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# Design and Fabrication of Two Dimension Compound Parabolic Concentrator for Iraqi Climate

Sabah Auda Abdul Ameer[1], Haroun A. K Shahad[2]
*[1,2]Mechanical Engineering Department, University of Babylon, Babylon-Iraq*

***Abstract*****: *The collectors are employed, when the temperature prerequisite is more than 100°C. In this work a two-dimension compound parabolic concentrator solar collector constructed of mild steel sheet with serpentine copper tube fixed on a flat plate absorber, has been designed for Iraqi climate. This compound parabolic concentrator consists of two stainless-steel parabolas. The concentrator is closed from the top and sides with 4mm glass sheets. The two parabolas are truncated at the top to reduce the apparatus height and the effect of shading. This two dimensional compound parabolic concentrator is designed to have a concentration ratio of 5. The serpentine copper tube is fixed on flat mild steel absorber plate. The copper tube and flat plate are black coated. The collector is tested in Iraqi weather during the months of August, September and October. Initial results show that the maximum absorber temperature is recorded in August which 120 ˚C with a reflector temperature of 69 ˚C and aperture cover glass temperature 43°C.***
***Keywords: Two Dimension, Compound Parabolic Concentrator, Non-Imaging Collector, Serpentine Absorber.***

## I. INTRODUCTION

The collectors are classified as either reflectors or refractors. In the present work the reflector type is used which is a compound parabolic concentrator (CPC). Concentrating collectors can increase the solar radiation intensity to about 10000 folds [1]. The focusing collector is a compound parabolic collector or collector of Winston as shown in figure (1). The compound parabolic concentrator consists of left and right reflectors in the shape of parabola which reflects the incident solar radiation onto the absorber. The right and left halves which belong to different parabolas have a common focal point. The absorber location is the distance between focuses of the two parabolas. The non-tracking type with seasonal tilt adjustments can produce concentration ratios in the range of (3-7) [1, 2, 3]. Most application use flat plate collectors that demand temperatures below the 90°C and a large of research efforts are already made.

In applications where the range of temperature is (90-300°C) the suitable collector is the concentrating type [1, 2]. F. Bloisi et. al [4] and Abdul-Jabbar, N. K. [5], analyzed four types of compound parabolic collectors which differ in the shape of the absorber. The effect of acceptance angle, height and the width of the collector is discussed by many researchers. Norton et. al. [6] investigates the possible use of compound parabolic concentrator in rural areas. They recommended the incorporation of a basin type still with an inverted absorber line-axis asymmetric CPC. The heat losses by convection can be minimized by inverted absorber configuration which can achieve higher temperatures. Lixi Zhang et. al [7] designed a heat generation system with a load capacity of 10 kW. The compound parabolic concentrator array is used as the main heat source with a concentration ratio equal 5, and the assistant heat source as gas boiler. The shape of compound parabolic concentrator is analyzed for thermal efficiency and the collector array is ranged suitably.

In this work a compound parabolic solar based authority is composed and tried. The design calculations are carried out according to a specified load. The dimensions of the compound parabolic solar collector will be determined by using the equations explained in the next section.

## II. DESIGN OF THE TWO DIMENSIONAL

The two dimensional compound parabolic collector contains of main three components:

### *A. Reflector*

Two reflectors in the shape of parabolas are made of stainless steel mirror image sheets.

### *B. Absorber*

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It is the component of compound parabolic concentrator where the entire amount of heat after reflection is absorbed. It is made of serpentine copper tube fixed on a flat plat MS (16 gauge). The copper tube and the flat plate are black coated.

*C. Aperture Cover*

The aperture and the side openings of the collector are closed with toughened glass of 4 mm thickness.

