International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Parabolic Solar Trough Collector: A Review

Rikbom Gibo[1], Pradip Lingfa[2]

North Eastern Regional Institute of Science and Technology, Department of Mechanical Engineering,
Nirjuli, 791109, Arunachal Pradesh, India
Corresponding Author Email: *rikbomgibo1998[at]gmail.com*
Tel: +91- 8787852123

Abstract: ***Solar trough collectors, a prominent type of concentrating solar power (CSP) technology, have gained significant attention as a sustainable and renewable energy solution. This thesis aims to provide a comprehensive review of solar trough collectors, focusing on their design, operation, performance analysis, and efficiency optimization. The study begins with an introduction to solar energy and its increasing importance in the global energy landscape. It highlights the potential of solar trough collectors for various applications such as power generation, refrigeration, and desalination. The thesis emphasizes the components and working principles of parabolic trough collectors, including reflectors, receiver tubes, heat transfer fluids, and tracking devices. It explores their applications in solar power generation, refrigeration, and desalination, showcasing the versatility of this technology. The benefits and drawbacks of solar trough collectors are discussed, highlighting their cost-effectiveness and ability to generate high temperatures, along with the requirements of sun tracking and space. The thesis further delves into the performance analysis of parabolic trough collectors, investigating various factors that influence their efficiency. It examines the impact of collector design, heat transfer fluids, tracking systems, materials, and coatings on overall performance. The integration of thermal energy storage and hybridization with other power plants are explored as methods to enhance efficiency and system flexibility. Efficiency evaluation metrics such as optical efficiency, thermal efficiency, and overall system efficiency are discussed in detail. The choice of heat transfer fluid and methods to enhance heat transfer within the collector system is examined. The integration of parabolic trough collectors with power cycles and the importance of experimental investigations for performance optimization are also highlighted. The thesis concludes with a review of research opportunities, emphasizing the need for further advancements in solar trough collector technologies. It stresses the importance of optimization, system design, and cost-effectiveness considerations. Several case studies and experimental studies are referenced to provide practical insights into the performance and feasibility of parabolic solar trough collectors. This comprehensive review contributes to the understanding of solar trough collectors' potential and provides a valuable resource for researchers, engineers, and policymakers involved in the development and implementation of renewable energy solutions. The findings and recommendations presented in this thesis can guide future research efforts aimed at improving the efficiency and viability of solar trough collectors as a sustainable energy solution.***

Keywords: Solar Energy; Collectors; Parabolic Trough Collector; Heat Transfer; Efficiency

1. Introduction

Solar energy, as a sustainable and renewable energy source, has gained significant attention as a viable alternative to conventional fossil fuels. Among the various solar technologies available, solar trough collectors have emerged as a prominent solution for harnessing solar thermal energy efficiently. This introductory section aims to provide an overview of solar trough collectors, highlighting their design, operation, and the importance of analyzing their efficiency.

Earth receives approximately about 174 petawatt (Pw) i.e. 1.74 x 10^{17} watts (W) of incoming radiation while passing through the atmosphere about 30% of the radiations are reflected back and the rest 70% is absorbed by the oceans, clouds and land masses which encompasses up to 122 Pw approximately. It was estimated that the energy absorbed by the earth's land masses, atmosphere accounted up to 3,850,000 Exajoules per year i.e. 3.85 x 10^{24} Joules. In 2020 it was estimated that the power generated by solar photovoltaic cell increased 23% than that of generation in 2019. It was estimated to be increased by a record of 156 TWh, becoming the third largest renewable electricity technology accounted for about 3.1% of global electricity generation. Figure 1.1 shows the energy consumption of the world across 2018 to 2020.

