This paper describes an experimental study of a parabolic trough collector (PTC). The objective of the paper is to perform parametric investigations of the effects of flow rate and absorber water inlet temperature on the collector’s thermal efficiency for different levels of solar insolation under the climatic conditions of Silchar, Assam, India. The analysis was carried out over a year’s period covering different seasons. The optimum values of these input parameters for various solar insolation levels are also found out. It was shown that the effect of the mass flow rate is more significant than the absorber water inlet temperature as the collector thermal efficiency at the optimum mass flow rate is greater than that at the optimum water inlet temperature. And it happens at low solar insolation rates such as 552 W/m². However, the highest thermal efficiency of the present collector is 65%, obtained when optimum values of input parameters are applied simultaneously. The present study provides insight as to the selection of these operating parameters for PTC-based solar water heaters in a low radiation zone like Silchar, Assam, India.

Keywords: Climatic conditions, Optimum mass, Solar insolation, Silchar, Water inlet temperature.

1. Introduction

Solar concentrator systems transfer heat from the sun to water which captures this heat as it circulates through the receiver pipe. The hot water thus produced is finally stored in a tank for domestic use. Solar energy applications for heat collection/refrigeration and electricity generation through various collector designs have become popular and received considerable attention \cite{1-8}. Rabl \cite{9} compared different solar concentrators in terms of their most important characteristics, namely concentration, acceptance angle, sensitivity to mirror errors, size

\begin{itemize}
  \item \cite{1} Frier, D. and Cable, R.G. 1999. An overview and operation optimization of the Kramer junction solar electric generating system. Proc. ISES World Congress, Jerusalem, 241–246.
  \item \cite{2} Francia, G. 1968. Pilot plants of solar steam generation systems. J. Solar Energy 12, 51–64.
  \item \cite{8} Green, M.A. 2004. Recent development in photovoltaics, Journal of Solar Energy 76, 3-8.
\end{itemize}
of reflector area and average number of reflections. Kalogirou et al. \cite{10} presented a parabolic trough solar collector system used for steam generation. A modeling program called PTCDES written in BASIC language was developed to determine the quantity of steam produced by steam generating systems. Bakos et al. \cite{11} conducted an experimental study to investigate the effects of using a continuous operation two-ax tracking on the solar energy collected. Qu et al. \cite{12} programmed a performance model for a solar thermal collector based on a linear tracking parabolic trough reflector focused on a surface treated metallic pipe receiver enclosed in an evacuated transparent tube. The effects on the collector’s performance of solar intensity and incident angle, collector dimensions, material properties, fluid properties, ambient conditions, and operating conditions were studied. It was reported that the collector thermal efficiency is highest when the incident angle is zero, and that the flow rate does not have much effect on efficiency. Naeeni and Yaghoubi \cite{13} studied heat transfer from a receiver tube of the parabolic trough collector at a 250kW solar power plants in Shiraz, Iran, by taking into account the variation effects of the collector’s angle of attack, wind velocity and its distribution with respect to height from the ground. Geyer et al. \cite{14} developed a high-performance parabolic trough collector for utility-scale generation of steam for heat applications and solar power generation using various heat transfer fluids in large solar fields. Arasu and Sornakumar \cite{15} investigated the performance of a new parabolic trough collector-based hot water generation system with a well-mixed hot water storage tank. The storage tank’s water temperature is increased from 35°C at 9:30 h to 73.84°C at 16:00 h when no energy is withdrawn from the storage tank. The average beam radiation during the collection period is 699 W/m². The main contribution and novelty of this paper is the parametric investigation of the effects of flow rate and absorber water inlet temperature on collector thermal efficiency at different levels of solar insolation for the climatic conditions of Silchar, Assam, India. For this, the optimum values of input parameters and highest efficiency of the present collector are found out, and finally, various conclusions are drawn.

