

# Factors Influencing the Design of Parabolic Trough Collector: A Review

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## Abstract

*Due to limited resource availability and high conventional energy usage, research into renewable energy has increased during the past few years. Utilizing collecting systems, significant renewable energy can be produced from the available solar radiation. The majority of solar energy harvesting systems use parabolic trough concentrating collectors. The performance of parabolic trough collectors as a whole is examined in this paper. The operating characteristics, such as the type of receiver and collector material, the medium for heat transfer, the type of application, and varied environmental conditions, all affect the performance.*

**Keywords:** Radiation, parabolic trough collector, thermal analysis, efficiency, energy

## INTRODUCTION

Energy consumption is based on the use of traditional energy sources. The release of highly poisonous gases influences the greenhouse effect, producing climatic changes and natural disasters, which reduces the need for traditional energy resources. Identifying a provider of renewable energy is crucial to solve these issues. Heat is transferred from the sun to water or any other substance that absorbs heat as it moves through the receiver pipe. Finally, a tank is used to store the hot water for residential usage [1]. Concentrated collectors are used in solar thermal power production to produce high temperatures with great thermal efficiency and a minimal collecting surface [2]. For low temperature applications, non-concentrating collectors were employed. When temperatures are high, a concentrator is employed instead of a nonconcentrating collector [3]. In order to optimize the design of the parabolic trough collector, the aspects to be taken into account are reviewed in this study.

## PARABOLIC TROUGH COLLECTOR

A solar collector [reflector] made of a reflecting material, such as glass, aluminium, or stainless steel, makes up a parabolic trough collector (PTC). It is used to catch the sun's intense rays and bounce them back towards the receiver, which is situated in the middle of the collector's focus line. The receiver consists of an absorber tube enclosed in an evacuated glass shell that is often coated with stainless steel or copper to selectively absorb solar light while emitting low levels of infrared radiation. To absorb solar energy and transfer the heat to the steam generator or the heat storage system, a fluid is circulated

through the absorber tubes [4]. A solar thermal collector's primary parts are its collection, receiver, fluid or heat transfer medium, tracking system, and storage tank [5]. The physical model of the trough collector and all of its accessories are shown in Figure 1. Along the focal line of the collector, a solid plug is placed in the absorber tube. The reflected radiation from the tube is prevented in the evacuated space, thereby preventing the heat losses [6].

Figure 2 depicts the stages of the energy transfer process. Figure 3 shows a diagrammatic

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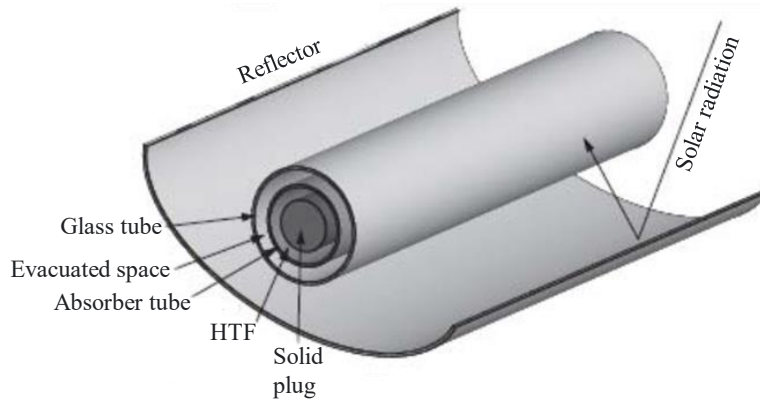
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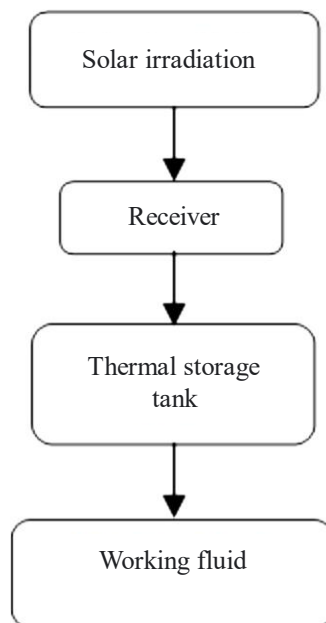
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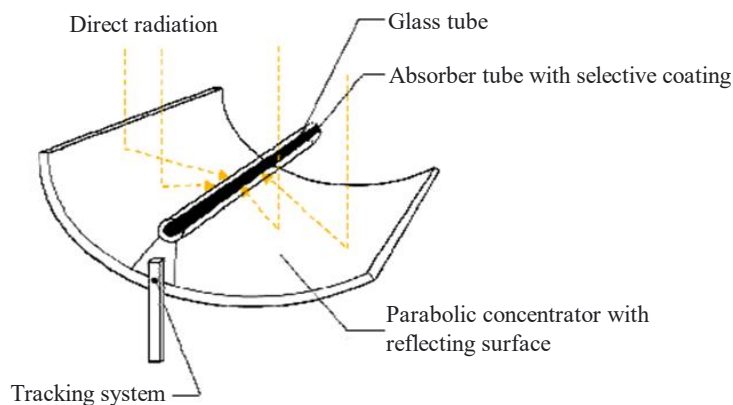
representation of the energy transfer procedure in a parabolic trough. When high-intensity rays hit a reflector, they are reflected to a receiver tube situated in the focal line. Through a pipe, it collects heat from the rays, and the glass cover deflects the rays that are released. Through the heat exchanger, high pressure steam is created [7].



