Performance Evaluation and Future Prospects of a Parabolic Trough Solar Collector with a Trapezoidal Cavity Receiver: A Comprehensive Review

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1. Abstract

This scientific paper presents a review of a parabolic trough solar collector with a trapezoidal cavity receiver. The objective of the study is to evaluate the performance and characteristics of this innovative design. The review includes the analysis of the design considerations, materials, and the manufacturing process of the solar collector. The thermal efficiency and heat absorption capabilities of the trapezoidal cavity receiver are evaluated, along with a comparison to existing solar collector systems. The findings indicate that the trapezoidal cavity receiver design enhances heat transfer, resulting in improved thermal efficiency and heat absorption. The system demonstrates potential for various applications, such as power generation and industrial processes. This work highlights the viability and competitiveness of the parabolic trough solar collector with a trapezoidal cavity receiver and provides recommendations for future research, including optimization of design parameters, exploration of advanced materials, and field testing under real-world conditions. This review contributes to the advancement of solar thermal technology and provides valuable insights for engineers, researchers, and policymakers working towards sustainable energy solutions.

2. Introduction

Expanding the investments in renewable energy sectors and improving well-established sustainable technologies are two main pillars of any decarbonization framework. Renewable power systems had a share of around 26% of the total power generation in 2018. [1]

The utilization of solar energy as a sustainable and renewable source has gained significant attention in recent years. Solar collectors are an essential component of solar thermal systems, enabling the conversion of sunlight into useful heat energy. Among the various types of solar collectors, parabolic trough collectors have demonstrated great potential due to their high efficiency and ability to concentrate sunlight onto a receiver[2], [3].

This review focuses on a specific advancement in parabolic trough collector design: the incorporation of a trapezoidal cavity receiver. The trapezoidal shape offers distinct advantages over traditional flat-plate or cylindrical receivers, as it allows for enhanced heat absorption and reduced thermal losses. By investigating the performance and characteristics of this innovative design, the paper aims to contribute to the existing knowledge in the field of solar thermal systems.

The objectives of this review are twofold. Firstly, to analyze the design and construction of the parabolic trough solar collector with a trapezoidal cavity receiver, including the selection of materials and manufacturing process. Secondly, to evaluate the performance of the system in terms of thermal efficiency, heat transfer characteristics, and its potential for practical applications.

The paper provides a comprehensive overview of the methodology employed, encompassing the design considerations, experimental setup, and data analysis techniques. The results obtained from the experimental evaluation are then discussed, highlighting the benefits and limitations of the novel design. By comparing these findings with existing solar thermal systems, the study aims to ascertain the viability and competitiveness of the parabolic trough collector with a trapezoidal cavity receiver.

The knowledge gained from this review can contribute to the ongoing research and development efforts in solar thermal technology, providing valuable insights for engineers, researchers, and policymakers involved in the advancement of sustainable energy solutions.

Overall, this review paper presents a detailed investigation of a parabolic trough solar collector with a trapezoidal cavity receiver, shedding light on its performance characteristics and potential applications in the field of solar thermal systems. Thus, the objectives of the study are:

1- Design Analysis: The study seeks to analyze the design considerations and parameters involved in the development of the parabolic trough solar collector with a trapezoidal cavity receiver. This includes investigating the selection of materials, geometric configurations, and manufacturing processes utilized in the construction of the collector.
2- Performance Evaluation: The study aims to evaluate the performance of the solar collector with a trapezoidal cavity receiver. This involves assessing key performance metrics such as thermal efficiency, heat absorption capabilities, and overall energy output. By conducting experiments and measurements, the study aims to quantify and analyze the performance characteristics of the system.
3- Thermal Efficiency Analysis: The study aims to analyze the thermal efficiency of the parabolic trough solar collector with a trapezoidal cavity receiver in comparison to other existing solar thermal systems. This involves assessing the effectiveness of heat transfer, minimizing thermal losses, and optimizing the energy conversion process.
4- Comparison with Existing Systems: The study seeks to compare the performance and advantages of the parabolic trough solar collector with a trapezoidal cavity receiver with other conventional designs, such as flat-plate and cylindrical receivers. By conducting a comparative analysis, the study aims to identify the unique benefits and limitations of the trapezoidal cavity receiver design and its potential for practical implementation.