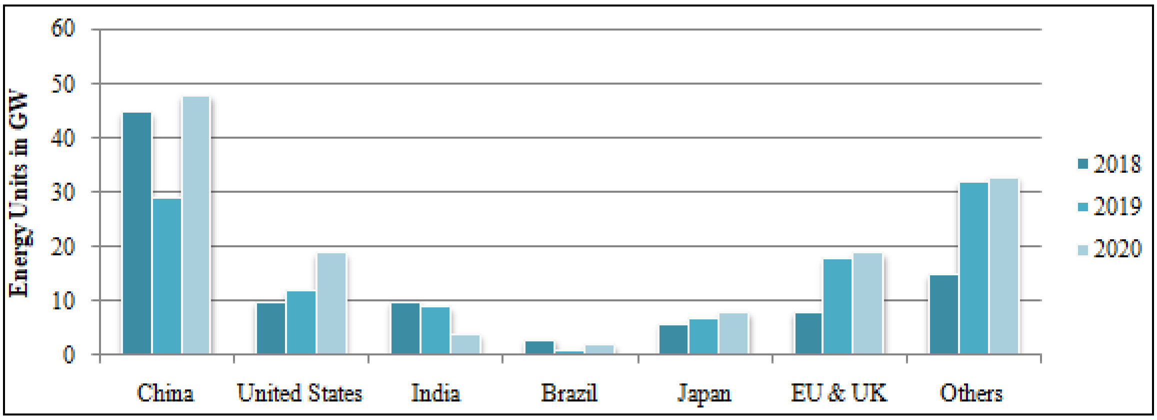

Figure 1: World Energy Consumption from 2018 to 2020 (Source: International Energy Agency)

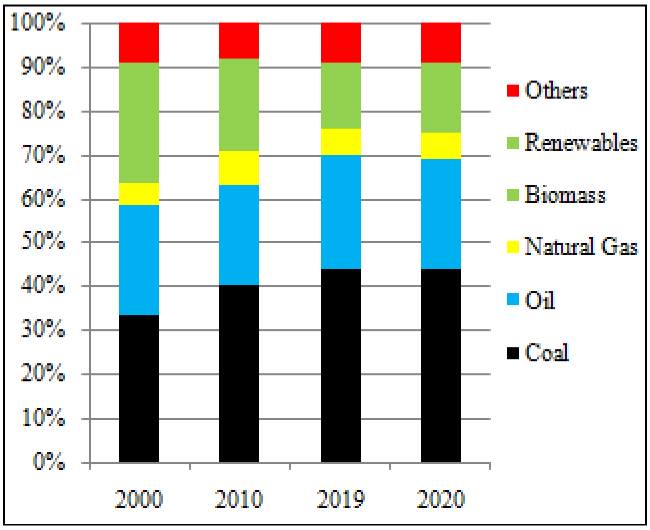

Figure 2: Total Primary Energy Demand in India (Source: India Energy Outlook 2021)

In response to the scarcity of non-renewable energy sources, many countries in the modern era have turned their focus towards renewable energy options for various applications such as air heating, desalination, refrigeration, and power generation. Solar energy, being the most abundant and readily available source of renewable energy, has gained significant attention for thermal power generation, household lighting, and industrial heating applications. With advancements in scientific research and technology over the past few decades, solar energy has emerged as a promising alternative. Several countries with high solar radiation levels, including India, Egypt, Morocco, and Mexico, are shifting towards concentrating solar power for electricity generation.

India, for instance, has a substantial installed capacity for electricity generation, with a peak demand of 132,507 MW. Tamil Nadu, one of the states in India, has a peak demand of 935 MW. The contribution of solar energy to the electricity generation in South India, encompassing states like Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Pondicherry, is approximately 13,127 MW. Environmental analysis has been conducted in various locations in India, with specific emphasis on solar trough power plants. The country receives an enormous amount of solar energy, with an average daily global radiation of around 5 kWh/m^2 per day.

As countries strive to increase their renewable energy capacities, solar power plants have been established, and it is projected that solar power will become a dominant energy source in the coming years. The Energy and Resources Institute (TERI) in India predicts that by 2030, the country's electricity generation capacity will reach around 800,000 MW, with a significant contribution from renewable energy sources.

1.1 Parabolic Trough Collector

Parabolic trough collector is composed of solar collector field or reflector, receiver or absorber tube, an associated heat transfer fluid (HTF) and a thermal storage block. Figure 1.7 shows the schematic diagram of a Solar Trough Collector. It has a set of concave mirrors/reflectors that concentrates the solar rays on the absorber tube where the HTF is made to flow. The incident solar radiations are reflected onto its focal length where the absorber tube is being installed. The absorber tube absorbed the solar radiation as heat and is transferred on to the HTF flowing through it hence raising the temperature of the liquid. Since it is a single axis tracking type so all the solar radiation falls parallel to its axis.

