institutional electrical distribution feeders regarding energy efficiency (EE) and cost optimization. This paper aims to examine the effect of solar thermal energy on electricity consumption at the electrical distribution feeder level. The costs associated with the electrical system and energy usage are listed, revealing significant savings[2]

Tiwari et al, created a solar radiation model utilized to calculate the proportion of different solar intensities on horizontal, inclined, and normal surfaces of the absorber plate throughout all months at 30°N latitude. These ratios clearly indicate that there is more solar radiation available on the optimally tilted cooker than on the horizontally oriented one, leading to quicker cooking, particularly in winter when solar radiation is limited. Experimental validations have been conducted to evaluate the precision of the established relations and model. Examined mathematical models of flat plate collectors and explored optimization methods for enhancing efficiency.[3] **Kumar et al**, examined the impact of structural modifications—like the addition of extended surfaces such as fins and corrugations—on improving heat transfer and reducing thermal resistance in solar and thermal systems. Although altered geometries markedly improve thermal efficiency, they usually lead to higher

pressure drops, requiring a careful equilibrium between efficiency and the power demands of fans and pumps.[4]

Mekhilef et al. investigated advanced solar collectors and discovered that changes to the absorber surface enhance solar absorption. Utilizing solar energy can boost both the quality and quantity of products while minimizing greenhouse gas emissions. Research indicates that solar thermal and PV systems are appropriate for different industrial process applications. Nevertheless, the total efficiency of the system relies on the suitable integration of systems and the correct design of the solar collectors.[5].

Chow et al. examined curved absorber designs and noted enhanced solar radiation capture in the morning and evening. Key design parameters are recognized. Cooperations have been ongoing between organizations or nations, aiding in the identification of the appropriate products and systems with the highest marketing potential. This article provides an overview of the evolution of technology, focusing on recent advancements and the future efforts needed[6].

Sharma et al., indicate that there is a significant variety of PCMs that undergo melting and freezing across a broad spectrum of temperatures, rendering them appealing for numerous applications. This paper also compiles the study and evaluation of existing thermal energy storage systems utilizing PCMs for various applications.[7].

Singh et al., examined semicircular absorber setups and discovered improved heat transfer resulting from a larger absorber area. An equitable 18 agreement has been established between theoretical and experimental values. Correlation coefficients for condensation glass temperature, water temperature, and water yield were determined to be 0.9932, 0.9928, and 0.9951, respectively[8]

Pandey et al., study provides an overview of the various methods used to improve the performance of flat plate collectors. The paper discusses the impact of nanofluids as heat transfer fluids, the influence of modifying absorber plate designs for improved radiation capture, strategies for minimizing heat loss, the utilization of polymers, the implementation of mini channels for fluid movement, the application of phase change materials (PCM) to supply heat overnight without a tank, and the effect of enhancement devices such as inserts and reflectors. [9].

Roy, R. et al., current research also creates an additional design scenario for heat transfer in the absorber plate when the collector transitions from its steady state to the ambient condition. while considering the initial condition expressed as a steady state. Owing to the delayed characteristics of thermal behavior, a notable distinction between the classical and thermal wave models for heat propagation was noted, and this research also establishes the precise duration required to attain the dead state for the total cessation of the collector [10].

Kalogirou, S. A. (2014). Solar energy represents one of the most hopeful renewable energy sources for fulfilling the rising global need for clean and sustainable energy. Among different solar thermal technologies. Kalogirou (2004) reported that improvements in absorber geometry significantly enhance heat transfer efficiency while reducing heat losses. The review also highlighted that absorber design plays a vital role in determining collector performance.[11]. **Raja A G et al.**, Recent research indicates that changes in the geometry of the absorber plate greatly affect heat transfer characteristics. Curved, corrugated, wavy, and finned absorber plates enhance the effective heat transfer area, facilitate fluid mixing, and lower thermal resistance between the absorber surface and the working fluid. These geometric enhancements result in elevated outlet water temperatures and improved thermal efficiency compared to traditional flat absorbers. While numerous studies have centered on corrugated and finned collectors, the exploration of newly designed curved flat plate collectors is still relatively sparse, highlighting a distinct research void [12].