**Figure 1.** Parabolic trough solar collector.



**Figure 2.** Method of energy transfer.



**Figure 3.** Energy transfer process in PTC.

## CONCENTRATOR

At 106°C, where the water is completely transformed into steam, the efficiency of the parabolic trough decreases by 28.29%, whereas 53.4% efficiency is attained at a maximum temperature of 104°C [8]. With an aperture size of 0.92 m<sup>2</sup>, a poly vinyl chloride concentrator generates high reflectivity of 0.85, an overall thermal efficiency of 30.77%, and water temperature of 85°C [9]. Based on experimental setups with the parameters of heat loss, environmental conditions, temperature, and heat flux, several mathematical models, simulations, and numerical methods are examined for parabolic trough solar collectors [10]. For the analysis of the effectiveness of process heat generation, various concentrating type collectors, including Compound Parabolic Collectors (CPC), Linear Fresnel Collectors (LFC), and PTC, are used. CPC is advised for thermal applications with Levelized Cost of Energy [LCOE] ranging from 2.5 to 16.9 kWh/m<sup>2</sup> and temperatures between 373 and 423 K. With rising working fluid temperature, the discrepancies between the LCOE values of the CPC and LFC collectors become smaller. Additionally, when LFC technology reaches a temperature of 523 K, it produces the lowest LCOE values [11]. The cylindrical parabolic trough system's overall efficiency is 71%, making it ideal for solar thermal applications, although the average efficiency is just 66% [12]. Gallium Arsenide [GaAs] solar cells with a single junction make up a CPC, which simultaneously produces electricity and high-temperature thermal power. High energy photons are used by the GaAs cells to produce electricity with a maximum temperature of 365°C. While electric efficiency is only 8%, thermal efficiency is 37% [13]. In relation to other parameters including the ambient temperature, wind speed, flow rate, and the temperature of the water entering and leaving the collector, the total radiation of the device is measured. The maximum temperature of 103°C with 98% thermal efficiency and the minimum temperature of 60°C with 63% thermal efficiency are both made possible by the high sun intensity. With a heat gain of 1500 W, steam is created at 103°C of outlet temperature with a thermal efficiency of 83% [14].

## REFLECTOR MATERIAL

Due to its high reflectivity, aluminium composite panel reflectors provide excellent performance with a maximum temperature of 87°C. The fluid temperature produced by a chrome plate reflector with a glass cover is 98°C, compared to 82°C for the identical reflector without a glass cover. Due to a wide spectrum of reflection, aluminium composite panel reflectors function well [4]. Low-cost PTC is created using copper receiver pipes with an aperture area of 2.14 m<sup>2</sup> and a rim angle of 45° and acrylic sheet as a reflector. With a temperature difference of 47°C, the maximum thermal efficiency and water temperature are 52.35% and 80°C, respectively [15]. For PTC analysis, a stainless steel reflector with a GI absorber tube is employed [16]. Thermal analysis of PTC is performed for the application of water heating. The efficiency analysis uses two different types of materials. These are glass-covered copper and aluminium tubes. The maximum water temperature from a copper tube with a glass cover is 68.7°C, but the maximum water temperature from an aluminium tube with a glass cover is 62.4°C. Copper tube generates with greater efficiency than aluminium tube [17]. Analysis was done on the PTC's performance when used to heat water with an aluminium sheet acting as a reflector and a manual tracking mechanism. It is a better choice in the winter because it lowers the expense of heating the water [18]. With an aluminium sheet acting as a PTC reflector, year-round performance is examined under various environmental situations. The non-evacuated receiver tube used for the operation had a black paint covering and a glass cover. With a mass flow rate of 0.010 kg/s and an aperture area of approximately 1.34 m<sup>2</sup>, the highest water temperature is seen in April [19]. Regarding the obtained maximum temperature, two various types of reflectors, such as aluminium sheet and aluminium foil, were employed to investigate the performance of PTC.

