Performance Enhancement of CPC Using Graphical Ray Tracing

G H Bargale¹ and Dr N K Chougule²

¹Research Scholar, ²Professor in Mechanical Engineering, Department of Mechanical Engineering, College of Engineering Pune, Maharashtra, India, E-mail: khotgargi1008@gmail.com

Abstract. This paper presents the approach of finding an optimized location of a tubular receiver for a compound parabolic collector (CPC) with 23.06° acceptance angle. At this angle reflected rays concentrate at and directly above the main focus of a parabola. Ray tracing plays vital role in analysing rays falling on collector surface and reflected to the receiver. Using this analysis, solar collectors are often designed or improved to enhance the thermal performance. As compound parabolic collectors (CPC) are non-imaging kind and positioned in E-W direction, they are capable of assembling and reflecting an enormous quantity of radiation to the receiver with least tracking. Ray tracing technique was used to evaluate the performance of CPC. A graphical ray tracing (GRT) with SolidWorks was employed to observe the pattern of solar ray concentration. The main aim was to design CPC for low to medium temperature thermal process heat applications, specifically for Textile industries. It is observed that over one tubular absorbers will work better for CPC to absorb most solar rays and two tubular receivers lined up horizontally enhanced the CPC daily average optical efficiency by up to 15-20% compared to the single tubular receiver with the same diameter. Ray- Tracing analysis would possibly provide necessary contributions to beat design problems, complementing the experimental results obtained through thermal testing and allowing the accomplishment of extra thorough testing outputs with lower experimental requirements.

1. INTRODUCTION

Solar collectors are classified as a concentrating and non-concentrating type, further they are classified as imaging and non-imaging types of solar collector. Compound Parabolic Collector (CPC) is come under non imaging and advantages of these type of collectors are they don’t need frequent tracking. Kalogirou, advocated CPC has been classified as a medium temperature application which would be suitable for applications such as textile, dairy etc.[1, 2]. Winston et al described the design and geometrical parameters for solar concentrator and demonstrated applications of cylindrical receivers at CPC and also demonstrated the edge-ray principle to investigate thermal performance of collector using the string method. [3]. Antonini et al modelled CPC for photovoltaic applications and illustrated that CPC absorbs good amount of solar radiation with minimum tracking of collector. [4], Mussard et al made several attempts by optical analysis to increase the concentration ratio and thermal performance [5]. Solar radiation falling of collector has been simulated as light rays falling of the surface. Behavior of rays can be analyzed using ray tracing method either manually or using any drafting or modelling tool in order to understand frequency of tracking to increase the thermal performance.
Non-imaging collector works on the fundamental principle of edge-ray. Rays when strike to the boundary gets reflected to the edges of a target area if optical surface is properly selected. Further it can be directed towards the point or line by designing proper CPC. Rabl A compared different type of solar concentrators with respect to different applications to the industry and also emphasized the study on optical and thermal properties of a CPC [6]. Duffie J A and Gaos et al stressed that the CPC is very close to be the ideal solar concentrator, as it reaches the highest concentration possible for any angle of acceptance [7, 8]. Wang et al derived formulae for calculating average reflections in a CPC. It was concluded that for an ideal CPC, only two parameters are required, acceptance angle and receiver diameter. With these values concentrator’s width and height can be easily calculated [9].

Previous researchers studied CPC theoretically as well as experimentally and it was suggested that CPC can be used for medium temperature applications without frequent tracking. With this context this paper aims to study behavior of light rays on CPC for Textile applications.

2. CONSTRUCTION OF CPC & RAY TRACING:
CPC is broadly classified as symmetrical or asymmetrical. The acceptance angle of CPC plays vital role in designing the system for particular applications. In order to collect solar radiation, receiver is located at a focal point. There are different positions where receivers are placed, we can find out the proper position of absorber tube by ray tracing analysis. As compound parabolic collectors (CPC) are positioned in E-W direction, they're capable of assembling and reflecting an enormous quantity of radiation to the receiver with least tracking when the acceptance angle is 23.06° (When the acceptance angle is greater than or equal to solar swing angle, there is no need of frequent tracking, which is 17.5° for location Ichalkaranji, Maharashtra, India). For the acceptance angle of 23.06°, the concentration ratio is 5 so for the 200mm absorber width, aperture width and height of the CPC are 1000mm and 2939.38mm respectively. Design CPC consists of calculation and selection of material for reflector and receiver. Generally material with high reflectivity and less absorptivity would be preferred for reflector and vice a versa for receiver. While constructing CPCs generally they are truncated to reduce area required and cost of the material without compromising the concentration ration. Design calculations arrive to truncate the CPC to 33% of original height.

CPC geometry constructed with highly reflective surface with minimum absorption in order to achieve maximum optical efficiency. The incident solar rays concentrated at the focus inside the collector due to concave profile of a reflector.