A two dimensional compound parabolic concentrator is shown in Fig. (1). It consists 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 compound parabolic concentrator axis by the acceptance angle $\theta_{max}$. 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. For the simple geometry it can be shown that [1]:

$$\tan\theta_{max} = \frac{D + d}{2H} \tag{1}$$

Where D is the width of aperture, d is the width of absorber and H the height of concentrator

$$\frac{D}{d} = C = \frac{1}{\sin\theta_{max}} \tag{2}$$

Using above equations

$$H = \frac{D(1 + \sin\theta_{max})}{2\tan\theta_{max}} \tag{3}$$

Rabl [8], has shown that the area of the concentrator or reflector, $A_{con}$, is related to the area of the apertures $A_a$, as

$$A_{con} = A_a(1 + \sin\theta c)\left\{\frac{\cos\theta max}{\sin^2\theta max} + \ln\left\{\frac{(1 + \sin\theta max)(1 + \cos\theta max)}{\sin\theta max\{\cos\theta max + (2 + 2\sin\theta max)^{0.5}\}}\right\} - \frac{\sqrt{2}\cos\theta max}{(1 + \sin\theta max)^{\frac{3}{2}}}\right\} \tag{4}$$

Rabl [8] has also shown that the average number of reflections, n, passing through a compound parabolic concentrator inside is acceptance angle is given as

$$n = \frac{1}{2\sin\theta_{max}}\left\{\frac{A_{con}}{A_a}\right\} - \frac{(1 + 2\sin\theta_{max})(1 - \sin\theta_{max})}{2\sin^2\theta_{max}} \tag{5}$$

The effective transmissivity of CPC, $\tau_{CPC,}$ accounting for reflection loss inside the CPC depends on the specular reflectivity, ρ, on CPC wall and the average number of reflections, n, is given by R. Winston [9, 11, and 12] as:

$$\tau_{cpc} = \rho^n \tag{6}$$

Cartesian coordinates are used in the equation of parabola (equ. 7) shown in Fig.1

$$y = \frac{x^2}{2b(1 + \sin\theta max)} \tag{7}$$

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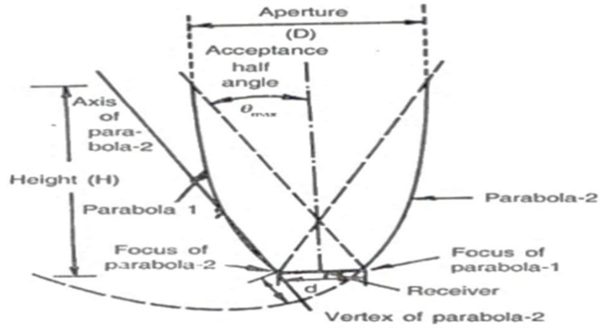


Fig: 1 Geometry of a compound parabolic Concentrator [10]

+

Aperture Area = W* L

Absorber Area = b * L

$$\text{Concentration Ratio } C = \frac{b}{w} \quad (8)$$

The reflector is constructed for a half acceptance angle of ($\theta_{max}$= 11.54°). The distance between MN and CD is the full height of the CPC, as in Fig (2). The absorber CD is flat plate type. Part of the solar radiation falls on the absorber directly while the other reaches the absorber via the reflector.

The second law of thermodynamics applies implies that for maximum possible concentration the concentration ratio should be given in terms of half acceptance angle as [8].

$$\text{Concentration Ratio (C)} = \frac{1}{\sin\theta_{max}} \quad (9)$$

The concentration ratio is also presented by $C = \frac{w}{b}$. It can be set $\frac{w}{b} = \left(\frac{1}{\sin\theta_{max}}\right)$ and that this concentration ratio is the maximum possible for the acceptance angle $2\theta_{max}$ [8].

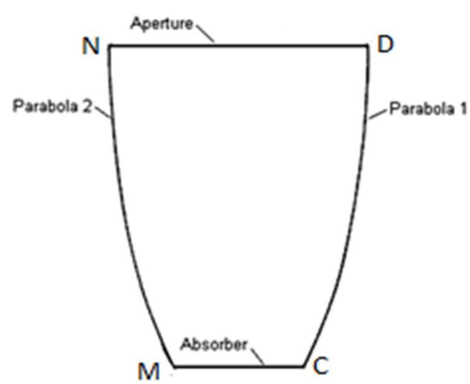


Fig: 2 2-D Compound Parabolic Concentrator [10]

