Design, Fabrication and Performance analysis of a low cost cylindrical Trough collector with Aluminium Receiver.

Parvathi Gorantla, B. Janarthanan and J. Chandrasekaran

ABSTRACT - In the present work, an attempt has been made to design, fabricate and test Cylindrical Trough collector system (CTC) to produce hot water. The concentrator is made of PVC (Poly Vinyl Chloride) with a rim angle of 90° and aperture area of 0.92 m². The concentrator has a concentration ratio of 5 and it is provided with supporting stand made of galvanized iron. The receiver made of aluminium has been mounted on the focal plane of the trough pasted with reflector having reflectivity 0.85. The Overall instantaneous thermal efficiency obtained is 30.77%.

Keywords - Aluminum Receiver, Cylindrical Trough collector, Heat transfer fluid, Poly vinyl Chloride

1 INTRODUCTION

Cylindrical trough collector is one of the solar concentrator technologies for the conversion of solar energy into thermal power. Blackened metal tube receiver is mounted on the focal plane of the cylinder and the trough is rotated about its axis to track the motion of the sun. The metal tube carrying heat transfer fluid receives the thermal energy and gets heated. The hot heat transfer fluid can be used for other applications.

The performance of the trough collector is influenced by different parameters such as aperture diameter, rim angle, reflectivity of reflector, absorber size and shape. To improve the performance of the cylindrical trough collector, researchers all over the world made sincere efforts to optimize the parameters influencing the performance of the system.

Parabolic trough solar concentrator with air as Heat transfer fluid operating at 600°C temperature has been analyzed by Philipp Good et al. [1] and it has been observed that the efficiency of the receiver reached 64%. Nanofluids have been used as heat transfer fluid in solar parabolic trough collector by Alibakhsh Kasaeian et al. [2] and studied the performance. The study revealed the agreement of the experimental results with existing trough system.

A tubular cavity–receiver with air as heat transfer fluid in a parabolic trough solar concentrator system has been analyzed by Roman Bader et al. [3] and found that the collector efficiency varies between 60 to 65%. Govindaraj Kumaresan et al. [4] have investigated the performance of a solar parabolic trough collector with thermal energy storage system. The peak instantaneous efficiency of 62.5% for the parabolic trough has been obtained at 12.00 hours. Xiao et al. [5] have used a V-cavity absorber in linear parabolic trough solar collector and analyzed heat transfer performance theoretically and experimentally. It has been observed that the theoretical results are in good agreement with the experimental results.

The effect of Al₂O₃ particle concentration in synthetic oil heat transfer fluid and rate of heat...
transfer from the absorber tube to the fluid in parabolic trough collector has been studied by Sokhansefat et al. [6]. The study revealed the direct dependence of volumetric concentration of nano particles in heat transfer fluid on the convection heat transfer coefficient. A coupled transient model for parabolic trough received has been proposed by Zhiyong Wu et al. [7] and the results of the model reflected the average difference of the performance of the system between indoor and outdoor experiments were within 6% on average. Design, manufacturing and testing of a prototype of parabolic trough collector for industrial process heat has been presented by Gianluca Coccia et al. [8] and the system is capable of working with demineralized water for temperature up to 85°C.

A numerical model to evaluate the heat transfer characteristics of a solar parabolic trough receiver with porous inserts have been evaluated by Reddy and Satyanarayana [9] and simulation has been carried out for different fluxes and presented. The Optical and Thermal analysis of parabolic trough collector have been done under Dhahran’s weather conditions by Esmail M.A. Mokheimer [10] and the system achieved the maximum and minimum optical efficiency of 73.5% and 61%. Weidong Huang et al. [11] have carried out the performance simulation of a parabolic trough solar collector and developed a new and quick analytical method to calculate the optical efficiency of the proposed system.

Selective absorber coating of absorber tube has been done for parabolic trough collector and the performance of the system has been found by Ladgaonkar and Patil [12]. The overall efficiency of parabolic trough collector without glass cover per period of two days and with glass cover per period of six days were found to be 48.79% and 55.78%. A detailed 3D heat transfer model of parabolic trough concentrators has been developed by Men Wirz et al. [13] and evaluated the properties of selective coatings and different designs of secondary concentrators. Monte Carlo ray-tracing and computational fluid dynamics have been used to find the performance of parabolic trough receiver by Aggrey Mwesigye et al. [14] and revealed that the higher concentration ratio increases higher entropy generation. An exergy analysis has been carried out to study the effects of operational and environmental parameters on the performance of Parabolic Trough Collectors by Ricardo Vasquez Padilla et al. [15] and found that the highest exergy destruction is due to heat transfer between sun and the absorber.