![Figure 1. Reflection of solar ray on CPC geometry](image-url)

Figure 1 depicts the reflection of solar rays on CPC geometry. Figure 1 demonstrates that incident ray falls at point C on reflector of CPC and reflected at an angle 2θ. Incident ray makes angle θ with the normal drawn at the point C, further it reflects with the same angle θ in the opposite direction normal to the tangent. This ray tracing analysis gives idea about location and diameter of a receiver.
3. RAY TRACING OF DIFFERENT CPC CONFIGURATION

As CPC is the combination of two parabolas, CPCs can be formed by different configurations. By combining two parabolas with shifting their focus linearly (Type A-with outer truncation & Type C-with inner truncation). By combining two parabolas such that their focus points coincide (Type B-with outer truncation & Type D-with inner truncation). Or asymmetric CPC (Type-E).

SolidWorks software was used to simulate the CPC as it is more flexible in designing and optimizing the CPC. Ray tracing is done in Solidworks by considering same no.of rays for all types and tracing the rays by their angle as shown in Fig.1.

SolidWorks was used to simulate CPC collectors with acceptance angle 23.06° and concentration ratio of 5. For all types, aperture width and height of CPC types are tabulated below in Table 1.

|        | A        | B     | C       | D      | E      |
|--------|----------|-------|---------|--------|--------|
| Absorber Width | 200     | 200   | 200     | 200    | 200    |
| Aperture Width  | 1183.74 | 815   | 2155.69 | 2377   | 1183.74 |
| Truncated Height | 979.20  | 979.2 | 985.61  | 1138.90| 1052.22|
| Diameter of Tube receiver | 58     | 58    | 58      | 58     | 58     |

All dimensions are in mm

In order to analyse performance of CPC collector with different design sun hour angle of 0° considered. The surface area of reflector has been divided into equal 100 parts. In order to estimate maximum concentration of solar rays, GRT is done. Tracing of 100 rays is carried out for this work. Figure 2 shows how the ray tracing is done for Type A considering the angle θ at every incident point with single tube receiver of diameter 58mm.

![Figure 2. Ray tracing of Type A CPC with single tube absorber](image)

Same procedure is followed for all above types and it was observed that most of the rays grabbed by receiver tubes directly and also after repetitive reflections of the rays. It is found from the ray tracing data shown in figure 3, Type C gives maximum coverage of rays but as it is formed by the inner truncation; its area is very large. On the other hand Type A gives good results for ray trace as well as it is formed by inner truncation so requires average area. Talking about Type B and Type D, they cover fewer rays as compared to remaining types. Whereas the Type E also covers good rays but as this is...
asymmetric CPC, this type is difficult to fabricate. So, Type A is selected as it covers good amount of rays with average area requirement and with ease of fabrication.

![Ray Trace analysis for different CPC Configurations](image1)

**Figure 3.** Ray Trace analysis for different CPC configurations

Further, Type A with single absorber and with two tubular absorbers is studied. Figure 4 shows the ray tracing with two tubular receivers ((a) two receiver tubes placed horizontal each of 58mm diameter denoted by A-2TH & (b) two receiver tubes placed vertical each of 58mm diameter denoted by A-2TV).

![Ray tracing of Type A CPC with two tubular absorbers ((a) absorbers placed horizontally, (b) absorbers placed vertically)](image2)

**Figure 4.** Ray tracing of Type A CPC with two tubular absorbers ((a) absorbers placed horizontally, (b) absorbers placed vertically)

It can be seen from ray trace analysis that the Type A CPC with two tubular receivers placed horizontally covers maximum solar radiation i.e. maximum rays falling on the reflector strikes the absorber tubes with direct or multiple reflections.

From Fig.5, it was observed that 50% of rays strike to CPC with the single tube receiver, 80% for two horizontal tube receivers of same diameter and 70% with two vertical tube receivers of same diameter. Optical efficiency of the CPC collector can be obtained by the ratio of radiation received by the receiver to the reflector of the collector.
As all the ray tracings are carried out at 12 noon, inclination of solar rays with time is not considered here. All results shown here don’t include time variation over a day. Also it is difficult to quantify thermal losses while calculating optical efficiency by ray tracing. So, optical efficiency is estimated to be 60% more in two horizontally placed tubular receivers CPC than single tubular receiver CPC from ray trace only. Considering all losses, it will surely improve the optical efficiency up to 20% which would be further validated by CFD analysis and experimentation. It reveals favourable results and motivation for further research in CPC for different applications.

4. CONCLUSION
Ray tracing was done for 5 different constructions with acceptance angle of 23.06°. Optimized location of a tube receiver for a compound parabolic collector (CPC) with 23.06° acceptance angle is found with the help of ray tracing. Graphical ray tracing is done with the help of SolidWorks following the property of reflection of solar ray. By considering different CPC geometries for concentration ratio of 5 and acceptance angle of 23.06°, Type A gives the feasible results. About 50% of solar rays are absorbed by the receiver in Type A. Whereas, considering two tubular absorbers placed horizontally with same diameter for Type A CPC, would enhance the optical efficiency about 60%. As all the ray tracings are carried out at 12 noon, inclination of solar rays with time is not considered here. All results shown here don’t include time variation over a day. Also it is difficult to quantify thermal losses while calculating optical efficiency by ray tracing. Considering all losses, it will surely improve the optical efficiency up to 15-20% which would be further validated by CFD analysis and experimentation.

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