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Effect of Receiver Configuration on Thermal Performance of Solar Compound Parabolic Collector

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ABSTRACT

Solar energy is encouraged to use for thermal and electrical needs for its renewable and non-polluting nature. This work is focused on testing of a non-tracking and low concentration compound parabolic collector (CPC) for a temperature range of 60 to 120°C. The CPC is tested with rectangular, triangular and circular receivers. The experimental test is carried out with these receivers with a similar intensity of solar radiation. The results obtained that the triangular receiver provides 10% better thermal performance than the circular receiver and 2% better than the rectangular duct receiver.

KEY WORDS: Compound parabolic collector, Edge ray principle, Solar Receivers.

1. INTRODUCTION

Solar Compound Parabolic Concentrator is a special type of solar collector invented in the shape of two meeting parabolas. Basic designs of flat-plate collector improved by using booster mirror of the parabolic reflector. Atul (2013), presented the cost effective CPC by varying reflector height, without much concession on the concentration ratio. In the results show that the thermal efficiencies and its enhanced reachable temperatures. Christoph (2012), tested the theoretical analysis of medium temperature CPC. Hossain (2011), reviewed the thermal behavior of the collector and the effect of the conductivity of the absorber plate. Rene Tchinda (2008), presented the thermal performance of an air heater with a truncated CPC had a flat absorber. The performance investigated the influence of the air mass flow rate, collector length and wind speed on the collector. Yoshiki and Tomokazu (2013), evaluated an exergy efficiency of CPC under various cloudy conditions. Many researchers have worked on different solar applications of CPC, with the influence of operation, concentrator, receiver configurations and heat transfer fluid by considering the moderate temperature. The present work has aimed the evaluation of solar CPC with rectangular, triangular and tube receivers.

Design of CPC: The design of the CPC is based on edge ray principle or string method. This leads to one of the most available algorithms of non-imaging optics. The design of CPC is considering that conveying the edges only, without regard to interior order, allows accomplishment of the sine law of concentration limit. When this same principle is applied to “strings” instead of rays, it gives the edge-ray algorithm of non-imaging optical design. The collector design proceeds to explain the problem of achieving the sine law limit of concentration for a flat absorber. Figure.1, shows that the loop one end of a “string” to a “rod” tilted at angle q to the aperture *AA*’ and tie the other end to the edge of the exit aperture *B’*. A trace out a reflector profile as the sting moves from *C* to *A*’. From simple geometry, the relation *BB*’ = *AA*’ sin θ immediately follows. This construction gives the 2D CPC. The profile of collector rotates about its axis of symmetry gives the 3D with radius (a) at the entry of sun rays and (b) at the bottom exit of the absorber. The 2D collector is an ideal concentrator that is; it works perfectly for all rays within the acceptance angle ofθ. The flat absorber case is a natural candidate for rotating about the axis because the square of the ratio of diameters ($\sin^2\theta$) agrees with the maximum concentration.

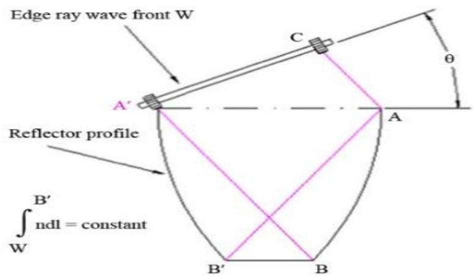
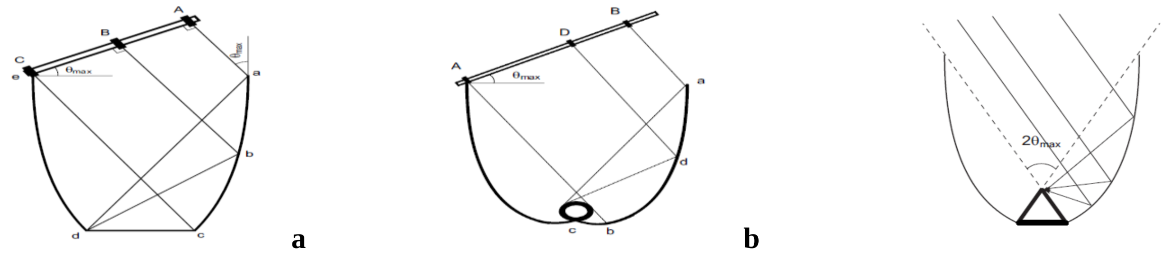


Figure.1. Edge ray of CPC Collector

The flat absorber case occupies a special place because of its simplicity. The concentration ratio is C=AA’/BB’ = 1/sinθ, C=(AA’/BB’)^2 = 1/ $\sin^2\theta$ = 3. Where, acceptance angle, θ = 20°, aperture length, AA’=12 cm, receiver size, BB’=4 cm, height of the CPC = 20 cm, the collector surface area, as = 240 cm^2 and the glazing if highly transparent glass of 3 mm thickness. The length of CPC collector depends on acceptance angle and the exit aperture. The size the concentrator can increase by reduction of acceptance angle. The CPC can be used as a three-dimensional rotational symmetry concentrator or as a CPC trough concentrator. The different receiver configurations with CPC are shown in fig.2. The construction details of CPC is given in the table.1. Figure.3 show that the CPC views of the front, top and side views.



a b c

Figure.2. (a) Rectangular Receiver (d-c), (b) Circular Receiver &(c) Triangular Receiver