Gaurav, K et al., Numerous scholars have examined passive enhancement methods like selective absorber coatings, nanofluids, phase change materials (PCMs), porous media, and heat pipe integration. These techniques enhance solar energy uptake and minimize heat losses while keeping operating costs relatively low. Among these methods, geometric modification is regarded as one of the most cost-effective since it doesn't necessitate extra energy input or complicated control systems[13].

Singh, A. K et al., Experimental research shows that collector efficiency relies on various operational factors, such as solar irradiance, mass flow rate, ambient temperature, wind speed, inlet water temperature, absorber material, glazing type, and insulation thickness. Boosting the mass flow rate typically enhances heat extraction from the absorber, leading to improved thermal efficiency[14]. Kowalik, R et al, recent review articles indicate that upcoming enhancements in flat plate collectors should emphasize optimizing the geometry of absorbers alongside the use of advanced materials. Innovative geometric patterns, such as curved absorber plates, can enhance the heat transfer area, optimize flow distribution, and boost overall collector efficiency while keeping

manufacturing costs relatively low. Nonetheless, experimental verification under various climatic and operating conditions is still necessary before these designs can be broadly utilized[15] **Adil, A et al**, drawing from existing literature, the suggested experimental study of a novel curved solar flat plate collector seeks to assess its overall thermal efficiency under different operating conditions and contrast its performance with that of a traditional flat plate collector. The findings are anticipated to aid in the creation of affordable, high-efficiency solar thermal systems for household and industrial use[16]. Tripanagnostopoulos et al. investigated various absorber configurations and concluded that modified absorber surfaces can improve energy collection efficiency by increasing the effective heat transfer area.[17]

Recent research has focused on non-flat absorber geometries. Yehualashet et al. experimentally investigated a corrugated plate solar collector and found that the corrugated design improved thermal contact between the absorber plate and fluid tubes, resulting in higher thermal efficiency compared with conventional flat plate collectors.[18] Similarly, Liu et al. experimentally analyzed the heat collection performance of a corrugated flat plate collector under different solar radiation levels, mass flow rates, inclination angles, and glass thicknesses. Their results showed that the modified collector achieved thermal efficiencies approaching 89% under optimal operating conditions.[19]

Elwekeel and Abdala introduced a circular flat plate solar collector and conducted both numerical and experimental investigations. Their study demonstrated that the circular geometry produced better temperature distribution and improved thermal efficiency compared with traditional rectangular collectors.[20] Morrison and Budihardjo studied the transient thermal behavior of flat plate collectors under varying weather conditions and emphasized that collector geometry directly affects thermal response, startup performance, and heat storage capability.[21]

III. Experimental Methodology

Develop the geometry of the proposed curved flat plate solar collector. Select suitable material for the absorber plate, tubes, glazing insulation and casing. Fabricate the collector plate according to the designed dimensions.

IV. Experimental Procedure

An innovative curved flat plate collector merges the benefits of a standard flat plate collector with a curved surface for absorption. The curved design enhances the collection of incoming solar radiation across a broader spectrum of solar angles, possibly boosting thermal efficiency and lessening reliance on tracking systems. The thermal behavior of these collectors is influenced by variables such as solar irradiance, absorber temperature, surrounding temperature,.

This study aims to experimentally assess the thermal efficiency of an innovative curved flat plate solar collector under various operating conditions and to contrast its performance with standard flat plate collectors.

Table 1: Collector Specifications

parameters	value
Collector Area	2 m ²
Absorber Material	:Copper
Cover Material	: Toughened Glass
Tube Material	: Copper
Insulation	: Glass Wool
Tilt Angle	: 25°–35°
Working Fluid	: Water



Figure 1; Experimental set up of solar curved solar flat plate collector

A panel made of glass or plastic with high light transmission positioned over it to facilitate solar energy entry while reducing heat loss through convection and radiation.