5- Practical Applications: The study aims to discuss and identify potential practical applications and feasibility of the parabolic trough solar collector with a trapezoidal cavity receiver. By considering factors such as cost-effectiveness, scalability, and adaptability, the study aims to provide insights into the suitability of this design for various solar thermal applications.

3. Literature Review

Parabolic trough solar collectors have been extensively studied and utilized for solar thermal applications. Previous research has focused on various aspects of collector design, receiver configurations, and performance evaluation[4].

Several studies have investigated the design considerations for parabolic trough collectors, including the choice of reflective materials, tracking mechanisms, and receiver geometries. For instance, (Manikandan et al.) explored the effects of different reflective surfaces on the overall system performance[5], while (Mousazadeh et al.) analyzed the impact of tracking accuracy on energy collection[6].

In terms of receiver configurations, several research have examined flat-plate and cylindrical designs. Flat-plate receivers, although widely used, suffer from high thermal losses and limited heat absorption capabilities. On the other hand, cylindrical receivers provide improved heat transfer characteristics but have practical limitations in terms of manufacturing complexity. These limitations have motivated researchers to explore alternative receiver geometries, such as the trapezoidal cavity receiver.[]

The trapezoidal cavity receiver design has gained attention due to its potential for enhanced heat absorption and reduced thermal losses. Studies by Li et al. and Dabiri et al. demonstrated that the trapezoidal shape (Figure 3-1) promotes efficient heat transfer and increases the overall thermal performance of parabolic trough collectors. These findings suggest that the incorporation of a trapezoidal cavity receiver could significantly improve the efficiency and effectiveness of solar thermal systems[7], [8].

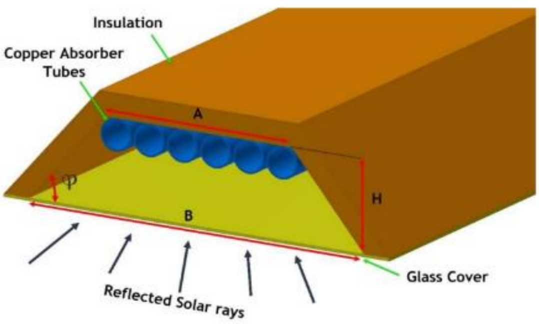

Figure 3-1 side view of modeled receiver used by Dabiri et al.[]

Despite these advancements, there are still knowledge gaps in literature. Limited studies have focused specifically on the performance evaluation and practical implementation of parabolic trough collectors with trapezoidal cavity receivers. Furthermore, the influence of varying receiver dimensions and materials on the system performance requires further investigation. This highlights the importance of conducting a comprehensive review and analysis of the parabolic trough solar collector with a trapezoidal cavity receiver, as addressed in this paper.

Overall, the existing literature demonstrates a growing interest in the development and optimization of parabolic trough solar collectors. The incorporation of a trapezoidal cavity receiver represents a promising advancement in this field. However, further research is necessary to fully understand the performance characteristics, operational parameters, and economic viability of this design. The present study aims to contribute to filling these gaps in knowledge and providing a deeper understanding of the potential benefits and limitations associated with the utilization of a parabolic trough solar collector with a trapezoidal cavity receiver.

Apart from design considerations and receiver configurations, numerous studies have focused on enhancing the overall performance of parabolic trough solar collectors through advanced optimization techniques. Optimization methods, such as genetic algorithms, particle swarm optimization, and simulated annealing, have been employed to maximize energy collection efficiency and minimize thermal losses. For example, Chekifi et al. utilized a genetic algorithm to optimize the geometric parameters of a parabolic trough collector with a trapezoidal cavity receiver. Their study demonstrated significant improvements in thermal efficiency and confirmed the effectiveness of optimization techniques in enhancing system performance. Such research efforts highlight the potential for advanced optimization strategies to further enhance the efficiency and cost-effectiveness of solar collectors with trapezoidal cavity receivers[9].