## ABSORBER CONFIGURATION

Heat is recovered from a solar source using a single tube absorber and a modified absorber. While a typical absorber's efficiency is only 26.7%, a modified absorber has a 42.1% efficiency [20]. With a nail-twisted tape and an Al<sub>2</sub>O<sub>3</sub>/water nanofluid as the working fluid, the impact of the absorber has been studied. The heat transfer efficiency of the solar trough collector can be significantly enhanced by

the nail twisted tape absorber with nanofluids [21]. The performance of a tiny linear solar concentrating collector used for the processing of heat and direct steam generation is investigated using a flat aluminium absorber with the barand-plate technique. With a temperature of 160 K, this collector's overall efficiency is 64% [22]. Using the Monte Carlo ray tracing approach together with FVM, it is explored if an absorber tube with a pin fin insert can improve heat transmission to the medium. The results are compared to those obtained experimentally. The mistake detected is less than 5%. The addition of a pin fin increases the system's efficiency by up to 12.0% by accelerating the overall heat transfer rate [23]. An experimental and numerical model is used to examine the effects of the failure of the absorber tube for three different types of tubes: vacuum tubes, lost vacuum (air), and broken glass (bare) tubes. When compared to alternative methods, utilising a vacuum tube significantly reduces heat losses [24]. Due to an increase in heat transfer rate and a reduction in thermal boundary layer thickness, an evacuated receiver can achieve thermal efficiency of 65-70%, which is 10% better than for a non-evacuated receiver [25]. For low temperature applications, evacuated unshielded receivers had a thermal efficiency of 55.2%, whereas shielded evacuated receivers had a thermal efficiency of 53.8% [26].

### WORKING FLUID

CFD is used to study the effects caused by various volume fractions of water-based nanofluid. With the volume fraction of nanofluid, the enhancement of heat transmission exhibits a progressive increase. Al<sub>2</sub>O<sub>3</sub> and CuO nanoparticles can respectively enhance the heat transfer rate by 28% and 35% [27]. Through sensitivity analysis, the impact of altering the working fluid and Reynolds number is determined. Using FEM, each component of the system is modelled, examined, and validated using the findings of an experimental analysis [28]. As a heat transfer fluid, Al<sub>2</sub>O<sub>3</sub>/synthetic oil nanofluid is used, and the performance of the system is examined using FEM with non-uniform flux distribution. When compared to synthetic oil nanofluid, the efficiency of the system is great and the temperature gradient is lowered when employing Al<sub>2</sub>O<sub>3</sub>/synthetic oil nanofluid [29]. Between temperatures of 300 K and 1300 K, a thorough investigation of the various working fluids, including pressurised water, Therminol VP-1, nitrate molten salt, liquid sodium, air, carbon dioxide, and helium, is made. When compared to other fluids, liquid sodium has a maximum efficiency of 47.48% at an inlet temperature of 800 K. The finest working fluids at temperatures above 1100 K are helium and carbon dioxide, whereas water is the best for temperatures up to 550 K [30]. Using CFD, the parabolic system with nanofluid as the fluid is investigated, and the results are experimentally verified. The largest relative error reported is 0.3% and 7.3%, and with an Al<sub>2</sub>O<sub>3</sub> concentration of 4%, the collector efficiency increases by 10% [6].

With variable solar radiation caused by radiant heat loss and medium exit temperature, thermal performance for PTC is expected. When the radiant heat surface area is small, the working fluid temperature rises [31]. Different heat transfer media, namely water and SAE20W50 engine oil, were used to evaluate the PTC. SAE20W50 engine oil can be used as the working medium, allowing it to function at high temperatures. But as compared to using water as the working medium, the collector's performance declines [32]. Under local climate condition, a PTC experimental study was conducted using water as the working medium, with a maximum efficiency of 65% to 70% [33]. To optimize the design, three different types of heat transfer fluids were studied by adjusting factors such as the aperture area, receiver diameter, and working fluid [34]. While transferring heat through the pipe, various modes of heat transfer take place. On the surface of the receiver pipe, conduction and convection modes of transfer lead to significant problems. Due to the variability in wind speed during testing, there are the greatest heat losses [35].

