# Performance Enhancement of Solar Parabolic Trough Collector by Fluid Flow Control and Solar Tracking System

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**ABSTRACT**

This paper presents the performance study on single axis solar Parabolic Trough Collector (PTC) with solar tracking for varied flow rate of working fluid. PTC is a line-concentrating collector that concentrates incident solar beam radiation energy at its focus and heats up the working fluid. The PTC performance is influenced by incident radiation, optical properties of surface reflective material, thermal properties of working fluid and storage medium along with tracking accuracy. Experiments were conducted on PTC with and absence of tracking mechanism at different flow rates of water. The experimental results such as fluid temperature rise, incident solar radiation and thermal efficiency of PTC were analyzed. A higher thermal efficiency was observed by the PTC experimental setup with solar tracking and controlled flow rate. There is a 27% average increase in efficiency of the PTC with solar tracking and flow control compared to static PTC in a daytime. The methodology of solar tracking with working fluid flow control is quite creditable and it could be employed in PTC solar farms for improved solar energy harvesting.

**KEY WORDS:** Parabolic Trough collector, Efficiency, Tracking, Flow rate.

## 1. INTRODUCTION

Solar energy is one of the vital sources of renewable energy with least ecological impact. Solar energy systems have emerged as a viable source of renewable energy over the decades and are now widely used for a variety of industrial and domestic applications. The demand for solar energy equipments like solar Parabolic Trough Collector (PTC) has been extensively acknowledged by the society. PTCs are devices used to extract energy from solar radiation to a working fluid, which can be used for applications, such as water heating, space heating, and power generation. Solar light waves essentially travel parallel to each other. The PTC is pointed directly towards the sun and a total focal output from all parts of the trough shaped reflector can be achieved. The parabolic collector system consists of four main parts: parabolic trough reflector, solar energy absorber tube, power supply, and tracking control mechanism. A typical parabolic trough collector is shown in Fig.1. The reflective surface is made of aluminium sheet fixed on a parabolic surface and fixed to lightweight aluminium or steel sections. Absorber tube, which is located at the focal axis through which the working fluid flows. It is made with copper coated with black paint to enhance heat absorption characteristics. A concentric glass tube, surrounding the absorber tube can be used to decrease convective heat transfer. The objective of the present work is to employ an economic tracking system for solar Parabolic Trough collector to increase the efficiency. An inclined single axis tracked parabolic trough collector was developed to generate hot water at a pressure close to ambient.

There are many studies on the use of solar collectors to implement as light fixtures, window covering systems, cookers, and so forth. In general, the power developed for such applications depends upon the amount of solar energy captured by the collector. Studies have been made on sun-tracking systems with different applications to improve the efficiency of solar systems by adding the tracking equipment to these systems. Various schemes for optimizing the tilt angle and orientation of solar collectors were analyzed for different geographical latitudes. The performance of a solar collector could be improved by tracking algorithms. Bairi (1990), proved that the amount of solar energy captured by a tilted collector could be increased by adjusting the tilt angle on a seasonal basis. A simple microprocessor could be employed to adjust adaptively the positions of the solar collectors towards the sun. Mathematical theories of tracking error distributions were developed to improve the algorithms of determining sun position.

Solar Parabolic Trough Collectors with automated tracking mechanism has proved improved performance. Yakup and Malik (2001), made efforts for optimum tilt angle and orientation for solar collector. The single-axis solar tracker follows the Sun's East–West movement, while the two-axis solar tracker follows the Sun's changing altitude angle. The objective of this work is to increase the efficiency a single axis solar Parabolic Trough collector (PTC) by varying flow rate of working fluid and employing a simple tracking system.

## 2. EXPERIMENTAL WORK

An experimental setup with solar PTC with microcontroller based tracking system is used to conduct experiments for performance evaluation. Table.1 presents specification of Parabolic Trough Collector used for the experimental. Fig.2 shows the schematic of the solar PTC experimental setup. The parabolic trough collector is made with a reflective aluminium sheet with 90% reflectivity was cut into the appropriate size and fixed to the parabolic collector frame. The Light Dependant Resistor (LDR) sensors were placed at the top and bottom edge positions and connected to microcontroller system.

Fig.3 shows the microcontroller based solar tracking circuit for PTC. This circuit control the DC motor for solar tracking. LDR were used as sensors, in which the resistance decreases with increasing incident light intensity. Pair of LDRs is connected at the either side of the parabolic trough.

Fig.4 shows the solar tracking control algorithm that is used to program the microcontroller. When the PTC is out of focus, unequal solar radiation will fall on the two LDRs, which cause the resistance variations of the LDRs. The output currents of the LDRs are fed to microcontroller through Analog to Digital Converter (ADC). The output signal from the microcontroller system tends the motor to rotate towards the left or right in the direction of LDR with lower light intensity.

