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Abdullahi, B.; Al-Dadah, Raya; Mouhmud, S.

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Optical Performance of Double Receiver Compound Parabolic Concentrator

B. Abdullahi[a], R. K. Al-dadah[a]*, S. Mouhmud[a]

[a]*School of Mechanical Engineering, University of BirminghamBirmingham, UK .*

Abstract

Conventional solar compound parabolic concentrators are fitted with one tubular receiver situated along the axis of the two parabolas. This work investigates the potential of using two tubular receivers in one compound parabolic concentrator. Using advanced ray tracing technique, the optical efficiency of a compound parabolic concentrator with two tubular receivers aligned horizontally and vertically was predicted. Results show that the horizontal configuration outperforms both the single and the vertical configurations by up to 15%. Horizontally aligned elliptical single tube was also investigated and results showed an increase in the average daily optical efficiency compared to the single tube configuration by 17%. This work highlights the potential of using either two tubular receivers or single elliptical one aligned horizontally in one concentrator to improve the optical efficiency.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Compound parabolic concentrator (CPC), ray tracing, optical efficiency, double tube concentrator, tubular receiver.

1. Introduction

Since the first design of Compound Parabolic Concentrators (CPCs) by Winston in 1974 [1], 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 radiation are reflected onto the receiver within wide range of acceptance angle. Rabl [2, 3] 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 [4]. 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

* Corresponding author. Tel.: Phone number: +44-121-414-3513. Email:; fax: +44-0121-414-3958.
E-mail address: r.k.al-dadah@bham.c.uk.

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Nomenclature

E(***a***:***b***)	Elliptical receiver with ***a*** and ***b*** major and minor axes respectively
HPCPC***x***	Heat pipe based compound parabolic concentrator with ***x*** acceptance angle
HA	Horizontally aligned double tube
VA	Vertically aligned double tube

technique, this work investigates the potential of using two tubular receivers aligned horizontally or vertically in one compound parabolic concentrator to improve the optical efficiency. Also the performance of a single receiver with elliptical shape to replace the two tubular ones was investigated.

2. CPC Optical Performance

Ray tracing technique is used to simulate the optical performance of concentrating collectors in terms of the intensity and distribution of the solar rays inside the collector and on the receiver. This technique utilises the laws of reflection to determine the direction and point of intersection of incident and reflected rays in relation to the reflecting surfaces. Optisworks software was used to simulate the optical performance of three CPC collectors with acceptance angles, heights and aperture width of (30°, 634.2mm, 303.5mm), (40°, 371.6mm, 229.6mm) and (60°, 180.7, 157.1mm) respectively. The receivers used are single tubular with diameter of 25mm, two tubular receivers of 25mm diameter aligned horizontally and vertically and a single elliptical receiver with major axis ranging from 45mm to 60mm and minor axis ranging from 20mm to 30mm aligned horizontally. Figure 1 shows the ray distribution on the receivers at sun hour angle of 0° for the four configurations of receivers used. From the figure, it can be seen that some rays reached the tubes directly or after one or multiple reflections.

