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(Review Article)

Research review on performance evaluation of a parabolic trough solar collector for hot water generation

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Abstract

This experimental study aimed to examine the impact of many parameters, including concentration ratio, optical efficiency, and thermal efficiency, on the performance of the trough solar collector. In the present day, nations throughout the globe exhibit a collective preoccupation with the issue of environmental pollution and its consequential impacts. However, it remains imperative for these nations to secure adequate energy resources in order to facilitate the progress and advancement of their respective countries. The utilization of conventional techniques, particularly those involving coal, fossil fuels, and organic matter, to generate the necessary energy yields a significant level of air pollution, which serves as the primary catalyst for global warming. The utilization of non-conventional methods for energy production is deemed more favorable in terms of environmental impact. However, the lack of economic viability serves as the primary deterrent for impoverished and emerging nations in adopting such non-conventional techniques. The geographical conditions have a significant role in determining the viability of nonconventional sources such as solar energy and wind energy. This study involved an analysis of the performance of a solar trough collector, with subsequent calculations of its efficiencies.

Keywords: Concentration ratio; nonconventional energy; optical efficiency; solar collector; thermal efficiency

1. Introduction

The utilization of renewable energy sources has become an imperative for nations in the contemporary day. Due to their finite nature and detrimental environmental impacts, non-renewable sources of energy provide limitations and contribute to the exacerbation of global warming. Solar energy is widely recognized as a sustainable form of energy, leading to its increased adoption by numerous nations in recent years [1]. India is a nation that possesses a significant abundance of sunlight, which can be effectively harnessed for the purpose of generating solar power. Although the initial costs associated with this endeavor may be higher, advancements in technology and improvements in device performance will ultimately facilitate the utilization of solar energy in a more efficient and cost-effective manner. Solar energy is particularly well-suited for countries such as India, where there is an abundance of sunlight, particularly during the summer season. However, there are certain states within India, such as Tamil Nadu, certain parts in the south, and Rajasthan, where the availability of solar energy is consistently high throughout the year. The Parabolic Trough Collector (PTC) exhibits several advantages, including its application in industrial steam generation [2] and hot water production [3]. In the United States, there are already nine solar power plants of significant commercial scale [4-5]. These installations are notable for their utilization of the most established and widely recognized solar thermal electric technology globally. Previous studies also examined the performance of parabolic trough solar collectors.

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The performance evaluation of a modified evacuated tube solar collector was conducted by A. Padilha et al. [6] using numerical analysis. A Computational Investigation of a Hybrid Water Heater Incorporating an Evacuated Glass Tube Solar Collector and Rice Husk The process of combustion was conducted by Piyanun Charoensawan and colleagues [7]. In their research, Pei et al. (2018) conducted a study on the efficacy of evacuated tube solar water heater systems, comparing their performance both with and without the use of a mini-compound parabolic concentrating (CPC) reflector (C<1). The authors, J.P. Praene et al., conducted a study involving the simulation of a solar power absorption system and the dynamic modeling of an evacuated tube solar collector. The user provided a numerical reference. The experimental investigation conducted by Yadav et al. (10) focused on the utilization of evacuated tube solar collectors for air heating purposes in India. The analysis conducted by A. Valan Arasu et al. [11] focused on the performance characteristics of a parabolic trough solar collector in terms of heat generation. The authors S.D. Odeh et al. [12] conducted a thermal analysis on parabolic trough solar collectors used for the purpose of electric power generation. The analysis of conduction heat loss from a parabolic trough solar receiver with active vacuum was conducted by Matthew Roesle et al. [13] using the direct simulation Monte Carlo technique. V. Padilla et al. [14] devised a streamlined approach for the design of parabolic trough solar power facilities. The analysis conducted by N. Naeeni et al. [15] focused on the wind flow patterns surrounding a parabolic trough solar collector.The current investigation involved the design and fabrication of a parabolic collector. The experiments were conducted using the same apparatus, and measurements were subsequently recorded. The collected data were subjected to calculations and analysis in order to determine the optical efficiency and thermal efficiency.

