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Fabrication and Experimental Performance Analysis of a Parabolic Solar Dish Collector

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ABSTRACT
Purpose: This study aims to design and experimentally evaluate the performance of a parabolic dish solar collector for water heating and evaporation. The primary objective is to measure the system's efficiency and explore ways to optimize solar energy utilization.
Methodology: A 180 cm parabolic dish covered with aluminum and a copper tube absorber was fabricated. Inlet and outlet water temperatures, solar irradiance, mass flow rate, and thermal efficiency were measured on April 16–17, 2023.
Results: The collector reached a peak efficiency of 76.5% at 12:30 PM, with solar irradiance of 956 W/m². Efficiency declined in the afternoon as solar irradiance decreased, showing a strong relationship between performance and solar radiation.
Conclusions: The parabolic dish collector is effective for water heating and evaporation. Its performance can be improved by expanding the exposure area, using more reflective materials, applying anti-scattering coatings, and adding an electronic sun-tracking system.
Limitations: The study is limited to a single dish size and specific climatic conditions. Manual measurements were conducted only during daytime, without accounting for seasonal variations or extreme weather conditions.
Contribution: This research provides empirical evidence on parabolic dish collector performance and practical recommendations for improving solar thermal efficiency.

Keywords: *Energy Efficiency, Evaporation, Parabolic Dish Collector, Solar Thermal, Water Heating*

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1. Introduction

The imperative to transition from fossil fuels to renewable energy sources has never been more pronounced, driven by the dual pressures of climate change and finite hydrocarbon reserves (Hasan et al., 2023). Solar energy, due to its ubiquity and sustainability, has emerged as a core component of global energy strategies, offering a pathway to reduce greenhouse gas emissions while fulfilling thermal and electrical demands across sectors (Tuncer, Variyenli, Khanlari, & Şatay, 2024). Solar thermal collectors capture incident solar radiation and convert it into heat, which can be directly used for water heating, steam generation, and other thermodynamic applications, contributing significantly to low-carbon energy systems (Kalogirou, 2023; Nishad, Srivastava, Maurya, Prakash, & Singh, 2026).

Among the diverse configurations of solar thermal technologies, concentrating systems such as Parabolic Dish Collectors (PDCs) have attracted considerable research interest due to their ability to focus sunlight onto a small receiver area, thereby achieving elevated temperatures and enhanced conversion efficiency compared to non-concentrating systems (Khanlari & Tuncer, 2023). PDCs represent a subset of Concentrated Solar Power (CSP) technologies characterized by high concentration ratios and flexible scalability, making them suitable for decentralized applications in remote or off-grid regions that lack access to conventional energy infrastructure (Loni, Asli-Ardeh, Ghobadian, Najafi, & Bellos, 2019; T. M. Pavlović, Radonjić, Milosavljević, & Pantić, 2012).

Despite technological advances, the performance of PDCs remains intrinsically linked to environmental and design parameters such as optical concentration, receiver geometries, Heat Transfer Fluid (HTF) properties, and operational strategies (Siva Reddy, Kaushik, & Tyagi, 2012). Recent studies have revealed that optimization of receiver design, integration of phase change materials, and utilization of nanofluids can significantly improve thermal and exergetic performance metrics, with reported efficiency improvements depending on system configuration and ambient conditions (Gaurav & Verma, 2026; Tuncer et al., 2024).

To bridge the gap between theoretical models and practical implementation, experimental investigations under realistic solar exposure are critical for validating performance trends and identifying areas for constructive improvement (Khatri, Goyal, & Sharma, 2025). This study constructs and tests a parabolic dish solar collector with a focus on empirical performance assessment through continuous monitoring of inlet and outlet water temperatures, mass flow rates, and incident solar irradiance. By grounding the methodology in systematic measurement and analysis, robust performance data are provided that can be compared with contemporary findings in the literature and utilized to guide future design enhancements (Bellos & Tzivanidis, 2019; Nishad, Maurya, Srivastava, Prakash, & Singh, 2024; Sathish, 2020).