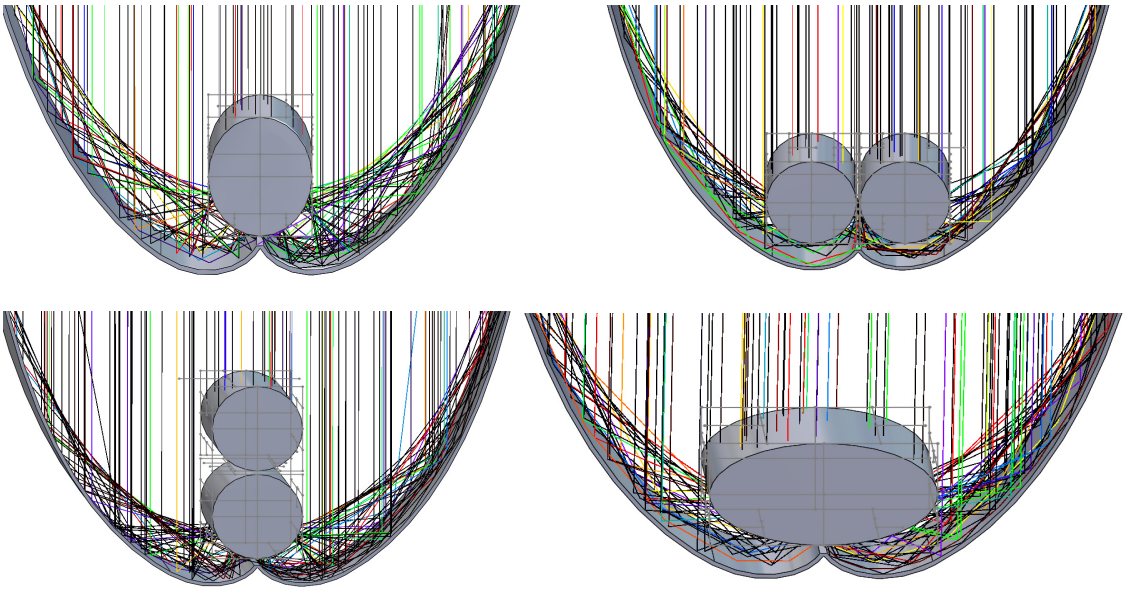

Fig. 1. Rays distribution on single, double (horizontal & vertical) and elliptical receiver configurations respectively

The optical efficiency of the collectors was determined as the ratio of the radiation received by the receivers compared to the radiation received at the aperture of the collector as shown by equation 1 [5]:

$$\eta = \frac{Power\ on\ the\ receiver}{Power\ on\ the\ aperture} \quad (1)$$

Figures 2-4 show the variation of the optical efficiency with solar time for the three CPCs with acceptance angles of 30 (HPCPC30), 40 (HPCPC40), 60 (HPCPC60) respectively where each figure compares three receiver configurations, one single tube, two tubes aligned horizontally and two tubes aligned vertically. From figures 2-4, it can be shown that the double tubes aligned horizontally outperformed the other configurations with an increase in the average daily optical efficiency of 14, 14.8 and 15% compared to the single tube for HPCPC60, HPCPC40 and HPCPC30 respectively. This result shows the advantage of using two tubular receivers aligned horizontally. However, the inner adjacent surfaces between the two tubes receive little radiation; therefore an elliptical configuration which surrounds the two tubes may provide an improvement. Figure 5 compares the optical performance of a single elliptical receiver with major axis aligned horizontally and vertically. It is clear from this figure that the horizontally aligned elliptical receiver gives higher optical efficiency (10%) than the vertical one. Figure 6 shows the effect of the length of minor and major axis of a horizontally aligned receiver on the CPC optical efficiency. It is clear from this figure that the receiver with major axis length of 60mm and

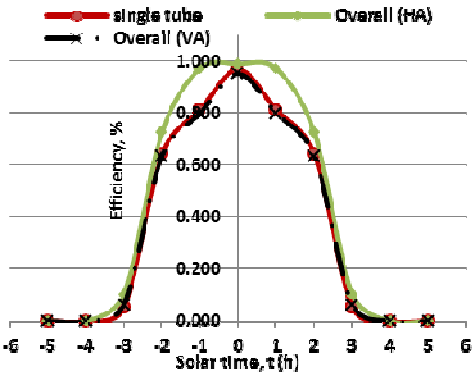

Fig. 2. Optical efficiency Vs Solar time (HPCPC30)

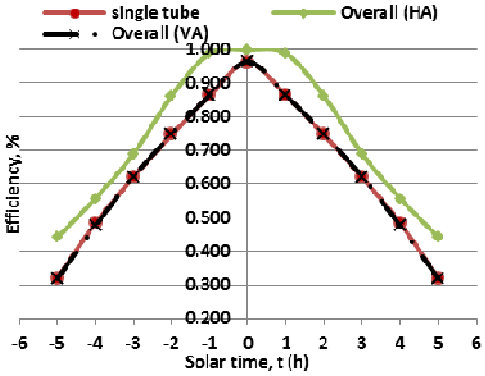

Fig. 3. Optical efficiency Vs Solar time (HPCPC40)