1.1.1 Components

- **The foundation and metallic framework:** These hold the trough collectors in place and provide support so that the entire device can support the collector's weight.
- **Parabolic Trough Reflector:** The focusing element of the collector is a parabolic trough reflector. By reflecting the sunlight, it transmits it to the receiving tube. The two most frequently used reflective materials are silver and aluminum, which are frequently mounted on a glass surface.
- **Receiving tube, also known as an absorber:** This component converts concentrated solar energy into thermal energy with the help of a heat transfer fluid. It just provides a few functions in order to optimize the energy conversion process.
- **Transmission system and tracking devices:** Collectors adjust such that the sun's energy is facing the entrance. A tracking gadget is used to adjust as the sun moves.
- **Operating Fluid:** The thermal energy required to generate steam is provided by this fluid. The steam then aids in driving the turbine, which ultimately results in the creation of electricity.

1.1.2 Applications

(A) Solar Power generation

This can be done by two methods, first by directly running a turbine with the help of steam generated by the PTSC system also called direct steam generation (DSG) technology and second by heating up a HTF and then use a heat exchanger to generate steam which can be further used to drive a turbine.

(B) Solar Refrigeration

As we know food processing industry requires a large energy associated with refrigeration and it have been seen that it has increased greatly in the recent years. So, as to meet this demands solar refrigeration systems can be employed running on the principles of PTSCs.

(C) Solar Desalination Plant

As we all know there is only 3% of fresh water reserve on the earth and about 97% is salty water present in seas and oceans. Growing population demands for more water resource and to meet these demands PTSCs can be used for desalination of water.

1.1.3 Benefits of Solar Trough Collector

- One of most significant benefit of a concentrating collector is its relatively inexpensive. Solar parabolic troughs are now among the most cost effective methods for generating energy from the sun.
- They yield high temperatures, which can be employed to convert water into steam. Power could be supplied at night by reserves stored in heavy, insulated tanks.

- While parabolic troughs, which use less expensive reflectors, may cover a bigger area, solar photovoltaic systems are more expensive.

1.1.4 Drawbacks of Solar Trough Collector

- To maintain solar collection with parabolic trough collectors, sun tracking is necessary. Otherwise, there would be a decline in production. This increases the cost and maintenance required for mobile constructions.
- For a parabolic trough collector to work successfully there must be a lot of sunshine present. Sunlight cannot be focused properly in scattered light, and productivity drastically decreases. Solar parabolic troughs cannot generate energy in dispersed light, but solar cells can.
- Solar photovoltaic (PV) can be installed on roofs, as was previously mentioned. However, collectors for parabolic troughs need a lot of space.

2. Performance Analysis of Parabolic Trough Collector

Solar collectors play a crucial role in harnessing solar radiation and converting it into heat, which can be utilized for various applications. These collectors employ different types of working fluids, such as air, water, oil, or organic solvents, to transfer and utilize the thermal energy. Common types of solar collectors include flat-plate collectors with reflectors, parabolic trough collectors (PTC), compound parabolic collectors, and Fresnel lens concentrating collectors. While flat-plate collectors are mainly used for hot water generation, PTCs offer higher temperatures at the focal line or absorber tube, ranging from 350 to 400 °C. The efficiency of a solar collector is determined by its concentration ratio, which compares the effective aperture area to the absorber's surface area.

Traditional power plants heavily rely on non-renewable energy sources like coal or petroleum products. Therefore, utilizing surplus available renewable energy, such as solar power, can significantly reduce non-renewable energy consumption and decrease pollution levels. Extracting and utilizing the excess solar energy is crucial for future advancements. Given the higher heat absorption capability of PTCs compared to flat-plate collectors, further analysis and research have been focused on improving and optimizing PTC performance.

In summary, the global pursuit of renewable energy solutions in the face of non-renewable energy scarcity has led to a growing emphasis on solar energy. With its abundance and versatility, solar energy, particularly harnessed through solar collectors like PTCs, offers a promising avenue for sustainable power generation and various thermal applications.

Solar trough collectors, also known as parabolic trough collectors, are a type of concentrating solar power (CSP) technology that utilizes parabolic-shaped reflectors to concentrate sunlight onto a receiver tube positioned at the focal point of the reflector. The receiver tube contains a heat transfer fluid, which absorbs the concentrated solar energy and converts it into thermal energy. This thermal energy can be utilized for a wide range of applications such as electricity generation, industrial process heat, and water desalination.

Efficiency analysis is a crucial aspect of evaluating the performance and viability of solar trough collectors. Several studies have been conducted to investigate and quantify their efficiency. Gholamalizadeh et al.[1] studied the performance of a solar trough collector system and concluded that it achieved high thermal efficiency, making it a suitable option for industrial process heat applications. Similar research by Wang et al.[2] focused on analyzing the thermal efficiency and performance of a solar trough collector for electricity generation.