The insights derived from such empirical evaluations are vital for advancing the design of efficient, scalable PDC systems capable of meeting diverse energy needs (Vishnu & Senthil, 2026). Moreover, improved understanding of reflective surface optimization, absorber tube positioning, and operational timing contributes not only to performance maximization but also informs potential integration with sun-tracking mechanisms and hybrid renewable systems. In this way, the present work contributes both to the practical deployment of solar thermal technology and the ongoing scholarly discourse surrounding renewable energy innovation and sustainability transitions (Bellos, Tzivanidis, & Torosian, 2018).

Recent developments in solar thermal technology have increasingly emphasized the integration of advanced materials and intelligent thermal management systems to enhance the operational stability and energy efficiency of Parabolic Dish Collectors (PDCs). The incorporation of nanofluids as Heat Transfer Fluids (HTFs) has been demonstrated to improve thermal conductivity and heat absorption characteristics, thereby increasing overall collector efficiency under varying solar irradiance conditions. Several experimental studies have reported that nanofluid-based systems are capable of achieving superior thermal performance compared with conventional water-based collectors due to enhanced convective heat transfer mechanisms and reduced thermal resistance within absorber tubes (Gaurav & Verma, 2026). Furthermore, the integration of thermal energy storage materials such as phase change materials has also been identified as an effective strategy for maintaining stable thermal output during transient solar conditions and intermittent radiation periods (Kalogirou, 2023).

In addition to material optimization, recent research has highlighted the importance of geometric configuration and optical accuracy in determining the overall efficiency of PDC systems. Parameters such as dish curvature precision, reflector surface reflectivity, focal point alignment, and absorber tube positioning have been recognized as critical factors influencing solar concentration ratios and thermal energy capture (Bellos & Tzivanidis, 2019). Experimental investigations conducted under real climatic conditions demonstrated that even minor deviations in reflector alignment may substantially reduce thermal efficiency and increase optical losses within the system (Khatri et al., 2025). Consequently, modern PDC developments have increasingly incorporated automated sun-tracking technologies and adaptive control systems to maintain optimal solar incidence angles throughout operational periods, thereby maximizing energy collection efficiency and improving long-term system reliability (Vishnu & Senthil, 2026).

Moreover, the growing global emphasis on sustainable energy transitions has encouraged broader exploration of hybrid renewable energy systems integrating PDC technology with complementary renewable sources and smart energy management frameworks. Hybrid configurations combining solar thermal collectors with photovoltaic modules, biomass systems, or thermal storage technologies have demonstrated considerable potential for improving energy continuity and reducing dependence on fossil-based backup systems (Hasan et al., 2023). Such integrated systems are particularly relevant for remote and off-grid applications where stable energy access remains limited. In this context, empirical studies focusing on operational optimization, environmental adaptability, and economic feasibility are increasingly regarded as essential for accelerating the commercialization and large-scale deployment of PDC technologies within sustainable energy infrastructures (Bellos et al., 2018).

2. Literature Review and Hypothesis/es Development

2.1 Overview of Solar Thermal Collectors

Solar thermal collectors have been extensively studied for their ability to convert solar radiation into usable heat energy (Murugan et al., 2022). These systems are widely applied in domestic water heating, steam generation, and various industrial thermal processes, providing a renewable alternative to conventional energy sources (García-Ferrero et al., 2025). Their design allows for effective capture of solar energy and efficient heat transfer, which is critical for reducing reliance on fossil fuels and lowering greenhouse gas emissions (Leong et al., 2016).

Among different types of solar thermal collectors, Parabolic Dish Collectors (PDCs) have been recognized for their superior performance (Ghafoor & Munir, 2015). Their high concentration ratio enables sunlight to be focused onto a relatively small absorber surface, which allows for significant temperature increases in the working fluid compared to flat-plate or parabolic trough collectors (Vishnu & Senthil, 2023). This concentration effect makes PDCs highly efficient in harnessing solar energy for high-temperature applications (Esfanjani, Mahmoudi, Rashidi, Valipour, & Yan, 2024).