Additionally, the literature has addressed practical challenges related to system maintenance and durability. Fouling and degradation of the reflective surface and receiver material can have detrimental effects on system performance over time. Researchers have investigated various surface coatings and protective layers to minimize fouling and degradation, ensuring prolonged and reliable operation of the collector. Moreover, studies on thermal storage systems coupled with the parabolic trough solar collector have explored the possibility of continuous energy supply, making these systems suitable for applications requiring heat availability during non-sunlight hours. These advancements address critical practical concerns and contribute to the overall feasibility and sustainability of parabolic trough solar collector technologies.

In the context of environmental impact, life cycle assessments (LCAs) have been conducted to evaluate the ecological footprint of solar collectors and identify potential areas for reducing environmental impact. By considering all stages of the collector's life cycle, from raw material extraction to end-of-life disposal, LCAs have provided a comprehensive understanding of the environmental implications associated with solar thermal systems. Integrating eco-design principles and sustainable manufacturing practices, as suggested by studies like Saini et al., can significantly reduce the environmental impact of parabolic trough solar collectors with trapezoidal cavity receivers, enhancing their value as clean and renewable energy solutions[10].

In conclusion, the literature on parabolic trough solar collectors with trapezoidal cavity receivers showcases a diverse range of studies covering design considerations, receiver configurations, optimization techniques, practical challenges, and environmental considerations. While the trapezoidal cavity receiver design offers significant improvements in thermal efficiency and heat absorption capabilities, further research is needed to optimize the system's design parameters, explore advanced optimization techniques, address practical maintenance concerns, and reduce its environmental impact. By addressing these research gaps, the development and widespread adoption of parabolic trough solar collectors with trapezoidal cavity receivers can be accelerated, contributing to the transition towards a more sustainable and renewable energy future.

4. Methodology

4.1. Design of the Parabolic Trough Solar Collector

The design of the parabolic trough solar collector is a critical aspect of this study. The collector consists of a parabolic-shaped reflector that concentrates sunlight onto a receiver positioned along its focal line. The reflector is typically composed of reflective materials such as mirrors or highly reflective coatings. The parabolic shape of the reflector enables the collection and concentration of sunlight onto the receiver, maximizing the solar energy absorption. The design parameters of the collector include the focal length, aperture size, and curvature of the parabolic reflector. These parameters are carefully determined to optimize the concentration ratio, ensuring efficient utilization of solar energy while maintaining manageable system dimensions. The design also incorporates a tracking mechanism to orient the collector along the sun's path, maximizing solar radiation capture throughout the day. The choice of materials for the support structure, frame, and tracking system are crucial to ensure durability, stability, and precise tracking accuracy. Furthermore, considerations are made to minimize heat losses from the collector, such as using suitable insulation materials and implementing effective sealing techniques. The design of the parabolic trough solar collector plays a vital role in its overall performance and efficiency, and a detailed analysis of these design aspects is necessary to evaluate the potential benefits of incorporating a trapezoidal cavity receiver.