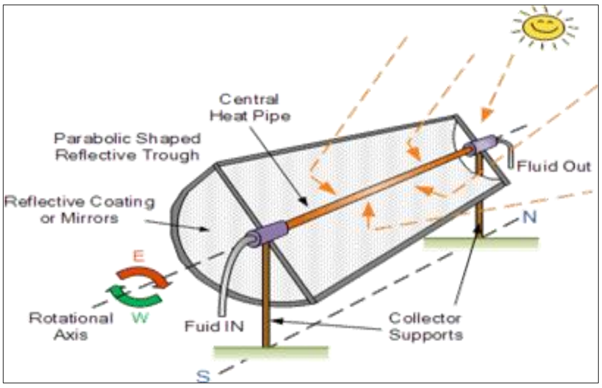

Figure 1 Parabolic trough solar collector system

1.1. Design Parameters

The structural simplicity of parabolic trough collectors distinguishes them from other varieties; nonetheless, their effective operation necessitates continuous tracking to ensure the concentration of solar radiations on the absorber tube throughout the day. The precision of the PTSC design is crucial, since it directly impacts the optical efficiency of the system. It is imperative that the dimensions in both the x and y axes are accurately determined. The design parameters refer to the specific criteria and constraints that guide the development and implementation of a design project. These parameters outline the essential, the design parameters of a parabolic trough collector can be categorized into two main classifications: geometric and functional. The geometric characteristics of a parabolic trough solar collector (PSTC) are its aperture width and length, rim angle, focal length, receiver diameter, glass envelope diameter, and concentration ratio.

Table 1 Specification of absorber tube

Reflective material	Stainless steel
Reflectivity of mirror	0.9
Absorber tube material	Glass with copper coating
Inside diameter of Copper tube	35mm
Outside diameter of copper tube	45.4mm

The functional parameters of photovoltaic solar thermal collectors (PSTC) encompass optical efficiency, instantaneous thermal efficiency, overall thermal efficiency, and receiver thermal losses. The aforementioned parameters are significantly impacted by the absorptivity of the absorber. The faults seen can be attributed to various factors, including defects in the reflector material, issues with the support structure, the receiver's positioning in relation to the focal plane of the Photovoltaic Solar Thermal Collector (PSTC), and misalignment of the PSTC with the sun due to tracking errors.

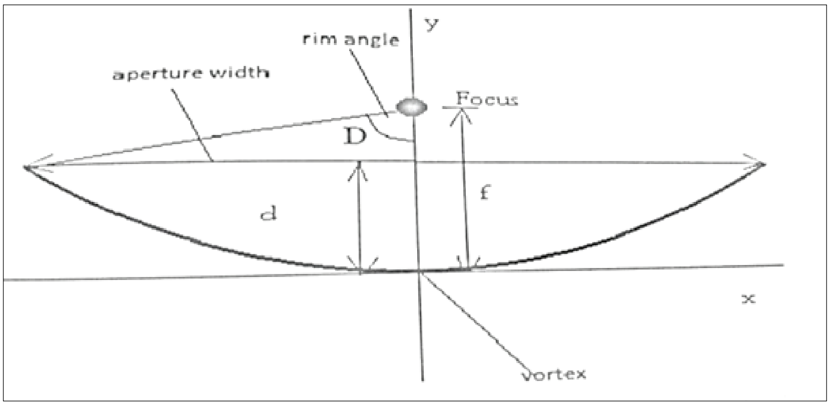

Figure 2 Design specifications of parabolic reflector

Table 2 Different parameters and their values for the fabricated PTSC

Parameter	Value
Collector aperture	1130mm
Collector length	1420mm
Aperture area	1.54m^2
Rim angle	90^0
Focal distance	100mm
Receiver diameter	35mm
Water flow rate	30KJ/hr
Tank material	Stainless steel
Tank insulation material	Glass wool
Water pump	25 W