Table.1. CPC receiver configurations

Description	Material	Dimensions
Concentrator	Anodized Aluminum Sheet	Parabolic as in string method
Receiver (Rectangular Duct)	Copper plate	2 mm thickness
Receiver (Triangular Duct)	Copper plate	2 mm thickness
Receiver (Cylindrical Tube)	Copper tube	2 mm thickness
Glazing	Plain glass	32 cm x 14 cm, Thickness 3 mm
Thermocouple	K-Type	0 to 400 °C

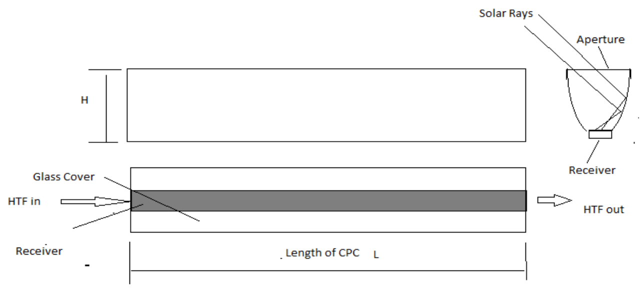


Figure.3. CPC Views – front, top and side views

3. RESULTS AND DISCUSSION

The solar radiation data, temperature behavior of rectangular, triangular and circular receivers, wind speed data, ambient temperature and comparison of three receivers are given below. Figure 4 shows the global radiation during the test days of CPC receiver. It shows the almost similar radiation on all the days with an increase from 10.00 am to noon time. The global radiation and ambient temperature are shown in Fig.5. The global radiation was higher on the first day of the trial and then almost same on other days. There were no significant changes in the wind velocity as well as ambient temperature. The temperature trend in the triangular receiver is steeper among the three receivers, and it indicates the higher temperature gain. The triangular duct has more optical efficiency than rectangular and circular receivers. The receiver provides better performance due to minimum convective losses, and it accounts 10 % more heat gain than the circular receiver and 2 % more heat gain than rectangular receivers.

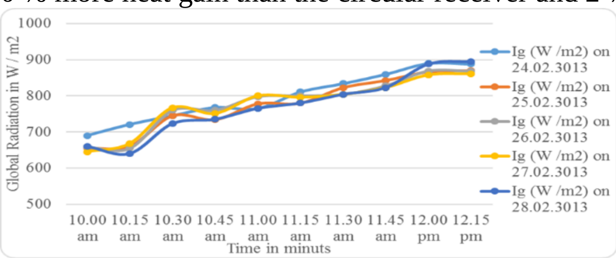


Figure.4. Variation of global radiation during test duration

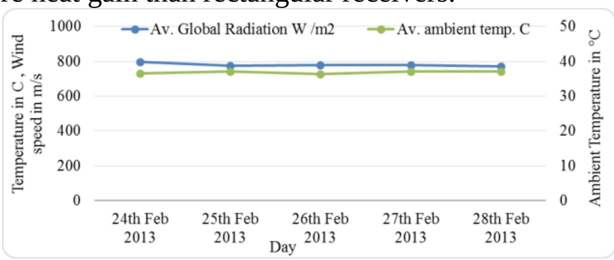


Figure.5. Variation of ambient temperature, wind velocity and global radiation on the test week

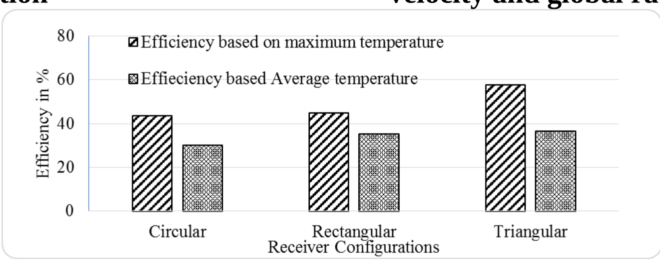


Figure.6. Efficiency of various receiver configurations

The air in the triangular receiver is closer to the plate surface, and it leads to more heat gain. The copper tube performance is comparatively less due to the less intercept of reflected rays from the curved reflectors to receiver tube. The maximum temperature obtained is 70.6 C, 69.4 and 66.2 C for triangular, rectangular and circular receivers respectively. The CPC collector efficiency depends on solar radiation, aperture area, and receiver surface. The heat gain by the air showed the triangular receiver has 57 % efficiency based on maximum receiver temperature and 36.48 % at a temperature of receiver surface which have significant difference among other receivers.

4. CONCLUSIONS

Three CPC collectors were designed and investigated with the CR value of 3. This CPC collector experimentally performed with the three receivers and solar incident on the receiver is approximately same. The test results showed the triangular receiver produces 10% better thermal performance than the circular receiver and 2% better than the rectangular duct receiver. The anodized aluminum reflector sheets with 0.82 reflectivities are used in this work, and it can be replaced with highly reflective mirror sheets, and better insulation has improved the yield the performance. The geometric CR is enhanced by increasing the height of the concentrator, and the expected receiver surface temperature is increased to around 150°C. The large scale fabrication of this CPC with more concentrator’s arrangement in parallel as a module and then the sequential connection between similar modules are fruitful to domestic heating as well as heating process applications in the temperature range of 60 to 120°C. The incorporation of phase change materials as integrated collector storage in this air heater improves the system efficiency and useful during non-solar periods.

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