Figure (2) illustrates the cross-section of compound parabolic concentrator with flat plate absorber. The full dimensions of two compound parabolic concentrators is shown in the fig. (3).The two dimension compound parabolic concentrator funnels the radiation from aperture cover to absorber. The focuses of parabolas 1and 2are at M and C respectively. Rabl [8] derived some general relations for full compound parabolic concentrator with flat absorber. Using the x-y coordinate systemshown in fig. 1 and by using the equation of parabola the profile of parabola 2 is determined. The height of Full CPC is given by

$$H = \frac{w}{2}\left(1 + \frac{1}{\sin\theta_{max}}\right)\cos\theta_{max} \quad (10)$$

The coordinates of point D: $x = b\cos\theta_{max}$, $y = b(1 - \sin\theta_{max})/2)$ .These coordinates of point D are used to draw a curve

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which represents the right hand parabola. The mirror image gives the left hand parabola, that results in two-dimensional compound parabolic concentrator. The upper part of the CPC can be removed (truncated) with little loss in performance [8].

The CPC is usually truncated by about 2/3 of its height to prevent interception of solar radiation by the upper part of the reflector. Cost of the truncated CPC is reduced without affecting its performance, with only a little loss in CR (Concentration Ratio). Also truncation reduces the shadowing effect. The modified CR is given by:

$$C = \frac{\text{Aperture width after truncation}}{\text{Width of the absorber}} \qquad (11)$$

Truncation is finished by drawing a flat line over the reflector at the chose stature (2/3 of the ascertained tallness). The truncation does not affect the acceptance angle. The benefit of this sort of CPC is that it doesn't require consistent following when arranged in the east – west direction. When concentration ratio is 2 to 10 small tilt adjustment times is required throughout the year.

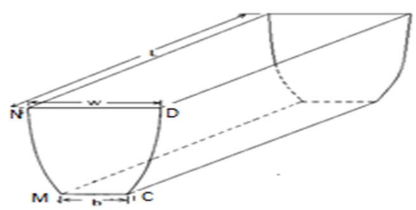


Fig: 3 2-D Compound Parabolic Concentrator [10]

The calculated dimensions of the CPC after truncation are shown below.
Height of CPC: 98 cm
Absorber width: 20 cm
Aperture width: 90 cm
Axial length: 250 cm
Concentration Ratio: 4.9

## III. RIG CONSTRUCTION

The reflector shape is drawn on a large size paper for full scale. Two stainless steel sheets of the required dimensions are used for two reflecting surfaces. Welding technique is used to fix absorber plate with reflector. The full scale drawing is used to fix the reflector profile (parabola).

In order to keep the aperture area constant the top distance between the two reflectors is kept constant by riveting these reflectors to the frame.

The temperature of the reflector surface is measured by a thermocouple. The aperture opening is closed by a 4 mm glass sheet. A serpentine copper tube of 28.7325 mm diameter is fixed on the mild steel plate. The collector is constructed so that it can be tilted by in any direction.

## IV. EXPERIMENTAL SETUP

The compound parabolic concentrator is then tested for several days in different months under outdoor conditions. Temperatures of absorber surface, aperture cover surface and reflectors are recorded. Also the solar radiation intensity is measured throughout the day. The experimental set up is shown in fig. (4).

Fig (4). The Experimental Rig

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Instruments used in this study:

*A.* Thermocouples Iron Constantine kind thermocouples are used to measure the temperatures of absorber, reflector surfaces, and surroundings.

*B.* Advanced Temperature Pointer is utilized to show the temperature (in degree centigrade) of the surface to which thermocouple is joined

*C.* Watch dog weather station is used to measure solar radiation intensity throughout the day.

## V. RESULTS AND DISCUSSION

As mentioned earlier temperatures of the effective surfaces are measured throughout the day. Table.1. shows the measured temperatures for the day 21$^{st}$ Aug 2016 as an example of measured data.

