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 m^2. 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.

- *Parvathi.G is currently pursuing Ph.D. in Department of Physics,in Karpagam Academy of higher Education Coimbatore-641021, India, PH- +91-422-2611146. E-mail: parvathi.baava@gmail.com*
- *Dr.B.Janarthanan is currently working as an Associate Professor Department of Physics, Karpagam Academy of higher Education Coimbatore-641021, India, PH-+91-422-2611146. E-mail: bjanarthanan2002@yahoo.co.in*

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 Al_2O_3 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 to85°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 hasbeen 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 pasted 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.

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 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 $CR = \frac{A_a}{A_r}$ (1)

Where A_a is the area of aperture (m)

A_r is the area of receiver (m)

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

Where W_a is the Aperture width

L is the collector length (m)

2.2 SPECIFICATIONS OF CYLINDRICAL TROUGH COLLECTOR

Rim Angle(ϕ_r)	**90°**
Focal Length(f)	**Focal plane**
Aperture width(W_a)	**0.23m**
Diameter of the receiver tube(D_o)	**0.018m**
Length of the cylindrical trough(L)	**4 meter**
Effective Aperture Area(A_a)	**0.92meter^2**
Concentration Ratio(C)	**5**
Reflectivity of the collector(r)	**0.85**
Absorptivity of the receiver tube(α)	**0.9**
Transsitivity of the receiver tube(τ)	**0.05**
Intercept factor(γ)	**0.9**

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 30minutes 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/m^2 has been obtained at 12.30pm.

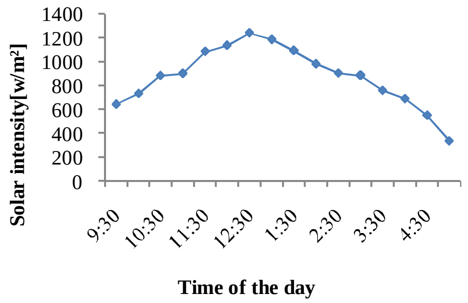

Fig. 2 Variation of intensity of solar radiation for one of the typical days in May 2015

Fig.3 shows the variation of wind velocity for the typical day considered for the prediction of dependency or independency on the performance of the proposed system. Moreover,the influence of wind velocity on the performance of the system is pronounced only if the velocity is higher than 6m/s.from observations, it is clear that throughout the day,the velocity of the wind did not exceed 6m/s and hence the convection and radiative heat transfer from the absorber tube to the ambient is found to be small. Also, the wind velocity is not constant throughout the working hours of the day. The variation of ambient temperature and inlet and outlet water temperature at the entry and exit of the trough systems has been recorded for every 30 minutes and plotted in the Fig. 4. It has been observed that the ambient temperature on the typical day varies between 21 and 36ºC during the working hours. Since it is a clear sunny day, the trough system delivers heat energy more effectively. The inlet water temperature has been measured at the entry place of the trough system and is almost less than 30°C. The water enters through the absorber tube and due to convection the flowing water absorbs the heat energy from the absorber and hot water is obtained at the exit. The hot water temperature has been measured for

International Journal of Scientific & Engineering Research, Volume 7, Issue 1, January-2016
ISSN 2229-5518

every 30minutes 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.

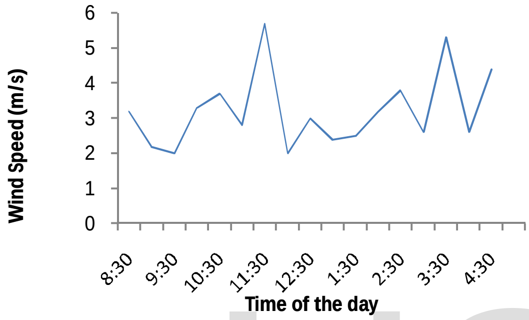

Fig. 3 Variation of wind velocity with time of the day

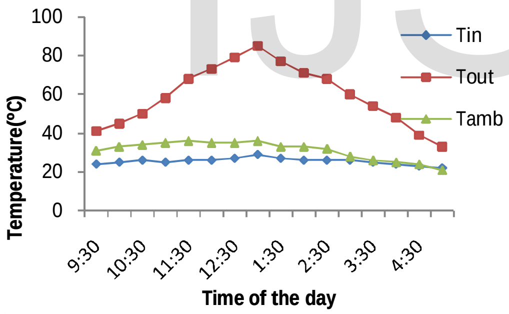

Fig. 4 Variation of ambient, outlet and inlet water temperature with time

In order to calculate the performance of the cylindrical trough system, ratio of useful output to input solar radiation incident on the collector aperture area has been found. The solar radiation incident on the aperture area of the collector gets is the sum of the radiation reflected towards the absorber area by the reflector on the curved surface of the semi-cylinder and direct solar radiation falling directly on the absorber tube. The overall efficiency η_c is the ratio between the useful output Q_u [W] delivered by the collector to the global irradiance/ [W/m^2] incident on the collector aperture area A_a [m^2].

$$\eta_c = \frac{Q_u}{A_a \times I_b} \quad (3)$$

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

$$Q_u = mC_p(T_0 - T_{in}) \quad (4)$$

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 upto 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.