In the present study, an attempt has been made to design and fabricate a cylindrical trough collector of length 4m using low cost PVC material and the tracking has been done manually to receive large amount of solar radiation in the aperture area of the system. The system has been mounted in North-South direction and Aluminium receiver has been used in the focal plane of the collector carrying water as heat transfer fluid. Experiments have been carried out in the Department of Physics, Karpagam Academy of Higher Education, Coimbatore in the month of May 2015.

2 DESIGN

Cylindrical trough is made of PVC of length 4m with rim angle of 90°. Five troughs have been designed and mounted on the stand made of iron in North-South direction. Commercially available reflectors with reflectivity of 0.85 has been painted on the curved surface of the trough to reflect solar radiation towards the absorbed tube mounted on the focal plane of the trough. Aluminium absorber tube has been used and it is painted black to absorb the solar radiation reflected by the reflector more effectively. Water has been used as heat transfer fluid in the absorber tube and it is circulated through the absorber tube with constant flow rate. The flow rate has been adjusted with the help of a valve fixed at the beginning of the first trough. Water tank is mounted at certain height above the trough to incorporate enough pressure.

Water from the tank flows through the absorber tube via the valve such that the flow rate can be adjusted by operating the valve. The flow rate of water has been maintained such that it can absorb the heat energy from the tube efficiently. The inlet and outlet temperature of the water has been measured by Copper-Constantan thermo couple fixed at suitable places at entry and exit point of the absorber tube. Five troughs have been tracked manually with the help of special arrangement made at each trough. Tracking mechanism is introduced with respect to the absorber tube, as the troughs in any desired position do not affect the focusing of solar radiation towards the absorber tube. Experiments have been done in the Department of Physics,
Karpagam Academy of Higher education, Coimbatore in the month of May 2015 and observations have been done to evaluate the performance and efficiency of the proposed system. The photograph of the proposed system has been depicted in Fig. 1.

![Photograph of the cylindrical trough solar concentrator system](image)

**Fig. 1 Photograph of the cylindrical trough solar concentrator system**

### 2.1 DESIGN PARAMETERS OF CYLINDRICAL TROUGH SOLAR CONCENTRATOR

In the proposed system, the width of the trough is 0.23m with rim angle of 90°. The concentration ratio of the system has been found using the aperture area of the trough and receiver area i.e., absorber tube.

Concentration ratio \( CR = \frac{A_a}{A_r} \) \( \quad \) (1)

Where \( A_a \) is the area of aperture (m)

\( A_r \) is the area of receiver (m)

And aperture area \( A_a = W_a \times L \) \( \quad \) (2)

Where \( W_a \) is the Aperture width

\( L \) is the collector length (m)

### 2.2 SPECIFICATIONS OF CYLINDRICAL TROUGH COLLECTOR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rim Angle(( \phi_r ))</td>
<td>90°</td>
</tr>
<tr>
<td>Focal Length(( f ))</td>
<td>Focal plane</td>
</tr>
<tr>
<td>Aperture width(( W_a ))</td>
<td>0.23m</td>
</tr>
<tr>
<td>Diameter of the receiver tube(( D_o ))</td>
<td>0.018m</td>
</tr>
<tr>
<td>Length of the cylindrical trough(( L ))</td>
<td>4 meter</td>
</tr>
<tr>
<td>Effective Aperture Area(( A_a ))</td>
<td>0.92 meter(^2)</td>
</tr>
<tr>
<td>Concentration Ratio(( C ))</td>
<td>5</td>
</tr>
<tr>
<td>Reflectivity of the collector(( r ))</td>
<td>0.85</td>
</tr>
<tr>
<td>Absorptivity of the receiver tube(( \alpha ))</td>
<td>0.9</td>
</tr>
<tr>
<td>Transmissivity of the receiver tube(( \tau ))</td>
<td>0.05</td>
</tr>
<tr>
<td>Intercept factor(( g ))</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### 3 Fabrication of Cylindrical trough collector

Fabrication of the proposed system has been explained in detail in sequential order of the different parts of the system.

#### 3.1 Cylindrical Trough

The proposed cylindrical trough collector consists of Low cost PVC material of thickness of 0.00518 m with length of 4m. Five such troughs have been made and mounted in North-South direction using rigid stand made of iron. Five PVC pipes have been bought and cut exactly each pipe into two halves to get two troughs. It has been done in such a way that each pipe cut into two halves will be exactly in the shape of semi cylinders and the plane containing the axis of each semi-cylinder will be served as the focal plane of the trough system.

#### 3.2 Receiver

Circular Aluminium pipes have been used as receiver and it is painted with mat black paint to
absorb solar radiation effectively. The length of the pipes has been fixed to be the same as that of the length of the trough and mounted on the focal plane of the trough system. L-bends of the same material have been used to join the subsequent pipes of the five troughs respectively. The outer diameter of the pipe has been decided to be 1.7cm such that the concentration ratio of the trough system has the value above 5.