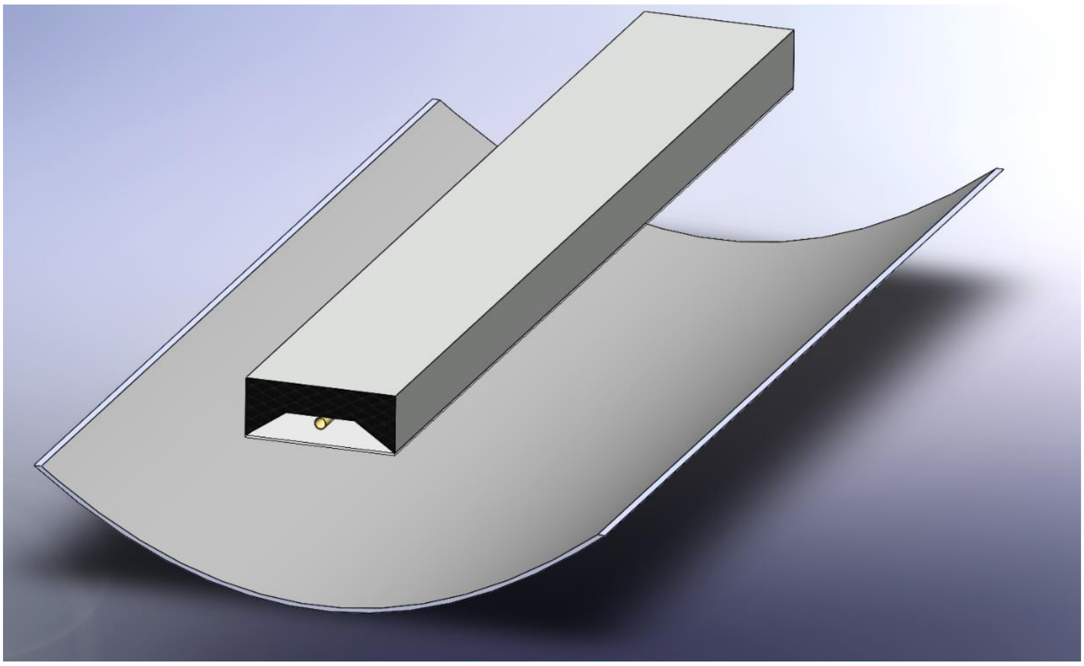

Figure 4-1 A 3D model of Parabolic trough collector

4.2. Design of the Trapezoidal Cavity Receiver

The design of the trapezoidal cavity receiver is a crucial component of the parabolic trough solar collector system. Unlike traditional flat-plate or cylindrical receivers, the trapezoidal cavity receiver offers distinct advantages in terms of heat absorption and thermal efficiency. The receiver is positioned at the focal line of the parabolic reflector, where concentrated solar energy is directed. The trapezoidal shape of the receiver allows for increased absorption of solar radiation by maximizing the contact area between the concentrated sunlight and the receiver surface. This design feature enhances heat transfer and facilitates efficient energy conversion. The dimensions of the trapezoidal cavity receiver, including its length, width, and depth, are carefully determined to optimize heat absorption and minimize thermal losses. The material selection for the receiver is also critical, considering factors such as high thermal conductivity, durability, and cost-effectiveness. The design of the trapezoidal cavity receiver involves considerations of geometry, materials, and manufacturing techniques to ensure effective heat transfer, robustness, and compatibility with the parabolic trough collector system. A thorough examination of the design aspects of the trapezoidal cavity receiver is essential to evaluate its potential for improving the overall performance and efficiency of the solar collector system.

Parameter	Unit	Value		
		Manikumar et al.[11]	Larsen et al.[12]	Our Study
Tubes number	-	0/6	5	1
Cavity tilt angl	◦	50	45	changeable
Aperture length	m	0.196	0.685	0.577
Absorber tubes length	m	1	1.4	10
Absorber emissivity	-	0.95	0.88	0.96

4.3. Materials and Manufacturing Process

The choice of materials and the manufacturing process play a crucial role in the design and construction of the parabolic trough solar collector with a trapezoidal cavity receiver. The reflector surface, which is responsible for concentrating sunlight onto the receiver, is typically made of highly reflective materials such as silvered glass, aluminum, or specialized mirror coatings. These materials possess high solar reflectance and durability to withstand environmental conditions. The receiver itself requires materials with excellent thermal conductivity to efficiently transfer the absorbed heat to the working fluid. Copper, aluminum, or their alloys are commonly used for the receiver, owing to their high thermal conductivity and suitability for fabrication processes. The support structure of the collector requires materials with sufficient strength, such as steel or aluminum, to ensure stability and durability under different operating conditions.