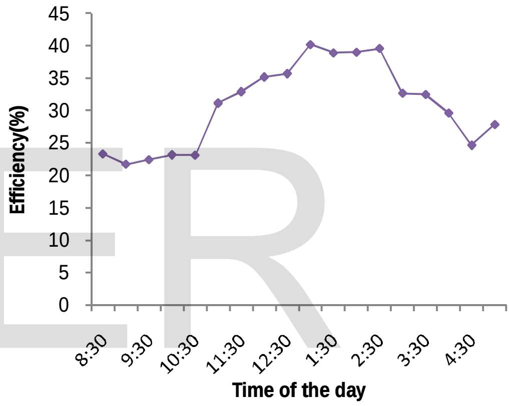

Fig. 5 Variation of instantaneous efficiency with time

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 1pmwhich 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.

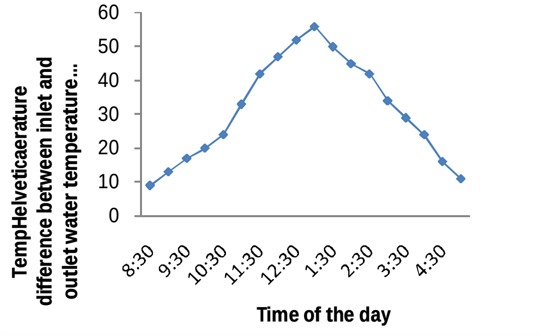

Fig.6 Variation of temperature difference between inlet and outlet water temperature

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 85ºC

(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_b - Incident Solar Radiation

T_a - Ambient temperature

η_c - Thermal efficiency

m - Mass Flow Rate

T_o - Outlet Temperature

A_a - Aperture Area

REFERENCES

[1] Philipp Good, Gianluca Ambrosetti, Andrea Pedretti & Aldo Steinfeld, “An array of coiled absorber tubes for solar trough concentrators operating with air at 600 °C and above”, Solar Energy ,Vol.111 , pp. 378–395, 2015.

[2] Alibakhsh Kasaeian, Samaneh Daviran, Reza Danesh Azarian &Alimorad Rashidi, “Performance evaluation and nanofluid using capability study of a solar parabolic trough collector”,Energy Conversion and Management, Vol.89, pp. 368–375 , 2015.

[3] Roman Bader, Andrea Pedretti, Maurizio Barbato, Aldo Steinfeld, “An air-based corrugated cavity-receiver for solar parabolic trough concentrators”, Applied Energy, Vol-138, pp. 337-345, 2015.

[4] Govindaraj Kumaresan, Rahulram Sridhar& Ramalingom Velraj, “Performance studies of a solar parabolic trough collector with a thermal energy storage system “, Energy, Vol. 47, pp. 395-402, 2012.

[5] X.Xiao, P. Zhang, D.D. Shao &M. Li, “Experimental and numerical heat transfer analysis of a V-cavity absorber for linear parabolic trough solar collector”, Energy Conversion and Management, Vol. 86, pp. 49–59, 2014.

[6] T. Sokhansefat, A.B. Kasaeian, F. Kowsary , “Heat transfer enhancement in parabolic trough collector tube using Al_2O_3/synthetic oil nanofluid” , Renewable and Sustainable Energy Reviews,Vol.33, pp.636-644, 2014.

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

dimensional numerical study of heat transfer characteristics of parabolic trough receiver", Applied energy ,Vol.113,pp.902-911,2014.

[8] Gianluca Coccia , Giovanni Di Nicola & Marco Sotte, "Design, manufacture, and test of a prototype for a parabolic trough collector for industrial process heat ", Renewable Energy, Vol. 74 ,pp.727-736. 2015.

[9] K. S. Reddy & G. V. Satyanarayanaa, "Numerical Study of Porous Finned Receiver for Solar Parabolic Trough Concentrator " , Engineering Applications of Computational Fluid Mechanics, Vol.2(2), pp.172-184, 2008.

[10] Esmail M.A. Mokheimer, Yousef N. Dabwan, Mohamed A. Habib, Syed A.M. Said, Fahad A.Al-Sulaiman,Techno-economic erformance analysis of parabolic trough collector in Dhahran, Saudi Arabia, "Energy Conversion and Management **"**, Vol.86, pp.622-633, 2014.

[11] Weidong Huang, Peng Hu& Zeshao Chen, "Performance simulation of a parabolic trough solar collector", Solar Energy, Vol.86, pp.746-755, 2012.

[12] Ladgaonkar P.S,Patil A.M, "Development and Performance Evaluation of Selective Coating of Absorber Tube for Parabolic Trough Collector", International Journal of Application or Innovation in Engineering & Management, Vol.3 (11), pp.169-174, 2014.

[13] MenWirz, Jules Petit, Andreas Haselbacher, Aldo Steinfeld, "Potential improvements in the optical and thermal efficiencies of parabolic trough concentrators", Solar Energy, Vol.107, pp.398-414, 2014.

[14] Aggrey Mwesigye, Tunde Bello-Ochende, Josua P. Meyer, "Minimum entropy generation due to heat transfer and fluid friction in a parabolic trough receiver with non-uniform heat flux at different rim angles and concentration ratios "**,** Energy, Vol. 73, pp.606-617, 2014.

[15] Ricardo Vasquez Padilla, Armando Fontalvo, Gokmen Demirkaya, Arnold Martinez, Arturo Gonzalez Quiroga, "Exergy analysis of parabolic trough solar receiver", Applied Thermal Engineering, Vol. 67(1-2), pp.579-586. 2014.