As a result, PDCs are particularly suitable for scenarios requiring dense thermal energy. Their ability to achieve elevated fluid temperatures enhances the overall effectiveness of solar thermal systems, making them ideal for applications in industries or processes that demand concentrated heat (Barone, Buonomano, Forzano, & Palombo, 2019). Empirical studies have demonstrated that well-designed PDCs can outperform other collector types, providing both high energy output and operational reliability (Majel, Obaid, & Zidane, 2023).

Recent advancements in solar thermal technology have increasingly focused on improving the thermal efficiency and operational stability of Parabolic Dish Collectors through the integration of advanced heat transfer mechanisms and optimized absorber configurations. Studies have demonstrated that the thermal performance of PDC systems can be significantly enhanced by modifying absorber geometries, improving reflector surface quality, and minimizing optical losses during solar concentration processes (Bellos & Tzivanidis, 2019). In particular, the positioning of absorber tubes at the focal point of the dish has been identified as a critical factor influencing thermal energy absorption and overall system efficiency. Experimental investigations further revealed that precise focal alignment contributes substantially to improved heat transfer performance and reduced thermal dissipation under fluctuating environmental conditions (Khatri et al., 2025).

Furthermore, increasing attention has been directed toward the integration of PDC systems with automated control technologies and hybrid renewable energy frameworks. Modern solar thermal systems frequently incorporate sun-tracking mechanisms to maintain optimal solar incidence angles throughout the day, thereby maximizing solar concentration and energy capture efficiency (Vishnu & Senthil, 2026). Hybrid systems combining PDC technology with photovoltaic modules, thermal energy storage systems, or biomass-based energy sources have also demonstrated considerable potential for improving energy continuity and reducing dependence on fossil fuels. Such developments are particularly relevant for decentralized and off-grid applications where stable and sustainable energy supply remains essential. Consequently, continued experimental and analytical investigations are regarded as necessary for advancing the commercial viability and technological maturity of parabolic dish solar collector systems.

2.2 Design Optimization of PDCs
Design optimization is a central focus in research on Parabolic Dish Collectors (PDCs) due to the direct impact of geometrical and material parameters on thermal performance. Critical aspects include the configuration of the heat receiver, the curvature and material of the reflective surface, and the smoothness of the reflector, all of which influence the efficiency of solar concentration and heat transfer (Eze, 2025). By carefully refining these parameters, researchers can enhance energy capture and overall system effectiveness (Sahu, Kopalakrishnaswami, & Natarajan, 2022).

Another key factor in design optimization is the integration of solar tracking mechanisms (Maurya, Kumar, & Sharma, 2022). PDCs that are precisely aligned with the sun can maintain optimal incident angles throughout the day, significantly improving thermal efficiency. Empirical studies have demonstrated that even minor adjustments in the positioning of the absorber or the alignment of the reflective surface can result in measurable gains in energy output, highlighting the system's sensitivity to precise design interventions (García-Ferrero et al., 2025). Consequently, precise geometric and material planning is essential for maximizing the energy output of PDCs. Optimization efforts not only improve efficiency but also enhance system reliability and operational stability. Recent experimental and modeling studies confirm that well-optimized PDCs outperform less carefully designed collectors, demonstrating the importance of integrating both mechanical design precision and material advancements in high-performance solar thermal systems (Majel et al., 2023).

2.3 Thermal and Exergetic Performance Analysis
Thermal analysis is a fundamental approach to evaluating the effectiveness of solar collectors in converting incident solar energy into usable heat (Ahmadi et al., 2019). By measuring temperature gradients, heat fluxes, and overall energy transfer, researchers can determine the operational efficiency of parabolic dish collectors (PDCs) and identify areas for improvement (Rahimi-Ahar & Hatamipour, 2024). Such analyses provide critical insights into the thermal behavior of collectors under varying operational conditions, including changes in ambient temperature and solar irradiance.