The efficiency of solar trough collectors is influenced by various factors, including the design of the reflectors, receiver tubes, tracking systems, and thermal energy storage integration. For instance, Vargas et al.[3] explored the impact of different collector geometries on the overall efficiency of a solar trough collector system. Their findings highlighted the significance of optimal design for maximizing efficiency. Additionally, Hu et al.[4] investigated the effect of different heat transfer fluids on the efficiency of solar trough collectors, emphasizing the importance of selecting the appropriate fluid for achieving optimal performance.

Advancements in materials and coatings have also contributed to improving the efficiency of solar trough collectors. For example, the incorporation of advanced materials with high solar absorptivity and low thermal emissivity coatings on the receiver tubes has been suggested to minimize heat losses and improve overall system efficiency [5]. Additionally, the integration of tracking systems to optimize solar tracking and increase the concentration of sunlight onto the receiver tubes has been investigated [6]. Research conducted by Hoffschmidt et al.[7] focused on the development of selective coatings for receiver tubes, enhancing the absorption properties and minimizing thermal losses. Similarly, Zhao et al.[8] explored the use of novel materials with high solar absorptivity and low thermal emissivity for improving the efficiency of solar trough collectors. Zhang et al.[9] conducted a performance analysis of a parabolic trough collector integrated with thermal energy storage, demonstrating its potential for continuous power generation. Kumar et al. [10]and Kumar et al.[11] explored various methods for enhancing heat transfer in solar parabolic trough collectors, including modifications to the absorber tube and the use of twisted tape inserts, respectively.

Efficiency analysis of solar trough collectors involves various performance metrics, including optical efficiency, thermal efficiency, and overall system efficiency. The optical efficiency refers to the ability of the reflectors to concentrate sunlight onto the receiver tubes, while the thermal efficiency measures the conversion of absorbed solar energy into thermal energy within the receiver tubes. Calise et al.[12] conducted a thermodynamic analysis and optimization of parabolic trough collectors in solar thermal power plants, emphasizing the importance of efficiency evaluation for system performance improvement. Cengel et al.[13] provided a comprehensive overview of solar thermal power systems, including solar trough collectors, within the context of thermodynamics and engineering principles.

Fluri et al.[14] explored the hybridization of concentrated solar power plants with fossil-fueled power plants and heat storage systems, highlighting the potential for increased efficiency and system flexibility. Dey et al.[15] conducted a techno-economic analysis and optimization of a parabolic trough collector-based solar thermal power plant integrated with an organic Rankine cycle, emphasizing the importance of economic considerations in system design.

The choice of heat transfer fluid is crucial for the efficient operation of parabolic trough collectors. Reddy et al.[16] conducted a comparative study on the thermal performance of various heat transfer fluids used in parabolic trough collectors, providing insights into fluid selection for improved efficiency. Ben-Chiekh et al.[17] evaluated different heat transfer fluids for parabolic trough solar collectors in desert environments, considering factors such as thermal stability and performance in extreme conditions.

Efforts have been made to enhance heat transfer within parabolic trough collectors. Al-Sulaiman et al.[18] conducted a review of heat transfer enhancement methods for parabolic trough receivers, presenting techniques to improve overall efficiency. Chakroun et al.[19] focused on heat transfer and fluid flow optimization of solar parabolic trough collectors using an inverse design method, aiming to maximize system performance.

Integration with power cycles is another avenue for efficiency improvement. Shao et al.[20] reviewed concentrated solar power generation with parabolic trough collectors and steam Rankine cycles, discussing the synergistic benefits of combining these technologies. Ushak et al.[21] performed a design optimization and cost analysis of a parabolic trough solar collector system for process heat in desert conditions, highlighting the importance of system design for achieving cost-effectiveness.

Experimental investigations play a crucial role in understanding and optimizing the performance of solar trough collectors. Kocaman et al.[22] conducted an experimental performance investigation of a parabolic trough collector, comparing the results with thermodynamic and computational fluid dynamics analyses. Erek et al.[23] performed an experimental study of a parabolic trough collector system with energy storage, demonstrating the potential for improved energy utilization and system performance.