2. Description of experimental set-up

The heart of the experimental set-up is a linear parabolic trough collector (PTC), also called reflector, which is a type of solar thermal collector lined with a polished metal mirror. The Solar radiations coming parallel to the focal line of the parabola are collected at the surface of the reflector i.e. parabolic trough collector (PTC) and then concentrated on a line focus of the absorber or the receiver tube. The receiver’s aperture area is 15.27 sq. feet. The external diameter of the receiver tube is 1 inch, and the width of the receiver is 3.8 feet. The water which passes through this tube collects the heat and heats up. It is then stored in the hot water tank. The water temperature at inlet to the absorber tube and surface temperature of the absorber tube are measured by thermocouple sensors which transmit the signals to a data logging facility connected to the present set-up. A sun tracker continuously tracks the sun and as a result the cycle can run efficiently. The tracker tracks the sun on an hourly basis by rotating the PTC at a 15° angle per hour. In concentrating collectors, the term concentration ratio (C) is a very important parameter. It is defined as the ratio of the collector or receiver area at

\[ C = \frac{A_{r}}{A_{c}} \]

\[ \text{where} \, A_{r} = \text{receiver area} \]
\[ \text{and} \, A_{c} = \text{collector area} \]

\[ A_{c} = \pi R_{c}^{2} \]

\[ A_{r} = \pi R_{r}^{2} \]

where \( R_{c} \) is the external diameter of the receiver tube and \( R_{r} \) is the aperture radius of the collector.

\[ C = \frac{\pi R_{r}^{2}}{\pi R_{c}^{2}} = \left( \frac{R_{r}}{R_{c}} \right)^{2} \]

\[ C = \left( \frac{3.8}{1} \right)^{2} = 14.44 \]

\[ C = 15 \]

The purpose of this study is to investigate the effects of collecting area, concentration ratio, and the concentration of radiation on the efficiency of the parabolic trough collector.

\[ \eta = \frac{Q_{c}}{Q_{i}} \]

\[ Q_{c} = mc \Delta T \]

\[ Q_{i} = \int_{0}^{t} I(t) \, dt \]

\[ \text{where} \, \eta = \text{e}}

which radiation collects at the absorber area where these radiations are concentrated. Thus, with the decrease in the absorber area, the concentration ratio increases and the quicker a higher temperature is reached. Thus, a higher concentration ratio means a higher temperature can be achieved. The concentration ratio of such linear concentrating collectors can reach a maximum value of 212. In the present linear concentrating parabolic trough collector, the concentration ratio is 45.83.

3. Results and discussion

In this section, a parametric analysis to determine the performance of the PTC was carried out in the solar insolation conditions of Silchar, Assam, India. Since the meteorological cycle normally repeats itself every year, the results presented here would be invariant of change in year. Figure 3 shows the variation of the collector thermal efficiency with respect to water inlet temperature to the absorber ($T_i$) for different levels.
of solar radiation recorded throughout a year at this location.

Figure 3 shows that for a given solar insolation, first the efficiency increases with the increasing water inlet temperature and after attaining the maximum value of efficiency, it decreases with further increases of the latter. Therefore, there is an optimum value of water inlet temperature at which efficiency is at the maximum for any particular solar insolation. Another important observation from the same figure is that higher radiation levels in the range of 800-900 W/m² are not advantageous for this place as these conditions decrease the attainable efficiency of the PTC. Similarly, a water inlet temperature in excess of 40°C drastically reduces the PTC’s efficiency. This implies that to obtain maximum efficiency, the fluid inlet temperature should be at its optimum value corresponding to a given solar insolation level. In the present work, the highest efficiency of about 0.46 is obtained at a water inlet temperature of 36.8°C for a solar insolation of 720 W/m².

Figure 4 shows the collector thermal efficiency variation with respect to the water’s mass flow rate through the absorber tube for different solar insolation levels at this location. From Figure 4, it is found that the PTC efficiency increases first to a maximum value with the increase in the mass flow rate. After reaching a maximum value, the efficiency starts to decrease with further increases in the mass flow rate. The mass flow rate at which efficiency is maximal is the optimum mass flow rate for a particular solar insolation. Thus, for different radiation intensities, different optimal mass flow rate values are obtained. However, with regard to efficiency, a solar insolation higher than 552 W/m² causes a drop in the collector thermal efficiency irrespective of the mass flow rate. The highest efficiency of about 0.51 is obtained at a mass flow rate of 4.8 kg/s for a solar insolation of 552 W/m². The water inlet temperature to be set for this radiation level should be around 34.8°C as can be seen from Figure 5. It provides an idea about the optimum water inlet temperature to be maintained at a particular solar insolation so that the collector efficiency is the highest at that level of solar radiation.