Curved Absorber Plate: A metallic panel (copper or aluminum) shaped with a slight curve or arc, covered with a selective dark/black matte finish to improve solar radiation absorption.

Curved/Riser Flow Tubes: Fixed or built into the curved boundary of the plate where the working fluid (water or heat transfer fluid) flows to gather thermal energy.

Casing & Insulation: Housed in a wooden or metal box with insulating substances on the bottom and sides to minimize conductive and convective heat loss to the surface.

The storage feed tank holds the working fluid that is supplied to the entry of the solar collector. **Circulation Pump or Control Valve:** Regulates the mass flow rate (MF) of the liquid passing through, while flow meter tracks the volumetric or mass flow rate of the moving water.

Thermocouples positioned at the collector's inlet, collector outlet, and along the absorber plate's curved surface to assess temperature changes. Solar power meter aligned parallel to the collector surface to measure the strength of incoming solar radiation.

V. Results and Discussion

The thermal performance of the newly developed curved flat plate solar collector was evaluated under different solar radiation levels. The collector outlet temperature, useful heat gain, thermal efficiency, and temperature difference were measured and analyzed. Solar radiation gradually increased from morning, reached a maximum around noon, and decreased during the afternoon. Maximum radiation was approximately 740 W/m².

VI. Temperature Distribution

The outlet water temperature increased steadily with increasing solar intensity.

Observations: Table 1

S.no	Time (Day)	Mass flow rate (kg/s)	Solar radiation W/m ²	Inlett temp T _i (°C)	Outlet temp T _o (°C)	Temperature rise (°C)	Thermal efficiency (%)
1	9.00	2	450	24	72	48	44.80
2	10.00	2	475	25	76	51	45.09
3	11.00	2	525	27	85	58	46.4
4	12.00	2	660	29	104	75	47.72
5	13.00	2	740	30	115	85	48.22
6	14.00	2	650	28	98	70	45.23

7	15.00	2	560	27	85	53	43.64
8	16.00	2	420	26	73	42	42.00

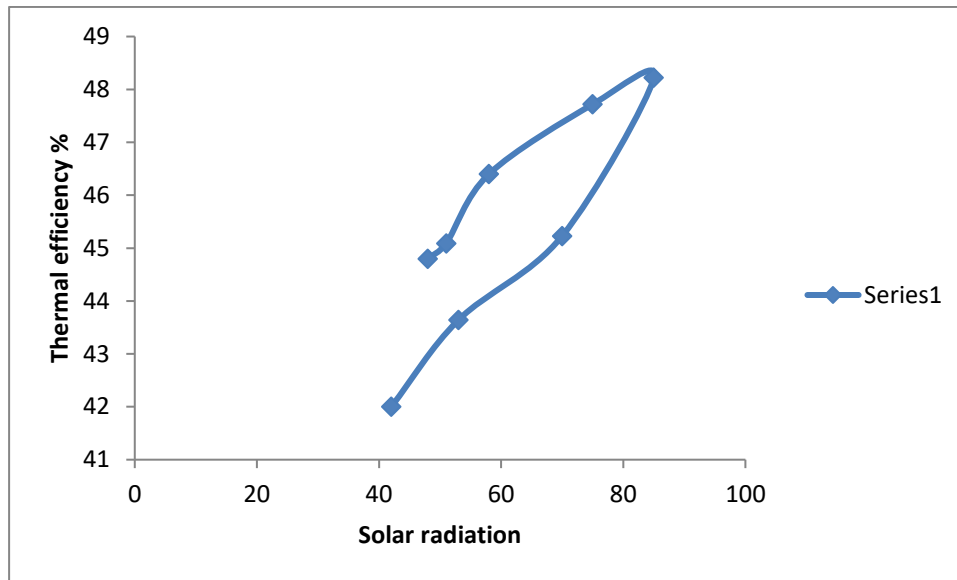


Figure 2: Variation of solar radiation with thermal efficiency

As solar radiation increases more solar energy is absorbed by the collector. Therefore the useful heat gained generally increases causing thermal efficiency to increase initially, higher solar radiation generally gives better thermal performance but does not keep increasing because of heat losses.