Exergy analysis complements thermal studies by assessing the quality of energy and identifying irreversibilities within the system. Exergy-based evaluations help pinpoint major sources of energy loss, typically concentrated at the receiver, and provide guidance for design interventions that can minimize inefficiencies (Vishnu & Senthil, 2023). This approach allows researchers to quantify the impact of material properties, fluid flow rates, and collector geometry on the system's ability to convert solar energy into work-equivalent heat, enhancing understanding of energy utilization (Vučković, Stojiljković, Vukić, Stefanović, & Dedeić, 2014).

Quantitative understanding derived from thermal and exergy analyses enables a more comprehensive assessment of PDC performance. Variations in water flow rates, solar irradiance, and surface materials can all influence collector efficiency, and exergy assessments provide a scientific framework for evaluating these effects (Majel et al., 2023). By integrating thermal and exergetic perspectives, researchers can develop design and operational strategies that optimize heat transfer, reduce energy losses, and improve overall system efficiency for practical solar energy applications (Ochmann & Rusin, 2023).

2.4 Advanced Working Fluids and Coatings

The use of advanced working fluids, particularly nanofluids, has been widely investigated for its ability to enhance heat transfer in parabolic dish collector (PDC) systems. Nanofluids, which are engineered by suspending nanoparticles in a base fluid, increase the thermal conductivity of the fluid and improve convective heat transfer, leading to higher energy efficiency. Studies have demonstrated that the inclusion of such fluids can significantly boost the performance of PDCs under varying solar irradiance and flow conditions (Vishnu & Senthil, 2023).

In addition to advanced fluids, high-performance absorber coatings play a crucial role in minimizing energy losses due to reflection and radiation. Selective coatings on the absorber surface can increase solar absorption while reducing thermal emission, thereby improving the overall thermal efficiency of the collector. When applied in combination with optimized collector geometry, these coatings enhance the system's capability to achieve elevated temperatures efficiently and maintain operational stability (Majel et al., 2023). Together, the integration of nanofluids and high-performance coatings underscores the importance of material selection and design precision in achieving high-performance PDC systems. These innovations ensure that solar thermal energy is effectively captured, transferred, and retained within the collector, supporting both enhanced thermal output and system reliability. This convergence of material science and geometric optimization has been recognized as a key factor in modern solar thermal research and practical deployment (S. R. Pavlović, Vasiljević, Stefanović, Stamenković, & Bellos, 2016).

2.5 Empirical Evaluations Under Real Conditions

Despite the abundance of theoretical analyses and numerical simulations in solar thermal research, there is a noticeable lack of experimental studies that simultaneously capture inlet and outlet temperatures, fluid flow rates, and solar irradiance in real-world operating conditions. Comprehensive measurements of these variables are critical to validate models and understand practical system behavior (García-Ferrero et al., 2025). To address this gap, the current study evaluates a full-scale 180 cm parabolic dish collector equipped with a copper absorber tube. The experimental setup allows precise monitoring of thermal performance parameters throughout the operational perio, ensuring that data reflect realistic environmental and solar conditions (Majel et al., 2023). The empirical data collected provide essential insights for the refinement of PDC design, the validation of theoretical predictions, and the formulation of effective operational strategies. By bridging the divide between simulation and practice, these real-world evaluations contribute to improved energy capture, system reliability, and the practical deployment of high-efficiency solar thermal technologies (Vishnu & Senthil, 2023).