Figure 6 shows the relation between optimum mass flow rates and solar insolation. Similar to the fluid inlet temperature, optimum values of mass flow rate also increase along with solar insolation to obtain maximum efficiency. Table 1 clearly shows the optimum flow rate values and water inlet temperatures to be maintained at different radiation levels for a maximum PTC efficiency. The optimum lines in Figures 3 and 4 are obtained by joining the highest efficiency values at various levels of solar radiation.
Figure 7 shows collector thermal efficiency variations with respect to water inlet temperature to the absorber. This plot for the present parabolic collector is generated for optimum mass flow rate conditions (i.e. 4.8 kg/s) and water inlet temperature to the absorber (i.e. 36.8°C). This plot shows a comparison of the three different efficiencies from three different sources primarily—the present collector, previous PTC investigated [17] and a flat plate collector investigated at NIT Silchar, Assam, India [18]. It is found that efficiency from all the three different setups decreases with the increase in water inlet temperature. The efficiency variation of the present collector matches well with the literature on collector efficiency qualitatively. Table 2 clearly shows the results of compared efficiencies at various solar insolation levels. Quantitatively, the present collector has a slightly lower efficiency compared to literature [17] because of the unavailability of an evacuated tube in the present setup. On average, the present collector’s efficiency is lower by about 20% compared to PTC.

![Figure 5. Optimum inlet temperature versus insolation](image)

![Figure 6. Optimum mass flow rate versus solar insolation](image)

**Table 1. Optimum operating conditions for different radiation levels**

<table>
<thead>
<tr>
<th>Observed solar insolation during different type of a year, $I_b$ (W/m²)</th>
<th>Optimum water inlet temperature, $T_{in,opt}$ (°C)</th>
<th>Optimum mass flow rate, $m_{opt}$ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>489</td>
<td>34</td>
<td>4.75</td>
</tr>
<tr>
<td>552</td>
<td>35.8</td>
<td>4.8</td>
</tr>
<tr>
<td>649</td>
<td>36.2</td>
<td>4.84</td>
</tr>
<tr>
<td>720</td>
<td>36.8</td>
<td>4.95</td>
</tr>
<tr>
<td>807</td>
<td>37.5</td>
<td>4.98</td>
</tr>
<tr>
<td>951</td>
<td>38.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

![Figure 7. Collector efficiency versus inlet water temperature](image)


efficiency as presented in literature \cite{17}. However, it has a much higher efficiency compared to a flat plate collector as presented in literature \cite{18}. Therefore, the parabolic trough collector is more suitable than the flat plate collector for the climatic conditions of this place.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
& Literature & Present & Flat plate \nparabolic trough & parabolic & collector & [Ref. 18] \\
[Ref. 17] & trough & & & \\
\hline
Efficiency & 70-75\% & 65\% & 65\% & \\
Insolation  & 700-800 & 700-800 & 700-800 & \\
W/m$^2$ & & & & \\
\hline
\end{tabular}
\caption{Comparison of the three efficiencies}
\end{table}

\section*{4. Conclusion}

In this paper, parametric investigations of the effects of flow rate and absorber water inlet temperature on the collector thermal efficiency were carried out for a year for different levels of solar insolation under the climatic conditions of Silchar, Assam, India. The optimum values of these input parameters for various solar insolation levels were also found out. From the study, the following conclusions are drawn:

i) There is an optimum value of water inlet temperature at which efficiency is the highest for any solar insolation. The highest efficiency of about 0.46 is obtained at a water inlet temperature of 36.8°C for a solar insolation of 720 W/m$^2$.

ii) Higher radiation levels in the range of 800-900 W/m$^2$ and absorber water inlet temperatures in excess of 40°C are not advantageous for this location as these conditions undermine attainable PTC efficiency. However, the low water temperature of the working fluid as experimented with in this work could be useful for various applications such as cleaning, washing, bathing etc.

iii) There is an optimum mass flow value rate at which efficiency is at the maximum for any solar insolation. The highest efficiency of about 0.51 is obtained at a mass flow rate of 4.8 kg/s for a solar insolation of 552 W/m$^2$.

iv) The effect of the mass flow rate is more significant than the absorber water inlet temperature as the collector thermal efficiency at the optimum mass flow rate is greater than that at the optimum water inlet temperature. And it happens for lower solar insolation levels around 552 W/m$^2$.

v) The highest thermal efficiency of the present collector is 65\%, obtained when the optimum values of input parameters are used simultaneously. It is higher than that of the flat plate collector though it is a little less than other literature PTC efficiency. It can be increased by inserting an evacuated tube around the receiver tube by preventing convection losses. Thus, the present study provides insight as to the selection of these operating parameters for PTC-based solar water heaters in a low radiation zone such as Silchar, Assam, India.