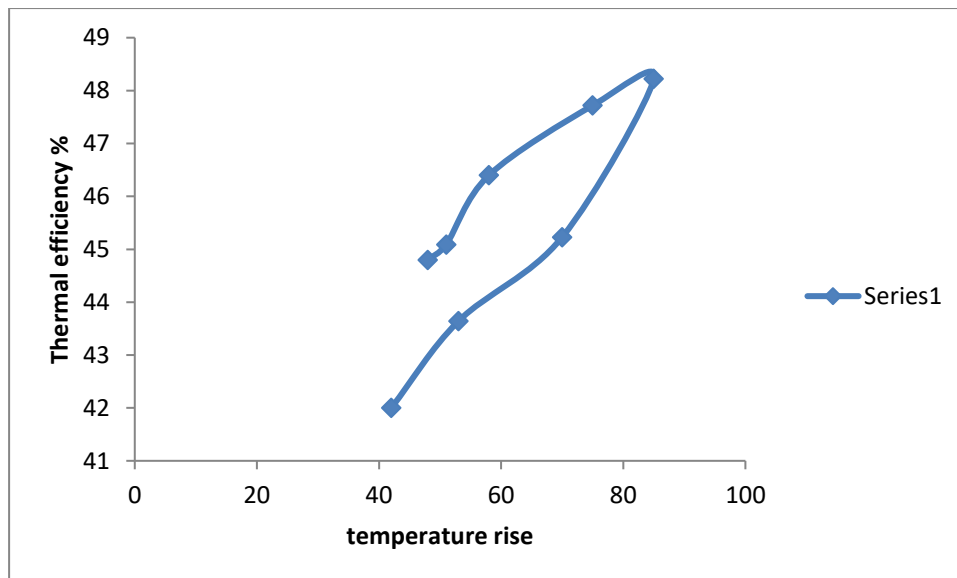


Figure 3: Variation of solar radiation with thermal efficiency

A graph illustrating variations in thermal efficiency as temperature increases. As the temperature of the working fluid or absorber plate increases compared to the outside air, thermal efficiency declines. Elevated operating temperatures raise thermal losses from the curved absorber plate to the surrounding area through convection and radiation..

VII. Conclusions

The current research examined the thermal behavior and performance traits of a newly designed curved solar flat plate collector. The primary goal was to evaluate the practicality of the curved design for enhancing solar energy usage and thermal efficiency in comparison to a standard flat plate collector.

1. The curved absorbing surface offers an altered angle of the absorbing area in relation to the incoming solar radiation. This can enhance solar radiation capture during the operational period and lead to increased useful heat acquisition.
2. Solar radiation was identified as one of the key factors influencing the performance of collectors. Increased solar radiation led to higher temperatures in the absorber and outlet fluid, which enhanced useful heat gain.
3. The collector's thermal efficiency relies on solar radiation, temperatures of the inlet and outlet fluids, environmental conditions, and flow rate. The curved collector demonstrated acceptable thermal efficiency. The collector reached a peak efficiency of around 48.22% in optimal weather conditions.
4. A curved absorber plate generally demonstrates higher overall thermal efficiency than a conventional flat plate. The curved shape produces increased turbulence in air or fluid.

VIII. Future Scope

This study lays the groundwork for additional research and enhancement of curved solar flat plate collectors. The subsequent areas are suggested for upcoming projects:

1. Various curvature radii and absorber shapes can be studied to identify the setup that yields the highest beneficial heat gain and thermal efficiency.
2. CFD simulations can be conducted to analyze fluid-flow patterns, temperature distribution, pressure drop, turbulence, and localized heat-transfer coefficients within the curved collector.

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