Design, Manufacture and Experimental Study of Compound Parabolic Collector

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Abstract - *In this project work CPC (Compound Parabolic Concentrator) with flat plate absorber with copper tubing inside and two parabolic reflectors is first designed and then fabricated for thermal performance analysis. Here the incident rays, after reflection from the reflector, are not focused at a point but are simply collected on a line of absorber surface. Design of compound parabolic trough solar collector (CPC) without tracking is presented in this work. The thermal efficiency is obtained which is between (24-29 %) without glass cover at mass flow rate between (0.003-0.004) kg/s at concentration ratio of (3.667) without need to tracking system. Results are calculated for Pune city (18.395464', 73.69645') by using manufactured prototype. Good agreement between present work and the previous work. CPC is generally oriented in E-W direction. The top portion of the reflector does not intercept much radiation, so the CPC is truncated to1/2 of its full height. Truncation saves a large amount of reflector material with only a little loss in concentration ratio. Design and fabricate CPC model for a half acceptance angle θc= 29.58º to achieve higher concentration ratio. Receiver designed consists of copper tubing of about 4mm ID to control water flow rate and to obtain high output temperature of water. Also an optimum mass flow rate for maximum efficiency is evaluated experimentally*.

Key Words: **Solar collector; Concentrating; Model, Solar energy, solar water heater, CPC collector, Flat plate receiver.**

1. INTRODUCTION

Since the first design of Compound Parabolic Concentrators (CPCs) by Winston in 1974, various studies were carried out to assess their performance and suitability for different applications due to the advantages of high optical efficiency where most of the incident radiations are reflected onto the receiver within wide range of acceptance angle. Rabl presented detailed analysis of CPC solar collectors' in terms of concentration ratio, acceptance angle, average number of reflections, sensitivity to mirror error and operating temperature. The use of various receiver shapes (like tubes, wedge, fins etc.) for different applications was presented by Rabl. Generally one tubular receiver is placed along the axis of the CPC to achieve maximum collection of the incoming rays from the aperture. However, no published work was found regarding the use of more than one receiver in one CPC collector. Using advanced ray tracing.

Solar parabolic trough collectors are the key element in the current commercial application of concentrating solar thermal power plants, heat pumps, hot water production, refrigeration systems, industrial air and water heat process. Although other concentrators promise higher concentration factors and higher system efficiencies, the parabolic trough will continue paving the way for concentrating solar power.

A two dimensional CPC consist of two distinct parabolic segments placed in such a manner that the focus of one parabola placed on the other. The axes of two parabolic segments are oriented away from the CPC axis by the acceptance angle θmax. The slope of the parabolic reflector surface at the entrance aperture is parallel to the CPC optical axis. Thus the solar rays entering the concentrator at the maximum acceptance angle are reflected tangentially to the surface of the absorber.

The present work is focused to design and manufacture a new type of 2-D CPC.

2. Design Considerations

2.1 Design of Collector

Concentration ratio is the ratio of aperture area upon receiver area (here, for flat receiver it is the ratio of aperture width upon receiver width)

For the simple geometry it can be shown that:

$$\tan(\theta) = \frac{D + d}{2H}$$

Where θ=Half incidence angle

D=width of aperture

d=width of receiver

H=height of collector

Also

$$C = \frac{D}{d}$$

The concentration ratio is generally between (3-5) for CPC without tracking and we have selected it as,

C=3.67

And width of collector selected is W=550mm

Length of collector selected L=1160mm

From calculations collector height H=1240mm which is high and to reduce reflective material requirement, we have truncated the height to its half i.e. H=620mm

By calculations following values of parameters for collector are obtained:

SrNo	Parameter	Value		Unit
01	Length of collector	1160		Mm
02	Width of collector	550		Mm
03	Half incidence angle	15.83		degree
04	Receiver width	150		Mm
05	Receiver length	1160		Mm
06	Collector height	620		Mm
07	Focal length of parabolas	150		Mm

1) Backing rib: Backing rib is used to support the reflecting surface and to give it strength under wind and other loads. Here material used for rib is plywood of thickness=12mm and it is precisely machined on wire tool board cutting machine.

