Experimental Investigation on Novel Parabolic Trough Collector

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Received 02 March 2021; Accepted 06 March 2021;
Publication 17 April 2021

Abstract

With the increase in demand of the cleaner energy, the use of renewable sources of energy is increasing day by day and solar energy is the answer to it. Several methods are used to harness solar thermal energy among them Concentrating Parabolic Collectors (CPC) are widely used. In this paper, A novel CPC is made, and an experimental study is carried out to find out its efficiency in manual and automated single axis tracking mode using water as working fluid. It was observed that the automated tracking method outperforms the manual tracking method with efficiency reaching up to 48% as compared to 42% in the later. Methods to improve efficiency of the CPC are not used in this study. CPC was found suitable for domestic use.

Keywords: Parabolic trough collector, solar energy, heat transfer, solar tracking.

1 Introduction

As the society is moving towards modernization the energy demand is increasing at rapid pace. Due to depletion in fossil fuel reserves and

Distributed Generation & Alternative Energy Journal, Vol. 35_3, 237–248.
doi: 10.13052/dgaej2156-3306.3534

environmental concerns, solar energy is the best alternative to fulfil energy demand. This form of renewable energy is the cleanest form with very little or no effect on environment [1]. There are several available methods to harness solar energy i.e solar thermal, Photo-voltaic (PV) among the most popular ones. Concentric solar power collectors (CSPC) outperforms the PV system as they can store solar thermal energy in different forms and have a simpler construction. CSPC technologies are commercially applied in many applications which includes solar power systems, Fresnel systems, parabolic trough receiver, parabolic dish, solar tower and many more [2]. Among all the parabolic trough collector (PTC) are contenders for economic feasibility of such systems. PTC's are equally effective for power generation and industrial heating applications as compared to flat collectors which are limited to heating only due to temperature constraints. A comprehensive review on PTC's is given in [3]. First pioneer in the solar electricity generation was in California's desert by using PTC systems. However, the cost of power production was more then the other power generation sources. Many attempts were made to bring down the cost of power production to as much as 75% so that they can compete with the existing energy production sources [4, 5] Attempts are made to improve the energy efficiency of PTC's. The methods utilized for the above purpose include increasing heat transfer to the fluid, increasing the concentration ratio and deploying solar tracking mechanism. Increasing heat transfer to the fluid is a promising way to increase the efficiency of PTC as it can reduce the size of the collector thereby reducing heat loss especially at high temperatures [6, 7]. Increasing the conductive heat transfer can solve the above purpose [8, 9]. Several attempts are made to increase this heat transfer by molten salts and nano fluids [10]. It is observed that the nano fluids are better than the conventional fluids to transfer heat in convective domain [11, 12]. Solar energy harvesting through nano fluids has dragged a lot of attention in recent times [13]. Some researchers carried investigation on CPC for industrial and domestic heating. Different designs using CPC for storage water heating was carried out by [14]. Integrated heat storage with CPC was investigated by [15] they found the maximum collector efficiency to be 38%. Updated designs to improve overall efficiency was done by [16] In his study two tubular receivers and an elliptical single receiver was investigated. Advanced sun tracking techniques were deployed to increase the optical efficiency of the system. An extensive review on CPC applications for domestic and industrial process heating was carried out by [17] A non-tracking external compound parabolic concentrator (XCPC) was investigated for 200°C applications by [18] Regression analysis to obtain tilt angle for a fixed type of solar collectors was recently don by [19]. There are several attempts made to enhance the solar energy harnessing techniques. The CPC plays a vital role as they can supply heated fluids at higher temperature. In this study a novel CPC is designed and its capabilities are studied under manual and automated single axis tracking modes.

2 Parabolic Trough Collector

Parabolic trough collectors are widely used collectors as a line concentrating device. They concentrate the parallel solar beams on to their focal line, where an absorber tube is placed to absorb the heat energy. Figure 1(a) shows the typical PTC and absorber tube placed at focal point.