Fig.5 shows the solar Parabolic Trough Collector experimental setup. The Table.1 presents necessary the specification of the PTC. The LDR sensors, thermometers and water flow meter were calibrated prior to experimentation. Water is used as working fluid for the experimentation due to its high specific heat capacity. This water is fed into the absorber tube with the help of a feed pump with a controlled flow rate. The experiment is performed under ambient conditions. The inlet, outlet temperature and flow rate of the water along beam radiation is observed during a period from 10.00 hours to 15.00 hours in a sunny day. The experiments were carried out in the month of April, 2016 at VIT University Campus, Vellore, India. Several sets of readings were noted for a specific time intervals and the mean values were tabulated for analysis.

## 3. RESULTS AND DISCUSSIONS

In the PTC experiments, the laminar flow of water was retained. The incident solar beam radiation, water temperature at the inlet and outlet of absorber tube were measured during a sunny day at the flow rates of 10, 20, 40, 60 and 80 litre/hour respectively. The rise in water temperature while passing through absorber tube is observed for the above flow rates. These experimental data were collected from the static PTC at angle normal to horizontal plane and PTC with solar tracking system.

The performance of the PTC was analyzed by water temperature rise between inlet and outlet of the absorber tube and experimental thermal efficiency. The thermal efficiency of PTC was computed using the absorber tube water temperature rise, water mass flow rate and solar incident beam radiation at the identical time intervals in consequent sunny days.

The collector efficiency is computed by the equation, $\eta = m\, C_p\, \Delta T / I_b\, .A_c$

Where, m is the water mass flow rate in kg/s, C is the specific heat of water J/Kg/K, ΔT is the difference between the outlet and inlet water temperatures (To-Ti) in °C, Ib is the intensity of direct solar radiation at the collector surface in $W/m^2$, Ac is the total collector area in $m^2$.

In the first phase, the rise in water temperate through the absorber tube at different flow rates were analysed for both static and solar tracked PTC during the daytime. The temperature rise variations were recorded during 10:00 hours to 15:00 hours in a sunny day at different water flow rates of 10, 20, 40, 60 and 80 litre/hour through the PTC absorber tube respectively. In addition, the temperature rise data were compared for static PTC and the solar tracked PTC. It is inferred that the amount of heat energy received by the PTC setup from the incident solar beam radiation is relatively increased by solar tracking system. It was observed that there is a higher temperature rise between inlet and outlet water temperature in the absorber for the flow rate of 10, 20 and 40 litres/hour during 12:00 to 13:00 hours. At these flow rates, the heat absorbed by the fluid in the absorber tube is relatively high as compared to the higher flow rates of 60 and 80 litre/hour. In general, it can be noticed that, the temperature rise increases till 13:00 hours and then decreases at a moderate rate, which may be due to ambient heat.

In the second phase, the thermal efficiency of the PTC at different flow rates were analysed for both static and solar tracked PTC during the daytime. The thermal efficiency of PTC is calculated with water temperature rise and incident solar radiation at the instant for different flow rates and plotted over hours of daytime.

Figure 6 (a) and (b) represents the comparison between the thermal efficiency plots for static and solar tracked PTC with water flow rates of 10, 20, 40, 60 and 80 litres/hour. It can be observed from Figure 6 (a) and (b), the thermal efficiency of the PTC is well influenced by water flow rate and action of solar tracking system.

The PTC efficiency increases gradually till 13:00 hours and drops in a higher rate after hours, due to ambient heat conditions. From Figure 6 (b), we can infer that the flow rate of 40 litres/hour, which was with a greater temperature rise, has exposed a higher thermal efficiency of 40% at 13:00 hours. This increase in efficiency is due to extensive heat transfer by the flow of water through absorber tube by solar tracking. The water flow rate of 80 litre/hour do not show significant efficiency in both static and solar tracked PTC in a day around, due to insufficient heat absorption by the flowing water with high velocity.

The incident solar beam radiations were varying from 460 w/m2 to 565 w/m2 in all the days of experiments. A higher incident solar radiation was measured using pyrheliometer at 13:00 hours. Figure 7(a) shows the good correlation factor $R^2$ value of 0.98 between average solar radiation (Ib) and time of the day (t). The incident radiation energy (Ib) is given by the polynomial equation, $I_b = -15.095\, t^2 + 381.36\, t - 1843.3$.