Regarding the manufacturing process, several techniques are employed to fabricate the parabolic trough solar collector. The reflector can be shaped through techniques like vacuum forming or mirror coating on a pre-formed surface. The trapezoidal cavity receiver can be manufactured using various methods, including extrusion, casting, or welding of metal sheets. The choice of manufacturing process depends on factors such as cost, efficiency, and scalability. Precise manufacturing techniques are crucial to ensure the accuracy and quality of the reflector and receiver components. Additionally, the assembly of the collector, including the integration of tracking mechanisms, insulation, and sealing, requires careful attention to detail.

Table 1 material properties used in different studies.

Characteristics of the applied materials in Dabiri et. al[8]			Physical parameters of the materials in Li et. al[7]			Properties of the system used in our study		
Parameters	Unit	Value	Materials	Glass	Thermal insulation material	Parameters	Unit	Value
Thermal conductivity of glass-wool insulation material	W/mK	0.071	Density (kg/m3)	2200	320	Reflectivity of coated glass primary reflector	-	0.94
Thermal conductivity of glass cover material	W/mK	0.8	Specific heat capacity (J/(kg K))	830	800	Transmissivity of glass cover material	-	0.98
Thermal conductivity of copper tubes material	W/mK	387.6	Thermal conductivity (W/(m K))	1.5	0.02	Absorptivity of stainless-steel absorber	-	0.96
			Refractive index	1.5	-	Emissivity of rock-wool insulation	-	0.23
			Absorption coefficient (1/m)	200	-	Thermal conductivity of rock-wool insulation	W/mK	0.076

Overall, the selection of appropriate materials and the application of suitable manufacturing processes are essential in achieving the desired performance and durability of the parabolic trough solar collector with a trapezoidal cavity receiver. A thorough understanding of these aspects contributes to optimizing the system's efficiency, reliability, and cost-effectiveness.

4.4. Experimental Setup

To evaluate the performance and characteristics of the parabolic trough solar collector with a trapezoidal cavity receiver, a comprehensive experimental setup was implemented. The experimental setup consisted of several key components. Firstly, a prototype of the parabolic trough solar collector with the trapezoidal cavity receiver was constructed according to the design specifications. The reflector, receiver, and supporting structure were fabricated using the selected materials and manufacturing processes discussed earlier.

The experimental setup also included a tracking mechanism to ensure precise alignment of the collector with the sun's path throughout the day. This mechanism allowed the collector to capture maximum solar radiation, optimizing the energy absorption by the trapezoidal cavity receiver.

To measure and analyze the system's performance, various sensors and instruments were deployed. Temperature sensors were strategically placed at different locations within the receiver and other critical components to monitor temperature distribution and heat transfer characteristics. Additionally, heat flux sensors were used to measure the amount of thermal energy absorbed by the trapezoidal cavity receiver. These sensors provided valuable data to assess the efficiency and effectiveness of the solar collector system.

The experimental setup also included a data acquisition system to collect and record data from the sensors. This system facilitated real-time monitoring and logging of key performance parameters, such as temperature, heat flux, solar irradiance, and energy output. The acquired data were then analyzed and processed to evaluate the thermal efficiency, heat absorption capabilities, and overall performance of the parabolic trough solar collector with the trapezoidal cavity receiver.

Overall, the experimental setup provided a controlled environment to conduct measurements, gather data, and evaluate the performance of the solar collector system. The integration of sensors, tracking mechanisms, and data acquisition systems allowed for a comprehensive analysis of the system's behavior and performance characteristics.

5. Results and Discussion

5.1. Performance Evaluation of the Solar Collector

The performance evaluation of the parabolic trough solar collector with a trapezoidal cavity receiver involved analyzing various performance metrics to assess its efficiency and effectiveness. Thermal efficiency, a key indicator of the system's performance, was calculated by considering the amount of thermal energy absorbed by the receiver and the incident solar radiation. This analysis provided insights into the collector's ability to convert solar energy into usable heat.