The dimensions of the PTC used in the experiment are shown in Figure 1(b). the relation between various parameters are given as:

$$f = \frac{w}{4\tan\frac{\varphi}{2}} \tag{1}$$

The Rim angle is given by:

$$\varphi = \sin^{-1}\frac{W}{2R} \tag{2}$$

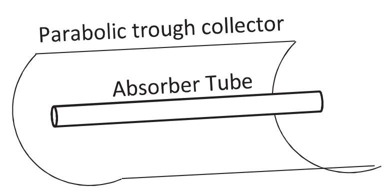

Figure 1(a) Parabolic trough collector.

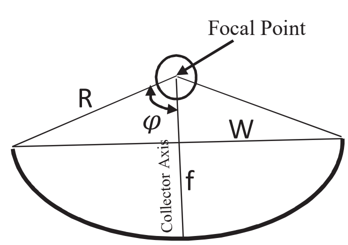

Figure 1(b) Geometric parameters.

Table 1 PTC specifications

Item	Value
Collector length (m)	1.5
Perpendicular distance from the vortex	0.2
Rim angle	90°
Parabola width (m)	0.8

Where, R is the radius of the PTC, W is the aperture width, φ is Rim angle and f denote the focal length. The PTC used in the experiment was designed with the specifications given in Table 1.

3 Experimental Setup

The parabolic trough collector used in the experiment was made from Galvanized Iron sheet of 24 SWG with Aluminium wafer sheet as the reflective coating consisted the reflective trough collector. Reflector optical efficiency was calculated from the incidence and reflected rays and was found to be 80%. This reflectivity was treated as standard and no attempt was made to improve it. A copper tube of 12.5 mm diameter was placed at focal lone of the trough receiver. No enveloping was done on the copper tube in the experiment as the primary aim of the experiment was to differentiate between the manual tracking and the automated tracking efficiencies of the PTC. A pyranometer was used to study the solar radiation. The parabolic trough was mounted on a steel frame which had provision for manual tracking as well as automated tracking. In manual tracking the PTC was adjusted manually after a suitable interval of time in order to keep beam radiation on the collector tube surface while in automatic tracking a DC electric motor and gear system was utilised to perform effective tracking. The experimental setup is shown in Figure 2.

Water tubes were connected to the system through the Rotameter (Flowtech: FS 401) to measure the water flow rate through the absorber tube, a water pump to circulate water and all the tubes are connected to a Reservoir tank as shown. The inlet and outlet temperatures were measured using T-Type thermocouples. A steady state condition was used to measure the temperature and all the measurements were taken in the Clear sky conditions from 9:30 AM to 4:30 PM. The heat extracted by the receiver is calculated

Figure 2 Experimental setup.

by Equation (3)

$$Q = mC_pT_2 - T_1 \tag{3}$$

Where, m is the mass flow rate, C_p is specific heat capacity of water and T_2 and T_1 are the inlet and outlet temperatures of the fluid. The efficiency of the CPC is given by the ratio of heat energy absorbed by water to the heat energy received from the Sun. and is given by Equation (4)

$$\eta = \frac{Q}{Q_i} \tag{4}$$

Where, Q_i is the heat energy received from the sun and is governed by the aperture are A_a and intensity of incoming radiation I_b as given in Equation (5).

$$Q_i = A_a * I_b \tag{5}$$

The heat energy absorbed by the working fluid depend upon several factors, however in present work no such heat transfer mechanism was used and the major contributors to the heat transfer phenomenon are given in Table 2.

The experimental setup was placed on the roof in the Indian state of Telangana, Warangal City (South India) and the Temperature and Solar beam data was logged into a data logger system. The automated tracking

Table 2 Physical properties

Property	Copper	Water
Density (Kg/m^3)	8930	998.2
Thermal conductivity (W/m-K)	384	0.6
Specific heat (J/kg-K)	386	4182

was performed on single axis with a pre-programmed microprocessor-based device.

4 Results and Discussion

The experiment was conducted by using manual and automatic tracking mechanism. The mass flow rate in all the experiments was kept constant at 0.0012 Kg/sec. and the temperatures were noted at an interval of 30 mns each. This provided enough time to give steady state temperature as well as to ensure enough resolution between two readings. The results of temperature difference with manual and automated tracking are given in Table 3.