Figure 7(b) shows correlation between water flow rate (f) and the corresponding thermal efficiency (η) of static solar PTC at mid-day 13:00 hours. A polynomial fit with a regression coefficient $R^2$ value of 0.92 is obtained from the regression analysis. The thermal efficiency of static PTC is given by the equation,

$$\eta = -0.0176 f^2 + 1.4259 f + 0.0431$$

Figure 7 (c) shows correlation between water flow rate (f) and the corresponding thermal efficiency (ηt) of a solar tracked PTC at 13:00 hours. A polynomial fit with a $R^2$ value of 0.93 is obtained from the regression analysis. The efficiency of solar tracked PTC is given by the equation, $\eta t = -0.0248 f^2 + 2.0512 f - 3.8864$

Figure 7(d) shows the comparison of thermal efficient of PTC at different water flow rates at 13:00 hours day time. At the flow rate of 40 litre/hour, as the water flow absorbs considerable heat energy and leads to greater efficiency. In addition, it can be found that the increase in thermal efficiency of the parabolic collector due to solar tracking with solar tracking is high at this flow rate. The tracking system of PTC make the most of the reception of incident solar beam radiation and substantial amount of heat energy is absorbed by the water flow in the absorber tube, which causes the increase in efficiency of the PTC.

The experiments on PTC reveal that the thermal efficiency of PTC increases as the working fluid flow rate increases to an extend and with solar tracking. A maximum efficiency of 40% was observed for a flow rate of 40 litre/ hour with solar tracking during mid-day as shown the Figure 7(c) and 7(d). There is a 27% average increase in solar tracked PTC thermal efficiency compared to static PTC with similar flow rate. The efficiency plots indicate that the PTC efficiency rises steadily until noon and then drops more swiftly in the post noon hours to reach lower values. The inlet water to the absorber tube of PTC gains a lot of heat from the suns radiation to warm up till noon, causing the more heat gain than compensation for PTC losses. Hence, the efficiency of the PTC higher in the afternoon hours compared to forenoon periods under solar tracked conditions.