2) Base Table: Base table is a welded channel frame on which all the assembly is mounted.It has drills to clamp backing ribs through bolts.

2.2 Design of receiver:

In case of the CPC concentration ratio is small (3-5) and so receiver area is large as compared to the parabolic and dish type collectors. To obtain high output temperatures and to obtain close control over water flow rate, we have designed a shell and tube type heat exchanger receiver for the heat transfer purpose to the water. Shell is an enclosed space between two metal plates sealed by silicon adhesive sealing and tightened by nut and bolts. Plates used are of copper and aluminium. Small diameter copper tubes are circulated through the space and ends of shell are sealed. Ends of copper pipes are connected by flexible plastic pipes at the ends of the shell.

The parameters selected for receiver are as follows:

Sr No	Parameter	Value	Unit/material
01	Upper plate	1160*170 (t=0.7)	mm/copper
02	Bottom plate	1160*185	mm/aluminium
03	Insulation	1160*162 (t=2.5)	mm/resin gf
04	Pipes	ID=4 OD=6	mm/copper
05	Side sealing		Silicon
06	End sealing		M-seal
06	Nut and bolts	M3 No:30	Mm
07	Plastic flexible pipe	ID=4 OD=6	mm /plastic

3) Insulation:

Insulation is an important parameter to minimize losses and to increase efficiency. A resin bounded fibreglass reinforced coating insulation is used for the purpose. Two layers of this combination are applied at the bottom surface of receiver below the piping.

4) Final assembly:

At the last when receiver is ready, final assembly is done. First backing plates are clamped to the base using M5 bolts. Ribs are connected to each other by light aluminium channels at the upper side.

Fig-1: CPC

3. EXPERIMENTAL PART

Pre experimental setup:

Experiment is taken on the constructed prototype on 8th april 2016 at Pune situated at co-ordinates (18.397655; 73.634138 altitude=560m). Before actual experiment part, collector is mounted axis positioning towards East-West direction. Tank and receiver flask are mounted on such a height that nearly 0.22kg/min water flow rate will be maintained.

Readings are taken between 10:00AM to 03:30 PM and following parameters are monitored:

1) Mass flow rate of water: Volume of water circulated through receiver is measured for 10 min and then it is converted to kg/sec.
2) Inlet water temperature: Inlet water temperature is measured after each 2min and average inlet water temperature for middle time for 5 readings is evaluated.
3) Outlet water temperature: Outlet water temperature is measured after each 2min and average Outlet water temperature for middle time for 5 readings is evaluated.
4) Time: Time interval of 2min and 10min is measured.

Calculations for performance testing:

To calculate values of mass flow rate (kg/sec), input energy at aperture, output energy and efficiency; an excel sheet is used and results are calculated as follows:

Results for performance testing:

Following results are obtained from the first observations and calculations data done above:

Time Vs Efficiency:

Efficiency Vs time graph is as shown in following fig.