The Temperature difference between the inlet and outlet of the PTC in case of manual tracking as well as automatic tracking are shown in Figure 3. It is observed that the temperature difference in case of Automated tracking is more then its counterpart, this is because of the fact that automated tracking provides a constant movement to the PTC as it traces the Sun's path leading to more absorbed energy while in case of manual tracking precision tracking is not possible. The highest temperature change is observed at around 2:00 PM to 2:30 PM in both the cases.

The heat absorbed by the fluid shows the similar trend as that of Temperature change due to obvious reason that it depends on temperature change, mass flow rate and specific heat as shown in Figure 4. Thus, automated tracking outperforms in case of heat absorbed by the fluid.

The overall efficiency of the system is better in Automated tracking which peaks to around 48% as compared to 42% efficiency in manual tracking system. The system is providing satisfying results in case of automated tracking using water as the working medium with efficiency as higher as 48% was achieved during 2:00 to 2:30 PM daytime. The efficiency is at the lower side in the morning time due to the obvious reasons that the solar radiation is not intense as well as system takes some time to achieve steady state condition.

Table 3 Temperatures, heat absorbed and efficiency in manual and automated system

Sr. No.	Time	T1 (°C)	T2 (°C)	ΔT Manual Tracking	Qmanual (Watts)	Efficiency (Manual)	T1 (°C)	T2 (°C)	ΔT Automatic Tracking	Qautomated (Watts)	Efficiency (Automated)
1	10:30	34	35	1	5.43	10.41	34	35	1	5.02	9.61
2	11:00	34	35	1	5.43	10.41	34	36	2	10.03	19.21
3	11:30	34	36	2	10.87	20.81	34	36	2	10.03	19.21
4	12:00	34	36	2	10.87	20.81	34	37	3	15.05	28.82
5	12:30	34	36	2	10.87	20.81	34	37	3	15.05	28.82
6	01:00	34	37	3	16.30	31.22	34	38	4	20.06	38.43
7	01:30	35	37	2	10.87	20.81	35	39	4	20.06	38.43
8	02:00	35	38	3	16.30	31.22	36	41	5	25.08	48.03
9	02:30	35	39	4	21.74	41.63	36	41	5	25.08	48.03
10	03:00	36	39	3	16.30	31.22	37	41	4	20.06	38.43
11	03:30	36	39	3	16.30	31.22	37	40	3	15.05	28.82
12	04:00	35	38	3	16.30	31.22	36	40	4	20.06	38.43
13	04:30	35	38	3	16.30	31.22	36	39	3	15.05	28.82

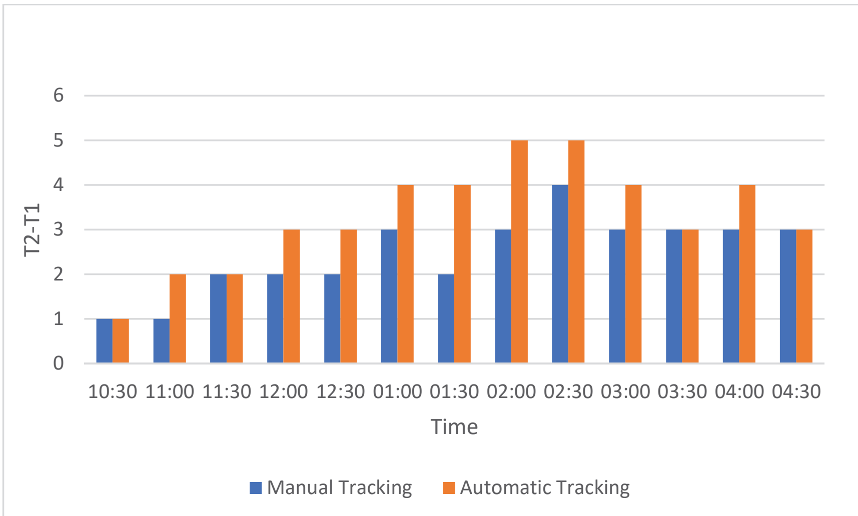

Figure 3 T2-T1 vs time for manual and automated tracking.