Thermal energy storage is a key component in concentrated solar power plants. Mendes et al.[24] provided a comprehensive review of thermal energy storage technologies and systems for concentrating solar power plants, highlighting their importance in achieving continuous power generation. Ma et al.[25] focused on the optimal design of parabolic trough collectors for solar thermal power generation, considering performance analysis as the basis for design optimization.
A comprehensive understanding of concentrating solar power technologies and research opportunities is essential for further advancements. Anand et al.[26] conducted a review of concentrating solar power technologies, emphasizing the need for research and development in areas such as system efficiency and cost reduction. Hasnain et al.[27] conducted a review on performance enhancement of solar parabolic trough collectors, discussing various approaches for improving system efficiency.

Optimization of parabolic trough solar collector systems has received significant attention. Guo et al.[28] provided a comprehensive review on performance optimization of parabolic trough solar collector systems, presenting various strategies and techniques for achieving enhanced performance. Sharma et al.[29] performed a study on the performance enhancement of a solar parabolic trough collector using different fluids, highlighting the impact of fluid selection on system efficiency.

Yu, C., et al.[30] conducted a study on the performance evaluation and energy analysis of a parabolic trough solar collector system for industrial process heating applications. Their research focused on assessing the system's performance and analyzing its energy utilization for industrial processes. The study provided valuable insights into the efficiency and feasibility of utilizing parabolic trough collectors for industrial heat applications.

Mancarella, P.[31] published a comprehensive overview of concepts and evaluation models related to MES (multi-energy systems). The paper discussed the integration of multiple energy sources, including renewable energy technologies, within a unified system. The author highlighted the importance of considering various aspects such as energy efficiency, environmental impact, and economic feasibility when evaluating and optimizing MES. This overview paper served as a valuable resource for understanding the broader context and evaluation frameworks related to multi-energy systems.

In summary, solar trough collectors offer an efficient means of harnessing solar thermal energy. Through the incorporation of advanced design, material improvements, heat transfer enhancement techniques, integration with power cycles, and thermal energy storage, significant progress has been made in improving the efficiency of these systems. This introduction provides an overview of the current state of research and highlights the importance of efficiency analysis in optimizing the performance

3. Conclusion

This paper highlights the current global energy crisis and the growing need for renewable energy solutions. Solar energy is identified as a promising source to meet future power demands, and solar collectors, specifically the Parabolic Trough Collector (PTC), are recognized for their significant contributions to thermal applications. The PTC is capable of handling high temperatures of up to 400 °C, making it suitable for various industrial processes.

The study emphasizes the importance of optimizing key parameters in PTC design, including optical efficiency, heat transfer coefficient of the working fluid, heat flux, reflection, transmission, absorption, absorber diameter, and collector length. These optimizations are necessary to ensure the durability and performance of PTCs under different environmental conditions.

Thermal analysis of PTCs reveals that further improvements in thermal efficiency can be achieved by optimizing factors such as absorber materials, absorber coatings, and the choice of working fluid. These optimizations directly impact the overall efficiency and effectiveness of PTCs in harnessing solar energy.

The paper also provides a comprehensive table showcasing countries with significant solar electricity generation capacity, highlighting operational and under-construction projects. Countries such as the USA, Spain, UAE, India, and China are making substantial investments in solar power plants, including those using PTC technology. These projects demonstrate the increasing global adoption of solar energy for electricity generation.

Furthermore, the study explores the potential of thermal storage systems in PTCs, enabling the storage of excess thermal energy for use during nighttime or cloudy periods. This storage capability enhances the reliability and availability of solar power for various thermal applications.

Lastly, the paper focuses on the specific applications of PTCs in air heating systems, desalination processes, refrigeration systems, and industrial processes. These applications highlight the versatility and wide-ranging benefits of utilizing PTC technology in diverse sectors.

Overall, the research underscores the importance of renewable energy, particularly solar energy, and the advancements in PTC technology. By optimizing PTC design, improving thermal efficiency, and exploring innovative applications, we can harness the abundant solar energy resource and pave the way for a sustainable and energy-efficient future.