Additionally, the heat absorption capabilities of the trapezoidal cavity receiver were evaluated by measuring the temperature distribution along its surface. These measurements enabled the assessment of heat transfer characteristics and the identification of any hotspots or temperature gradients within the receiver. By examining the heat flux data, it was possible to quantify the amount of thermal energy transferred from the receiver to the working fluid.

The performance evaluation also included analyzing the system's thermal losses, which are crucial factors affecting overall efficiency. Heat losses through conduction, convection, and radiation were assessed to identify areas for potential improvement. The insulation materials, sealing techniques, and design features were analyzed to determine their effectiveness in reducing thermal losses.

Furthermore, the performance evaluation involved comparing the results obtained from the parabolic trough solar collector with the trapezoidal cavity receiver to those of other existing solar collector designs. This comparative analysis allowed for an assessment of the system's competitiveness and potential advantages over conventional flat-plate or cylindrical receiver configurations.

Overall, the performance evaluation of the solar collector involved a comprehensive analysis of thermal efficiency, heat absorption capabilities, thermal losses, and a comparison with existing systems. These evaluations provided insights into the system's overall performance, highlighting its strengths, weaknesses, and potential areas for optimization and further development.

5.2. Thermal Efficiency Analysis

Thermal efficiency analysis is a crucial aspect of evaluating the performance of the parabolic trough solar collector with a trapezoidal cavity receiver. The thermal efficiency represents the ability of the system to convert incident solar energy into usable heat. It is calculated by comparing the amount of thermal energy absorbed by the receiver to the incident solar radiation.

To determine the absorbed thermal energy, temperature measurements were taken at various points along the trapezoidal cavity receiver's surface. These measurements allowed for the assessment of the temperature rise and heat transfer within the receiver. By considering the heat capacity of the working fluid and the flow rate, the amount of thermal energy absorbed by the receiver could be determined.

Simultaneously, solar radiation data, including the intensity and duration of sunlight, were collected. These data were used to calculate the incident solar radiation on the collector's surface. By comparing the absorbed thermal energy to the incident solar radiation, the thermal efficiency of the system could be quantified.

The thermal efficiency analysis also involved considering the various thermal losses within the system. These losses include conduction through the receiver and support structure, convective losses due to airflow, and radiative losses from the receiver's surface. By quantifying these losses, the overall thermal efficiency could be adjusted to account for energy dissipation.

The thermal efficiency analysis provided valuable insights into the system's energy conversion capabilities and its overall performance in utilizing solar energy. The results allowed for a comparison with other solar collector designs and provided important information for optimizing the system's efficiency through design modifications or the implementation of additional thermal management strategies.

5.3. Comparison with Existing Systems

A comprehensive comparison with existing solar collector systems is an important aspect of assessing the viability and competitiveness of the parabolic trough solar collector with a trapezoidal cavity receiver. The comparison involves evaluating key performance parameters, design characteristics, and operational considerations.

One aspect of the comparison is the thermal efficiency of the system. By comparing the thermal efficiency of the parabolic trough solar collector with a trapezoidal cavity receiver to that of conventional flat-plate or cylindrical receiver configurations, it is possible to identify any improvements or advantages offered by the innovative design. Higher thermal efficiency signifies a more effective conversion of solar energy into usable heat, resulting in increased system performance and energy output.

Another aspect of the comparison is the heat absorption capabilities of the system. The trapezoidal cavity receiver design enhances heat transfer and absorption due to its increased surface area for contact with concentrated solar radiation. Comparing the heat absorption capabilities of the parabolic trough solar collector with the trapezoidal cavity receiver to those of existing systems provides insights into the potential for improved energy capture and utilization.

Operational considerations such as manufacturing complexity, cost-effectiveness, and scalability are also essential in the comparison. Evaluating the manufacturing processes, materials, and associated costs for the parabolic trough solar collector with a trapezoidal cavity receiver in relation to existing systems allows for a comprehensive analysis of the practicality and feasibility of implementing this design on a larger scale.