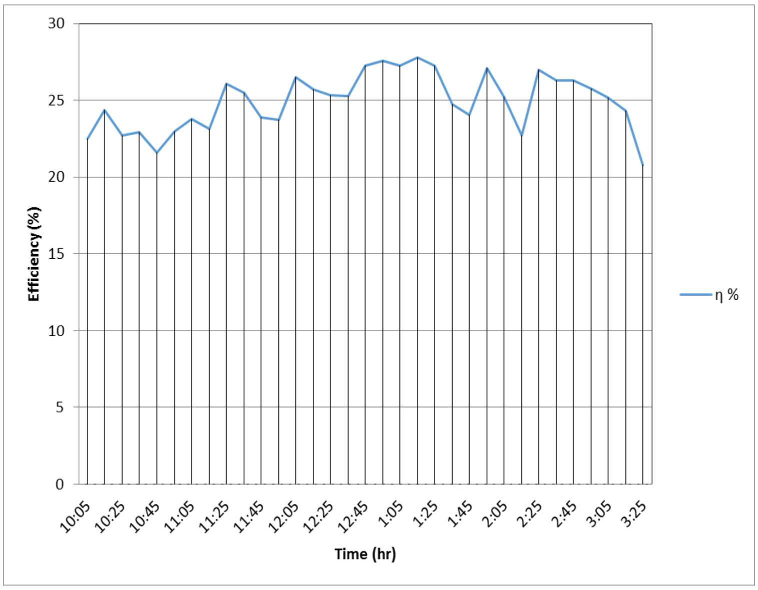

Fig-2: Efficiency vs Time

From above chart we can conclude that:

- Efficiency is in the range of 24%-28%.**(Without glass cover)**
- At the start when solar azimuth angle is low efficiency is low and it goes on increasing with the time. At the solar noon (about 12:40 PM) efficiency becomes maximum and after which it goes on decreasing.

4. CONCLUSION

The parabolic trough solar collector system is mainly used for the power production as the temperature of steam coming from it is very high. It is also used for water heating, air heating and other applications as well. The CPC technology can be very useful for the water heating applications if cost of the system is reduced to some extent.

In this proposed work there is a use of systems approach (Graphical approach) for the evaluation, comparison, ranking and optimum selection of the CPC system.

Following conclusions can be drawn from the prototype testing:

- Use of flat plate receiver with copper tubing yields overall efficiency of about 25% without use of glass cover to the receiver.
- Maximum efficiency obtained is nearly equal to 27%.
- The effect of increase in mass flow rate of water on the performance parameters such as efficiency and outlet temperature is discussed.
- As mass flow rate increases, efficiency first increases, reaches maximum value and then starts to decrease while water temperature quite increase at the start and then goes on decreasing continuously.

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6. REFERENCES

[1] 'Theoretical Study of the Compound Parabolic Trough Solar Collector' by Dr. Subhi S. Mohammed Tadahmun Ahmed Yassen Dr. Hameed Jassim Khalaf Mechanical Engineering Department- University of Tikrit.
[2] ' Compound Parabolic Concentrator' by Parikh Aradhya Anil. (2009).
[3] ' Development of a Compound Parabolic Solar Concentrator to Increase Solar intensity and duration of effective temperature. by A. Borah, S.M. Khayer and L.N. Sethi.
[4] 'Analysis of a New Compound Parabolic Concentrator-Based Solar Collector Designed for Methanol Reforming' by Xiaoguang Gu1 School of Mechanical and Manufacturing Engineering, The University of New South Wales, Sydney, New South Wales 2052, Australia.(2015)
[5]'Experimental study of a parabolic solar concentrator' by A.R. El Ouederni, M. Ben Salah, F. Askri, M. Ben Nasrallah (2009).
[6] ' Optimum Settings for a Compound Parabolic Concentrator with Wings Providing Increased Duration of Effective Temperature for Solar-Driven Systems: A Case Study for Tokyo' by Muhammad Umair , Atsushi Akisawa and Yuki Ueda Graduate School of Bio-Applications and Systems Engineering, Tokyo University of Agriculture and Technology, Naka-cho, Koganei-shi, Tokyo, Japan (2013).
[7] ' Design and Development of a Three Dimensional Compound Parabolic Concentrator and Study Of Optical and Thermal Performance' by S.Senthilkumar, N.Yasodha, Department of Basic Sciences, Kongu Polytechnic College, Perundurai, India (2010).
[8] 'Analysis of Heat Losses of Absorber Tubes of Parabolic through Collector of Shiraz (Iran) Solar Power Plant' by M. Yaghoubi, F. Ahmadi, and M. Bandehee (2013).