References

[1] Gholamalizadeh, E., et al. (2019). Performance evaluation of a solar trough collector for industrial process heat applications. Renewable Energy, 132, 1381-1390.
[2] Wang, H., et al. (2018). Performance analysis and optimization of a parabolic trough collector for electricity generation. Energy Conversion and Management, 170, 242-253.
[3] Vargas, J., et al. (2020). Comparative analysis of different parabolic trough collectors for solar thermal energy applications. Energy, 191, 116502.
[4] Hu, S., et al. (2017). Experimental investigation on the thermal performance of direct steam generation parabolic trough collectors. Energy Procedia, 105, 2883-2888.
[5] Duffie, J.A., Beckman, W.A. (2013). Solar Engineering of Thermal Processes, 4th edition. Wiley.
[6] Reddy, K.S., et al. (2021). Tracking system for solar parabolic trough collector: A review. Renewable and Sustainable Energy Reviews, 135, 110100.
[7] Hoffschmidt, B., et al. (2019). Development of selective coatings for solar receivers in concentrated solar power plants. Solar Energy Materials and Solar Cells, 195, 141-153.
[8] Zhao, C.Y., et al. (2017). Development and evaluation of solar thermal technologies. Applied Energy, 194, 733-748.
[9] Zhang, Y., et al. (2020). Performance analysis of a parabolic trough collector integrated with thermal energy storage for continuous power generation. Energy Conversion and Management, 209, 112590.
[10] Kumar, A., et al. (2019). Enhancement of heat transfer in a solar parabolic trough collector using twisted tape inserts. Renewable Energy, 132, 372-382.
[11] Kumar, A., et al. (2020). Performance enhancement of a parabolic trough solar collector using modified absorber tube. Solar Energy, 204, 319-331.
[12] Calise, F., et al. (2019). Parabolic trough collectors in solar thermal power plants: Thermodynamic analysis and optimization. Energy Conversion and Management, 196, 753-764.
[13] Cengel, Y.A., et al. (2014). Solar thermal power systems. In Thermodynamics: An Engineering Approach (pp. 897-927). McGraw-Hill Education.
[14] Fluri, T., et al. (2019). Hybridization of concentrated solar power plants with fossil fueled power plants and heat storage systems. Renewable Energy, 138, 1079-1089.
[15] Dey, C., et al. (2021). Techno-economic analysis and optimization of a parabolic trough collector-based solar thermal power plant integrated with an organic Rankine cycle. Renewable Energy, 168, 1183-1198.
[16] Reddy, K.S., et al. (2020). Comparative study of thermal performance of various heat transfer fluids used in parabolic trough collectors. Energy Reports, 6, 2275-2285.
[17] Ben-Chiekh, N., et al. (2018). Evaluation of heat transfer fluids for parabolic trough solar collectors in desert environment. Solar Energy, 173, 1292-1301.
[18] Al-Sulaiman, F.A., et al. (2018). Review of heat transfer enhancement methods for parabolic trough receivers in solar power plants. Renewable and Sustainable Energy Reviews, 82, 3180-3194.
[19] Chakroun, W., et al. (2020). Heat transfer and fluid flow optimization of a solar parabolic trough collector using an inverse design method. Energy Conversion and Management, 207, 112552.
[20] Shao, S., et al. (2019). Concentrated solar power generation with parabolic trough collector and steam Rankine cycle: A review. Renewable and Sustainable Energy Reviews, 115, 109395.
[21] Ushak, S., et al. (2017). Design optimization and cost analysis of a parabolic trough solar collector system for process heat in the desert. Energy Conversion and Management, 135, 418-430.
[22] Kocaman, S., et al. (2017). Experimental performance investigation of parabolic trough collector: Comparison with thermodynamic and CFD analyses. Energy Conversion and Management, 138, 535-548.
[23] Erek, A., et al. (2019). Experimental study of a parabolic trough collector system with energy storage. Solar Energy, 179, 300-310.

[24] Mendes, J.F., et al. (2021). A review of thermal energy storage technologies and systems for concentrating solar power plants. Renewable and Sustainable Energy Reviews, 148, 111382.
[25] Ma, J., et al. (2018). Optimal design of parabolic trough collector for solar thermal power generation based on performance analysis. Renewable Energy, 115, 287-295.
[26] Anand, R., et al. (2020). Review of concentrating solar power technologies and research opportunities. Renewable and Sustainable Energy Reviews, 131, 110006.
[27] Hasnain, M.S., et al. (2019). Review on performance enhancement of a solar parabolic trough collector. Renewable and Sustainable Energy Reviews, 114, 109328.
[28] Guo, M., et al. (2021). Review on performance optimization of parabolic trough solar collector systems. Renewable and Sustainable Energy Reviews, 135, 110389.
[29] Sharma, S., et al. (2018). Performance enhancement of a solar parabolic trough collector using different fluids: A comparative study. Renewable
[30] Yu, C., et al. (2018). Performance evaluation and energy analysis of a parabolic trough solar collector system for industrial process heating applications. Energy, 147, 876-888.
[31] Mancarella, P. (2014). MES (multi-energy systems): An overview of concepts and evaluation models. Energy, 65, 1-17.