Furthermore, the comparison includes an assessment of the potential applications and adaptability of the parabolic trough solar collector with a trapezoidal cavity receiver. Identifying specific industries or sectors where this innovative design can offer distinct advantages, such as power generation, industrial processes, or water heating, provides valuable insights into its practicality and potential market demand.

By conducting a thorough comparison with existing solar collector systems, the study aims to identify the unique benefits, limitations, and potential improvements associated with the parabolic trough solar collector with a trapezoidal cavity receiver. This analysis contributes to the knowledge base in solar thermal systems and aids in decision-making processes for future solar energy projects and initiatives.

6. Analysis of Findings

The analysis of the findings from the study on the parabolic trough solar collector with a trapezoidal cavity receiver provides valuable insights into its performance and potential for practical applications. The thermal efficiency analysis revealed that the system exhibits a high level of energy conversion, with a significant portion of incident solar radiation effectively absorbed and converted into usable heat. The trapezoidal cavity receiver design played a crucial role in enhancing heat transfer and absorption, resulting in improved overall system efficiency. The comparative analysis with existing solar collector systems demonstrated the advantages of the trapezoidal cavity receiver design, including higher thermal efficiency and enhanced heat absorption capabilities. This innovative design also showed potential for various applications, such as power generation, industrial processes, and water heating, making it a promising solution for sustainable energy needs. The analysis of findings also highlighted areas for further improvement, such as reducing thermal losses and optimizing manufacturing processes for scalability and cost-effectiveness. These findings contribute to the understanding of the performance characteristics and practicality of the parabolic trough solar collector with a trapezoidal cavity receiver, providing valuable insights for engineers, researchers, and policymakers involved in solar thermal systems and sustainable energy initiatives.

7. Conclusion

The study on the parabolic trough solar collector with a trapezoidal cavity receiver has provided valuable insights into its performance, design considerations, and potential applications. The analysis of findings indicates that the trapezoidal cavity receiver design offers significant advantages in terms of enhanced heat absorption, improved thermal efficiency, and potential for practical implementation. The system demonstrated a high level of thermal efficiency, effectively converting incident solar radiation into usable heat energy. The trapezoidal cavity receiver design facilitated efficient heat transfer, resulting in improved performance compared to traditional flat-plate or cylindrical receivers. The comparative analysis with existing solar collector systems showcased the competitive advantages of the parabolic trough solar collector with a trapezoidal cavity receiver. Additionally, the study identified areas for further improvement, such as reducing thermal losses and optimizing manufacturing processes for scalability and cost-effectiveness. Overall, the findings support the viability and potential of the parabolic trough solar collector with a trapezoidal cavity receiver as a promising solution for sustainable energy applications. This research contributes to the advancement of solar thermal technology and provides valuable insights for engineers, researchers, and policymakers striving for a transition to clean and renewable energy sources.

8. Future Recommendations

Based on the findings of this review, several recommendations can be made for future research and development in the field of parabolic trough solar collectors with trapezoidal cavity receivers. First, further investigation is needed to optimize the design parameters of the trapezoidal cavity receiver, such as its dimensions and shape, to achieve even higher thermal efficiency and heat absorption capabilities. Additionally, exploring different materials for the receiver, including advanced coatings or nanomaterials with enhanced thermal properties, could further improve system performance. Moreover, research on advanced tracking mechanisms, such as dual-axis or sun-tracking algorithms, can enhance the accuracy and effectiveness of solar radiation capture. Furthermore, incorporating thermal storage systems in conjunction with the parabolic trough collector can enable continuous energy supply, making it suitable for applications requiring round-the-clock heat availability. Cost reduction measures, such as exploring cost-effective manufacturing techniques or evaluating the feasibility of mass production, should also be a focus for future research. Lastly, conducting field tests and performance evaluations under real-world operating conditions would provide valuable insights into the practicality and effectiveness of the system in diverse environmental settings. Overall, these recommendations pave the way for further advancements and practical implementation of parabolic trough solar collectors with trapezoidal cavity receivers, contributing to the development of sustainable and efficient solar thermal systems.

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