2.6 Hypotheses

Based on the literature review and empirical insights from previous studies on Parabolic Dish Collectors (PDCs), the following hypotheses are proposed to guide this research:

- H_1: Implementing a parabolic dish collector will significantly enhance thermal efficiency in water heating compared to non-concentrating solar collectors, as high concentration ratios enable greater heat absorption and energy density
- H_2: Precise optimization of absorber placement and alignment with incident solar radiation is expected to improve energy capture and temperature elevation, reflecting findings that minor adjustments in receiver positioning can substantially affect system performance
- H_3: Water flow rate variations will directly influence outlet temperature and overall collector efficiency, consistent with studies indicating that thermal and exergy performance is sensitive to flow dynamics and heat transfer rates
- H_4: The integration of reflective materials and sun-tracking systems will further enhance thermal efficiency by minimizing energy losses, corroborating experimental research that highlights the combined effects of material quality and operational alignment on performance

These hypotheses are constructed to directly connect the research design with the established literature, ensuring that experimental evaluation addresses key factors identified in previous studies and providing a clear framework for testing the performance improvements of the fabricated parabolic dish collector.

3. Methodology

3.1 Experimental Setup

The experimental investigation involved the fabrication and assembly of a parabolic dish solar collector designed for water heating and evaporation. The collector utilized a parabolic dish with a diameter of 180 cm, covered with high-reflectivity aluminum sheets to maximize the concentration of solar radiation. A copper tube, measuring 0.9 cm in diameter and 37.5 cm in length, was installed at the focal point to serve as the primary heat absorber. The collector structure included robust supports, fasteners, and a flat plate for initial solar radiation capture, ensuring stability and optimal alignment. Water was circulated through the absorber tube, and precise measurements of flow rate and temperature were enabled through calibrated thermometers and volumetric timing measurements.

3.2 Fabrication Procedure

The construction process began with accurate measurement and surface preparation of the parabolic dish to ensure minimal irregularities for optimal reflection. The focal length was calculated as half of the dish's radius (90 cm) to accurately position the absorber at the point of maximum solar concentration. Aluminum sheets were meticulously applied to the dish surface, ensuring uniformity and smoothness to reduce scattering losses. The copper tube absorber was supported using skewers placed according to the calculated focal length, with open ends for water inlet and outlet. Finally, the dish was oriented toward the sun using shadow alignment techniques, maximizing incident solar energy throughout the experimental period.

3.3 Experimental Procedure

Temperature measurements were recorded at the absorber to confirm effective solar concentration, with peak temperatures exceeding 200°C. Water was then circulated through the copper tube, and the volumetric flow rate was determined by timing the filling of a 1.5-liter container at the outlet. This allowed calculation of mass flow rate and subsequent thermal energy transfer. Incident solar radiation, alongside inlet and outlet water temperatures, was measured at regular intervals throughout the experiment (April 16–17, 2023). These measurements enabled detailed assessment of the system's performance and the impact of varying solar irradiance on thermal efficiency.

3.4 Data Analysis

The mass flow rate (M') of water was calculated using the volumetric flow rate (V') and the density of water (ρ = 1000 kg/m³), while thermal efficiency (η) was determined based on the ratio of useful heat gained by the water to the incident solar energy on the collector. The calculations incorporated the specific heat capacity of water (4180 J/kg°C), measured temperature differentials, solar irradiance, and the collector's aperture area. Efficiency was then analyzed over time to identify peak operating conditions and to examine the relationship between solar irradiance, water flow rate, and thermal performance. The methodology ensures that experimental results are reproducible and provides a comprehensive basis for performance evaluation and design optimization.

3.5 Reliability and Validation

To enhance the reliability of the experiment, all temperature and flow rate measurements were repeated multiple times under identical conditions. Data validation was performed by comparing results with published performance benchmarks for similar parabolic dish collectors. This methodological rigor ensures the robustness of findings and their applicability to broader solar thermal applications, providing empirical evidence to support the hypotheses and guide future improvements in collector design and operation.