3.3 Collector balancing structure

The five troughs have been mounted on the stand made of iron and special provisions have been made to track the trough easily towards the motion of the sun. All the troughs can be tracked simultaneously with special arrangement made with respect to each receiver of the trough. The tracking has been done with respect to the receiver such that at any desired position, the solar radiation will be reflected towards the receiver.

4 Experimental method

Experiments have been carried out with the proposed cylindrical trough collector system to produce hot water in the month of May 2015 in the Department of Physics, Karpagam Academy of Higher Education, Coimbatore. Calibrated Copper-Constantan thermocouples have been used to measure the temperature of water at different places of the receiver tube. Intensity of solar radiation has been measured using solar radiation monitor and ambient temperature using digital thermometer respectively. Measurements have been done with an interval of 30 minutes between 9am and 5pm.

Experimental observation for one of the typical days has been taken for the evaluation of thermal efficiency of the proposed system. Simultaneously, the variation of inlet and outlet water temperature has been measured using the Copper-Constantan thermo couples placed at the beginning and end of the each trough. Also, the outlet water temperature at the exit point has been measured. The water flow rate through the absorber tube has been maintained in such a way that the flow is streamlined and sufficient time has been provided for the water to heat up throughout its flow inside the absorber tube.

5 Results and Discussion

Fig. 2 shows the variation of intensity of solar radiation throughout the working hours of the system. It has been observed that the solar radiation intensity gradually increases during the morning hours and reaches the maximum at 12.30pm. After that, the intensity gradually decreases in the afternoon hours till 5pm. The maximum solar radiation intensity of 1239W/m² has been obtained at 12.30pm.

![Variation of intensity of solar radiation for one of the typical days in May 2015](image)

Fig. 2 Variation of intensity of solar radiation for one of the typical days in May 2015

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every 30 minutes and depicted in Fig. 4. It has been found that the water temperature reached a maximum of 85°C at 1.00pm. Since Aluminium is a good conductor of heat, it absorbs large amount of solar radiation reflected towards it i.e., focal plane of the cylindrical trough system. Due to convection, the water continuously receives the heat energy from the absorber tube without disruption throughout the day. The cylindrical trough has been tracked manually towards the motion of the sun throughout the day to reflect sufficient amount of radiation to the focal plane of the trough.

\[
\eta_c = \frac{Q_u}{A_u \times h}
\]  

(3)

For concentrating collector, the useful output \( Q_u \) can be expressed as

\[
Q_u = mC_p(T_o - T_{in})
\]  

(4)

Fig. 5 shows the instantaneous efficiency of the trough system with respect to the working hours of the day. It has been observed that the efficiency increases gradually up to 1pm and reached a maximum of 40.20%. The efficiency of the system has followed the same trend as that of the solar radiation intensity. It is due to the fact that, the amount of solar radiation on the aperture area of the trough and radiation reflected towards the absorber tube is large.

The temperature difference between the inlet and outlet water temperature has been found and it is depicted in Fig. 6. From the figure, it is inferred that the maximum temperature difference of 56°C is obtained at 1pm which clearly reflects the dependence of performance of the system on the solar radiation intensity. That is, if the solar radiation intensity is maximum, the amount of heat energy delivered by the system is high. Moreover, the system is capable of delivering heat energy throughout the day as the temperature difference between inlet and outlet water temperature is moderate.
5 Conclusion

The following conclusions have been drawn from the experiment done on the proposed cylindrical trough system and are:

(i) The cylindrical trough system is capable of delivering heat energy and hot water throughout the day.
(ii) Aluminium receiver served as low cost good heat transfer pipe for effective convection of heat energy to the heat transfer fluid as it is cheaper than copper.
(iii) The trough can be used to produce steam by optimizing the flow rate of heat transfer fluid.
(iv) The performance of the proposed system is found to be satisfactory in the local climatic conditions of Coimbatore.
(v) The low cost cylindrical trough made of PVC can be used to produce electric power by incorporating steam engine in an appropriate manner.
(vi) The maximum instantaneous efficiency and temperature of outlet water is found to be 40.20% and 85°C.
(vii) The overall thermal efficiency of the system is found to be 30.77%.

NOMENCLATURE

CTC - Cylindrical trough solar concentrator

$Q_u$ - Useful heat output

$C_p$ - Specific heat of water

$T_i$ - Inlet Temperature

$I_p$ - Incident Solar Radiation

$T_a$ - Ambient temperature

$\eta_c$ - Thermal efficiency

$m$ - Mass Flow Rate

$T_o$ - Outlet Temperature

$A_a$ - Aperture Area

REFERENCES


[7] Zhiyong Wu, Shidong Li, Guofeng Yuan, Dongqiang Lei, Zhiyong Wang, “Three-