1.2. Formula used for performance testing of hot water generating PTSC

$$\text{Collector efficiency} = \frac{Qu}{AI} = mCp\ (To - Ti)/AI$$

Where,
Qu = Useful heat gain (KJ/hr)
A = Aperture area (m^2)
I = Solar Radiation Intensity (W/m^2)
m = Mass flow rate (Kg/hr)
Cp = Specific heat capacity of water (J/Kg-K)
T_i, T_0 = Outlet and inlet temperature of water (^{0}C)

Effective aperture area: (W- Dco) × L;

Where,
W = Width of the reflector
Dco = Outside diameter of glass cover tube

1.3. Specimen calculation

Flow rate of water = 42 Kg/hr Area of collector = 1.54 m^2

Total heat available = (pyranometer reading × 60 × 4.186 ×104) / (pyranometer constant ×1000)

= (5.2 × 60 × 4.186 × 104) / (5.56 × 1000) = 2349.54 KJ/hr-m^2;

Heat available in collector = Total heat available × area of collector

= 2349.54 × 1.54

= 3618.29 KJ/hr

Heat gained by water = mw × Cpw × Δt

= 42 × 4.187 × (40 - 30)

= 1758.12 KJ/hr

Efficiency = (Heat gained) / (Heat available) × 100 = 48.58%

2. Result and Discussion

The primary application of the parabolic trough solar collector system is in power generation, owing to its ability to achieve high temperatures in steam. Additionally, it finds utility in the heating of water, air, and various other applications.

The potential of PTSC technology in water heating applications is significant, provided that the system cost is effectively minimized.

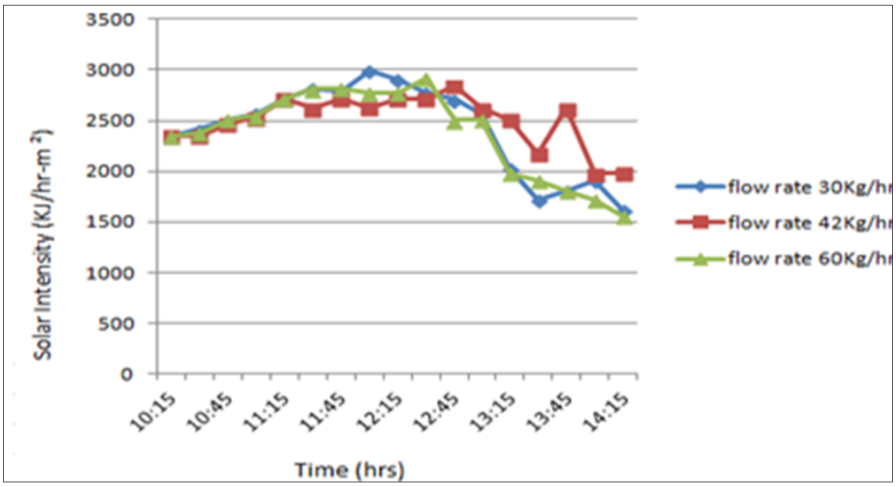

Figure 3 Graph between Solar Intensity and Time

Figure 1 depicts the graphical representation of the relationship between solar intensity, measured in kilojoules per hour per square meter (KJ/hr-m^2), and time, measured in hours. The solar intensity was measured throughout a time span of 15 minutes, specifically from 10:15 hours to 14:15 hours. Graphs were generated to depict the relationship between solar intensity and different flow rates, namely 30 kilograms per hour, 42 kilograms per hour, and 60 kilograms per hour. The sun irradiance was measured at various flow rates.

Figure 4 depicts the graphical representation of the relationship between collector efficiency, expressed as a percentage, and the passage of time, measured in hours. The efficiency of the collector was determined for various flow rates, and a graph was generated to illustrate the relationship between these variables.