4. Results and Discussion

4.1 Temperature and Solar Irradiance Trends

The parabolic dish collector exhibited a distinct temperature profile throughout the measurement period. Inlet water temperature remained relatively constant, while the outlet temperature demonstrated a steady increase during midday, corresponding to peak solar irradiance values. Maximum outlet temperature was recorded at 36°C around 12:30 PM, coinciding with an irradiance level of 956 W/m².

These results highlight the direct correlation between incident solar radiation and thermal energy gain, consistent with prior studies emphasizing the importance of irradiance in optimizing collector performance (García-Ferrero et al., 2025).

4.2 Collector Efficiency Analysis

Thermal efficiency was calculated by comparing the useful heat gained by water with the incident solar energy. The peak efficiency reached 76.5% at midday, aligning with periods of high solar irradiance. As the afternoon progressed, efficiency gradually decreased to approximately 61% due to declining irradiance and ambient temperature fluctuations. This temporal trend aligns with literature reports, indicating that collector performance is highly sensitive to diurnal variations in solar radiation and environmental conditions (Eze, 2025).

4.3 Impact of Flow Rate and Absorber Configuration

The measured water flow rate significantly influenced thermal efficiency. Lower flow rates allowed water to remain longer in contact with the heated absorber, leading to higher outlet temperatures but potentially reducing overall energy transfer due to limited mass circulation. Conversely, higher flow rates resulted in moderate temperature increases while enhancing energy throughput. This observation confirms findings from exergy-based assessments that highlight the critical role of fluid dynamics in PDC performance (Rahimi-Ahar & Hatamipour, 2024).

4.4 Discussion of Design and Material Considerations

The experimental outcomes underscore the importance of precise absorber positioning and high-quality reflective surfaces in maximizing energy capture. The aluminum-coated dish effectively concentrated sunlight onto the copper absorber, confirming that reflective material properties and surface smoothness are critical for minimizing scattering losses. These results support prior studies that advocate for material and geometric optimizations to enhance PDC efficiency (Majel et al., 2023; Vishnu & Senthil, 2023).

4.5 Implications and Comparative Analysis

Comparing the observed efficiencies with previously reported data for similar PDC systems, the fabricated collector demonstrates competitive performance, validating the design and fabrication methodology. The findings indicate that integration of sun-tracking mechanisms, improved reflector coatings, and optimal flow rate management could further increase efficiency. These insights provide a foundation for future optimization of PDC systems and practical implementation in residential and industrial applications, bridging the gap between laboratory experimentation and real-world energy utilization scenarios.

5. Conclusions

5.1 Conclusion

The experimental investigation of the 180 cm parabolic dish solar collector demonstrated a maximum thermal efficiency of 76.5% under peak solar irradiance conditions. The results confirm that PDCs effectively concentrate sunlight onto a small receiver area, significantly enhancing water heating and evaporation performance. The study highlights that careful absorber positioning, high-quality reflective surfaces, and optimized water flow rates are critical factors for achieving optimal thermal output. These findings support the proposed hypotheses and align with current literature on high-efficiency solar thermal systems.

5.2 Research Limitations

While the study provides valuable empirical insights, certain limitations must be acknowledged. The experiments were conducted over a limited time period and under specific climatic conditions, which may not fully represent seasonal or regional variations. The collector size was fixed at 180 cm, limiting the generalization of results to other dimensions or scaling scenarios. Additionally, manual measurement techniques may introduce minor errors in temperature and flow rate readings, despite repeated trials to ensure accuracy.

5.3 Suggestions and Directions for Future Research

Future research should explore PDC performance over extended periods and across different seasons to capture variability in solar irradiance and ambient conditions. Investigations using larger or modular collector designs may provide insights into scalability and practical deployment. Incorporating automated measurement systems and high-precision sensors can enhance data accuracy and reduce human error. Moreover, integrating sun-tracking systems, advanced reflective coatings, and alternative working fluids such as nanofluids could further optimize thermal efficiency. Lastly, comparative studies between PDCs and other concentrating solar collector types would provide a broader understanding of performance trade-offs and design considerations for diverse applications.

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