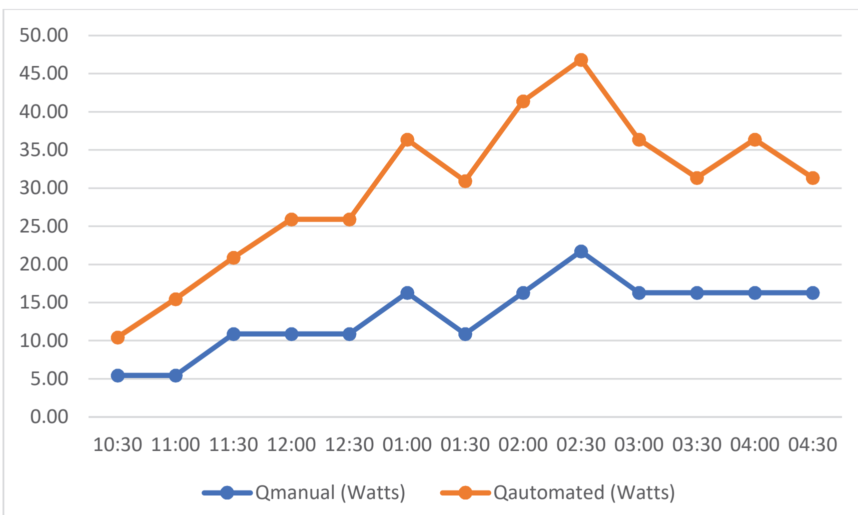

Figure 4 Heat input vs time in manual and automated tracking.

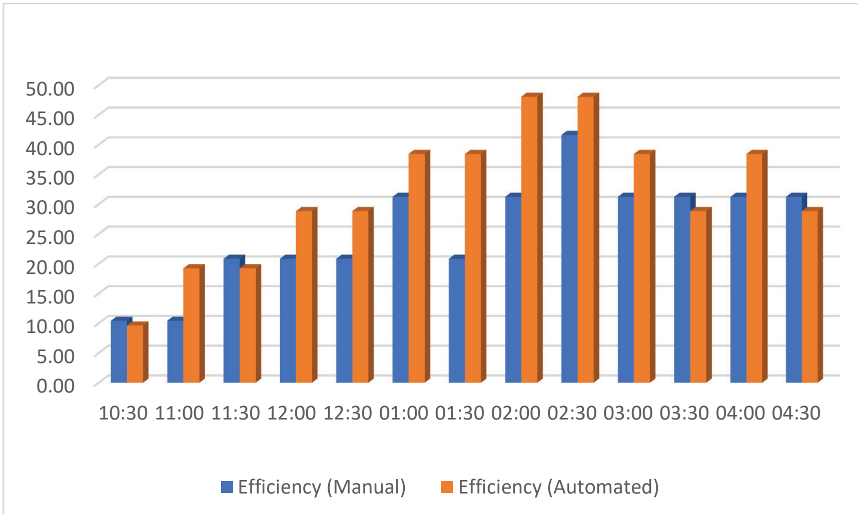

Figure 5 Efficiency vs time for manual and automated tracking.

5 Conclusions

Based on the above results there is a trend of increasing efficiency in case of Automated tracking as compared to manual tracking. Thus, an automated tracking mechanism must be deployed in such systems to obtain better results. The temperature difference between the inlet and outlet can be increased by suitable arrangements like multi pass system or making selective surface on the tube which can increase the overall efficiency of the system. Heat transfer capacity to the fluid can be enhanced using the nano fluids in the absorber tube.

Conflict of Interest: The authors declare that they have no conflict of interest.

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K. Sridhar received his Bachelor of Technology in Production Engineering from MJCET, Osmania University, Hyderabad in 1992. his Master of Technology in Heat Power Refrigeration and Airconditioning from JNTU college of Engineering, Andhra Pradesh, India in 1996, and received his Ph.D. degree in Energy Systems from the Jawaharlal Technical University of Hyderabad, India. Dr. Sridhar is highly motivated faculty in field of thermal sciences. He has guided several M.Tech and B.Tech students and published several research papers at national and international level . His research interests are Thermal Engineering, Heat Transfer and Solar Energy.