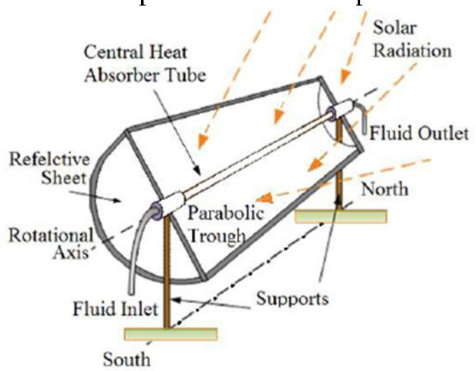


**Fig.1. Schematic of single axis parabolic trough collector**

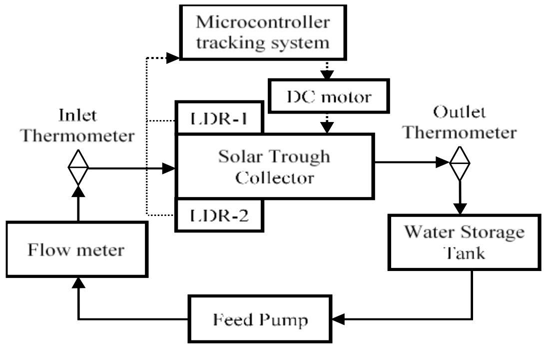


**Fig.2. Schematic of the solar PTC experimental setup**

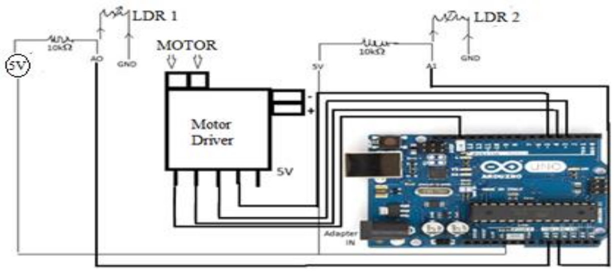


**Fig.3. Microcontroller based solar tracking circuit for PTC**

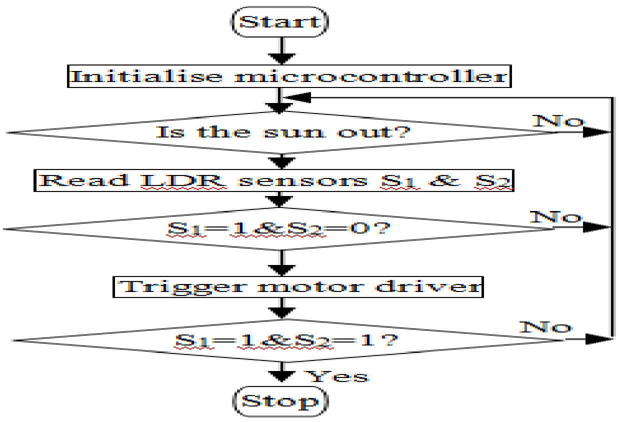


**Fig.4. Solar tracking control algorithm**

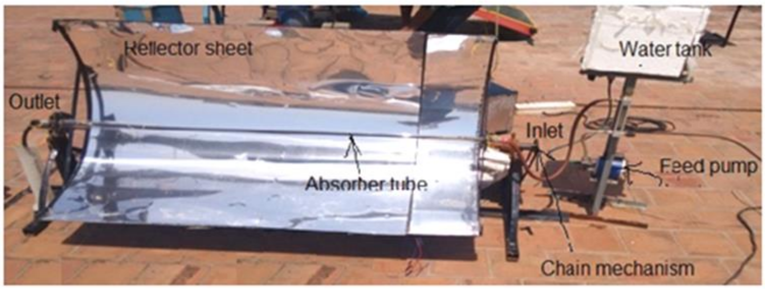


**Fig.5. Solar Parabolic Trough Collector**

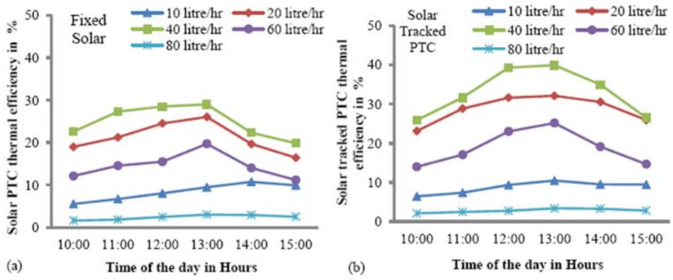


**Fig.6. Solar PTC thermal efficiency plot for different flow rates**

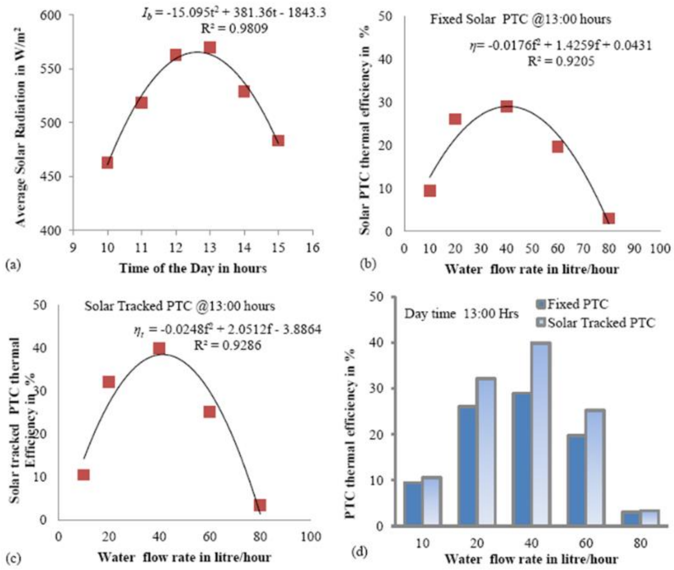


**Fig.7.(a) Correlation between time of the day and average solar radiation; (b) Correlation between water flow rate and static PTC thermal efficiency; (c) Correlation between water flow rate and solar tracked PTC thermal efficiency; (d) Solar PTC thermal efficiency plot for different flow rates**

**Table.1.Parabolic Trough Collector Specification**

| Parameter | Value |
|---|---|
| Aperture width | 0.910 m |
| Length of collector | 1.500 m |
| Concentration ratio | 22.85 |
| Absorber Tube diameter | 0.015 m |
| Orientation | East-West Axis |
| Modes of operation | Tracking / Fixed |
| Absorber tube material | Copper tube in evacuated glass tube |
| Absorber tube length | 1.490 m |
| Diameter of outer tube | 0.030 m |
| Diameter of inner tube | 0.007 m |
| Elevation of collector | 0.450 m |

## 4. CONCLUSION

A performance analysis is carried out with solar Parabolic Trough Collector (PTC) setup with different water flow rates, in order to enhance the solar PTC performance. The developed solar tracking system was able to track the sun position and improves the PTC efficiency. The efficiency of the solar PTC setup has increased by 27% with solar tracking system compared to static position of PTC in a day. A higher efficiency of 40% is obtained from the solar parabolic trough collector setup with solar tracking and with a water flow rate of 40 litre/hour.

A good correlation between PTC thermal efficiency and water flow rate with correlation factor of 0.92 is observed from the regression analysis. This method of working fluid flow control with solar tracking increases the thermal efficiency of PTC, which will lead to sustainable energy harvesting from solar radiation. It is recommended that an automatic solar tracking system with a fluid flow control could be employed in solar parabolic trough collector farms to increase the energy efficiency. Besides, minimizing the heat loss could provide a satisfactory performance for the present system.

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