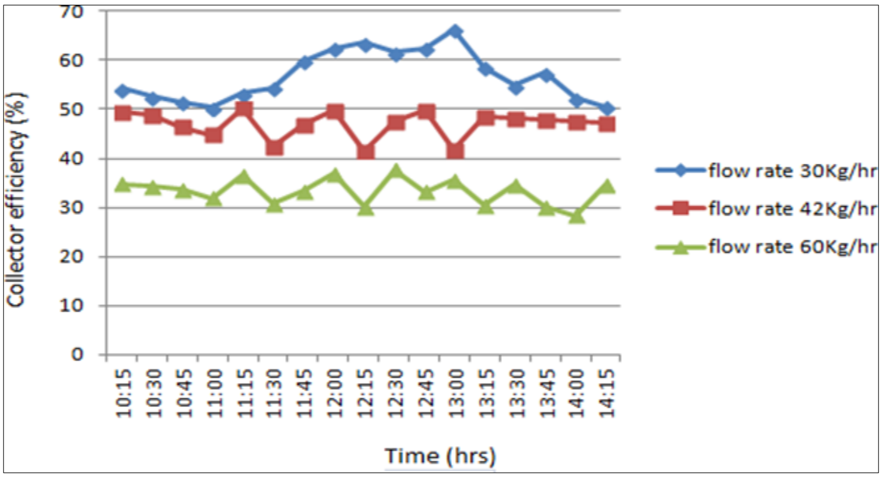

Figure 4 Graph between collector efficiency and Time

Figure 3 illustrates a graph depicting the relationship between time and solar intensity. It is observed that, initially, solar intensity exhibits an upward trend as time progresses. However, after a certain period, the solar intensity experiences a continual decline. The graph depicted in Figure 4 illustrates a positive correlation between collector thermal efficiency and time. Specifically, as time grows, the collector thermal efficiency also increases due to the rise in solar intensity, leading to an increase in temperature up to the peak level. However, after the peak temperature, as the temperature declines, the collector thermal efficiency begins to decline.

The calculation was performed to determine the total heat availability, heat available at the collector, heat obtained by water, and thermal efficiency at a flow rate of 42 kg/hr. The resulting values were determined to be 2349.54 KJ/hr-m^2, 3618.29 KJ/hr, 1758.12 KJ/hr, and 48.58, respectively.

3. Conclusion

To facilitate efficient heat transmission, Parabolic trough solar collectors use materials that undergo a phase transition from liquid to gaseous. Heat pipes (high thermal efficiency conductors) are a distinguishing feature of these solar collectors, and they are housed inside of hermetically sealed tubes to prevent air leakage. These heat pipes are composed of copper and have absorption plates (coated copper fins) affixed to them; the fins' width is equivalent to the pipe's inner diameter. A metal condenser tip protrudes from the top of each heat pipe.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Broesamle, H., Mannstein,H., Schillings, C., Trieb,F., 2001, Assessment of Solar Electricity Potential in North Africa Based on Satellite Data and A Geographic Information System,Solar Energy,70:1-12.

[2] Cohen, G.; and Kearney, D. 1994. Improved parabolic trough solar electric system based on the SEGS experience. Proceedings of the ASES Annual Conference, Solar 94: 147-150.

[3] Paradeshi, L., Srinivas, M., & Jayaraj, S. (2016). Parametric studies of a simple direct expansion solar assisted heat pump operating in a hot and humid environment. Energy Procedia, 90, 635-644.

[4] Kim, W., Choi, J., & Cho, H. (2013). Performance analysis of hybrid solar-geothermal CO2 heat pump system for residential heating. Renewable energy, 50, 596-604.

[5] Zhang, X., Zhao, X., Xu, J., & Yu, X. (2013). Characterization of a solar photovoltaic/loop-heat-pipe heat pump water heating system. Applied Energy, 102, 1229-1245.

[6] Bansal, P., Vineyard, E., & Abdelaziz, O. (2012). Status of not-in-kind refrigeration technologies for household space conditioning, water heating and food refrigeration. International Journal of Sustainable Built Environment, 1(1), 85-101.

[7] Saisanit, P., PattanaIm, N., Hachanont, P., & Chanpueng, W. (2008). Hot shower from air Conditioning Unit. Research report at Rajamangala University of Technology Thanyaburi.

[8] Kumar, S., Buddhi, D., & Singh, H. K. (2016). Performance analysis of solar hybrid air-conditioning system with different operating conditions. Imperial Journal of Interdisciplinary Research, 2(10), 1951-56.