### DISCHARGE

Compared to the water inlet temperature, the mass flow rate has a greater impact. At the lowest mass flow rate, the collector thermal efficiency exceeds the lowest water inlet temperature. The collector's maximum thermal efficiency, which is 65%, was attained with the ideal input parameter values [1]. Due to the structure, non-uniform heat flux distribution is obtained at the receiver tube's outer surface, and numerical methods were used to determine the thermal stress distribution in the steel tube [36]. Three

different flow rates of 30 kg/hr, 42 kg/hr, and 60 kg/hr were used in the analysis, with impacting factors such concentration ratio, optical efficiency, and thermal efficiency. The amount of solar intensity rises over time, which is followed by a rise in the thermal efficiency of the collector. As the sun intensity drops, the efficiency drops as well. For a flow rate of 42 Kg/hr, it was discovered that the total heat availability, heat available at the collector, heat obtained by water, and thermal efficiency were, respectively, 2348.54 KJ/hr-m<sup>2</sup>, 3617.29 KJ/hr, 1757.12 KJ/hr, and 48.57% [37].

## PERFORMANCE

The mechanical characteristics of a six-meter-long PTC's structure were analysed using FEM. Thermal efficiency and mass flow rate-dependent temperature variations were calculated. The highest temperature at which the maximum efficiency of 22.4% was achieved was attained was 123 °C at a pressure of 2 bars [38]. The simulation tool, which models using the FEM for different operating circumstances, was used to investigate the thermal and optical efficiency of the PTC. When the concentration ratio is at 45 degrees from vertical and the Reynolds number fluctuates due to the water inlet temperature, the highest optical efficiency of 75% is reached. When the temperature is low, the flow is laminar and has a convection coefficient of roughly 300 W/m<sup>2</sup> K. When the temperature is high, the flow is turbulent and has a convection coefficient of 1000 W/m<sup>2</sup> K [39].

Investigations were done into the impact of wind load, heat loss, collector type, and receiver tubes. The airflow around the receiver tube and the wind's aerodynamic forces are resisted by the PTC. By adjusting the parabola's focal length, or the depth of the trough, the system was examined with three alternative trough geometries. As the depth of the parabola increases, the aerodynamic force on the trough also rises, leading to the greatest temperature difference between the receiver and the surrounding air. The yaw angle increase greatly reduces the aerodynamic strain on the trough, while the heat flow surrounding the receiver tube actually shows a little decrease [40].

Based on energy balancing equations and a thermodynamic study, the performance under the condition of direct normal sun irradiation has been studied. To remove inaccuracies caused by oscillations in outlet temperature and DNI, several control volume approaches have been utilised to estimate solar irradiance based on the time intervals of the data gathering system [41]. For calculating the optical efficiency of the parabolic trough solar collector in three common solar thermal usage locations, a mathematical model has been developed. Based on the cosine effect, shadowing effect, and end loss impact, the performance characteristics were estimated. For 365 days, optical efficiency was computed and simulated. The optical efficiency of PTCs changed from 0.4 to 0.8. In June, optical efficiency was at its highest, and in December, it was at its lowest [42].

## TRACKING MECHANISM

For the investigation of the capacity of bending and torsion forces on the support frame under a dead and wind load with an aluminium and mirror collector, FEM has been designed. Under dry weather conditions, the efficiency of aluminium was found to be 8% lower than for the mirror reflector with a microcontroller automatic tracking mechanism [43]. For the tracking system, various collector placements have been examined using a refrigerant [44]. The coordinate transformation and MCRT approach were used to simulate the circumferential flux distribution on absorber tubes. With a geometric concentration ratio of 20 and 90 rim angles, the installation error in the X and Y directions was 0.2% and 1.0% to 0.5%, respectively, and the tracking error was 4 mrad. The inaccuracy grows in size as the incident angle rises. As the concentration ratio rises, the error decreases [45]. Variations in fluid flow, rising fluid temperature, and incident solar radiation, both with and without the presence of a tracking system, have all improved PTC performance. When employing a system with a tracking mechanism, efficiency was 27% higher than when it wasn't engaged [46]. By splitting the receiver into numerous control volumes along its length and taking into account all modes of heat transmission, a thorough two-dimensional numerical heat transfer study was carried out for the PTC system under local climatic circumstances. The tracking system had a 96% effectiveness in the polar east-west direction

and a 94% efficiency in the horizontal east-west direction [47]. Instead of assessing concentrator performance, optical properties of reflector and absorbing materials were examined for various materials.

## CONCLUSION

Analysis of the thermal performance of PTC revealed variations based on the parameter and radiation intensity consumption. The utilisation of the solar radiation has been different for different areas, so the overall performance for the same system at different locations changed. The outlet temperature of the medium showed an increase or decrease through changes in the concentrating ratio of the reflector and characteristics of the absorber tube. When employed for other purposes, PTC was only used to a little extent. The majority of PTC was used for the production of energy. The PTC's total effectiveness is dependent on the reflector, absorber tube, and working medium, but it can reach its optimum efficiency when the system is using a solar tracking mechanism to make the most of the sun's light.

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