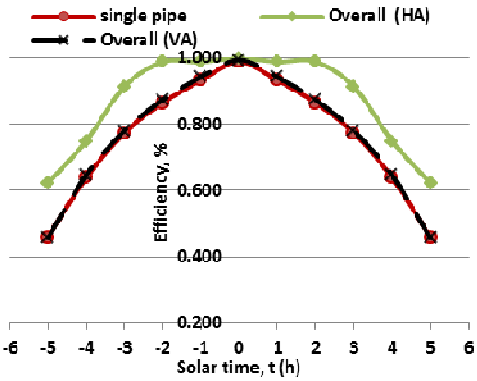

Fig. 4. Optical efficiency Vs Solar time (HPCPC60)

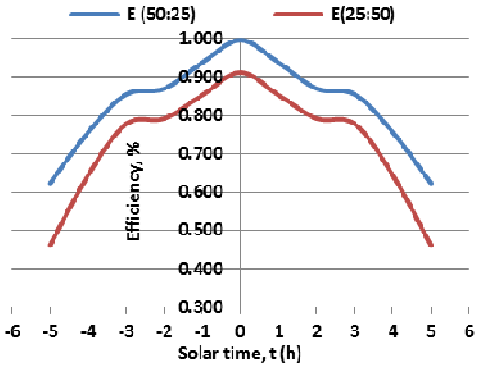

Fig. 5. Optical efficiency Vs Solar time (Elliptical)

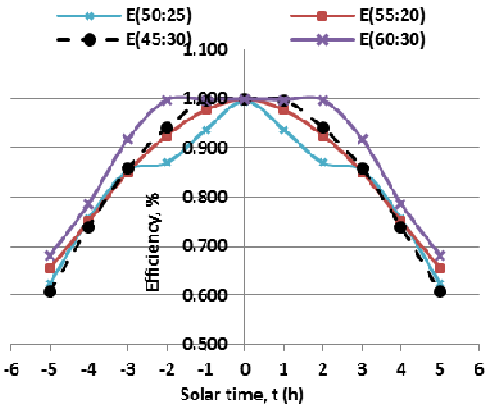

Fig. 6. Optical efficiency Vs Solar time (horizontal aligned Ellipse)

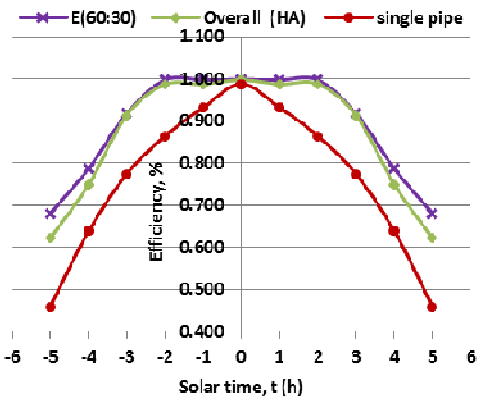

Fig. 7. Optical efficiency Vs Solar time

minor axis length of 30mm gave an improved optical efficiency up to 8% Compared to others. Figure 7 compares the optical performance of the elliptical receiver E(60:30), two tubular receivers and the single tubular receiver in the horizontal configuration. It can be seen that configuration E(60:30) gives the best performance out of the three configurations with 17% increase in the daily average optical efficiency compared to the conventional single tubular receiver of 25mm diameter.

3. Conclusions

Conventional solar compound parabolic concentrators are fitted with one tubular receiver situated along the axis of the two parabolas. The potential of using two tubes in a compound parabolic concentrator and that of using elliptical receiver are investigated to improve the optical efficiency. Results from ray tracing simulation showed that two tubular receivers aligned horizontally improved the CPC daily average optical efficiency by up to 15% compared to the single tubular receiver with the same diameter. As for the vertically aligned two tubes configuration, no improvement in the optical efficiency was predicted. Elliptically shaped single receiver with 60mm and 30mm major and minor axes respectively has shown an increase in the daily average optical efficiency of about 17% compared to single tube with 25mm diameter. These results highlight the potential of using more than one tubular receiver in one concentrator or elliptical single receiver in improving the optical efficiency. Therefore, further work is recommended to investigate other parameters like the effect of tube diameter, the number of tubes and other cross sectional shapes in order to maximise the optical efficiency.

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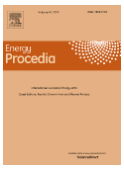

Biography

Bala Abdullahi is a PhD research student in the School of Mechanical Engineering, University of Birmingham, UK. He is currently working on the optimization of heat pipe based compound parabolic collector for solar thermal applications.