Table 1. Observation Table

| IST (Hours) | Intensity of Solar Radiation ($W/m^2$) | Glass Cover Temperature (°C) | Reflector Surface Temperature (°C) | Absorber Surface Temperature (°C) |
|---|---|---|---|---|
| 9 | 567 | 35 | 45 | 60.5 |
| 10 | 678 | 38 | 53 | 75 |
| 11 | 809 | 41 | 64 | 99 |
| 12 | 860 | 42 | 67 | 115 |
| 13 | 865 | 43 | 69 | 120 |
| 14 | 714 | 40 | 58 | 100 |
| 15 | 200 | 39 | 52 | 80 |

The table indicates that the radiation intensity is low during morning hours and reaches its maximum value at noon time. The aperture glass cover has high transitivity (0.92) so it transmits most radiation on to the reflector and the absorber plate surface. Both the reflector surfaces reflect the radiation on the absorber surface which has an absorptivity of (0.98) as indicated by the manufacturer. This means that most transmit radiation is absorbed by the absorber. Figs. (5, 6, 7) illustrate the variation of the solar radiation with daytime hours on 21st day of Aug., Sept. and Oct. These figures explain that the maximum radiation occurs at noon to afternoon at 13:00 PM. Figs also show that August has higher solar radiation than other two months because the solar declination angle decrease from 21-Aug. to 21-Oct. i.e. (11.754º, -0.2018º and -11.754º) respectively. Fig. (8) Shows the maximum absorber temperature variation in three months, i.e. (120°C, 95°C and 82°C). The figure shows that the maximum temperature occurs in August due to higher radiation. Fig. (9) illustrates the variation of absorber temperature with daytime's hours during the 21$^{st}$ day of each month (Aug. Sept and Oct).Figure also show maximum absorber temperature in August month because higher solar radiation than other two months. Fig. (10) shows the variation of temperatures for absorber, reflector and aperture cover surface during 21$^{st}$ of August.

The figure shows that the absorber temperature reaches its maximum value at about 13:00 PM. The absorber temperature peaks after the maximum radiation. It is obvious from these recorded temperature that there is a good feasibility of using solar energy in refrigeration absorption systems.

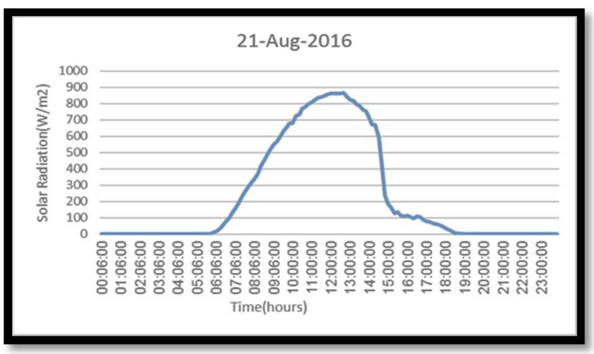
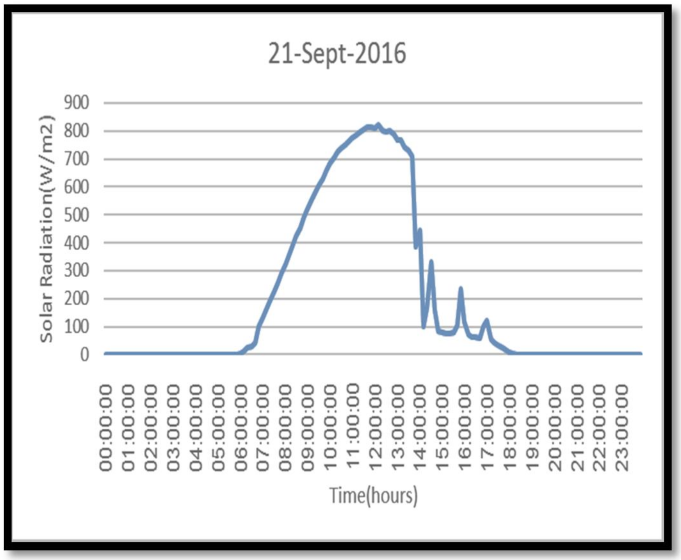



Fig. (5). Measured Hourly Solar radiation for the day21/8/2016



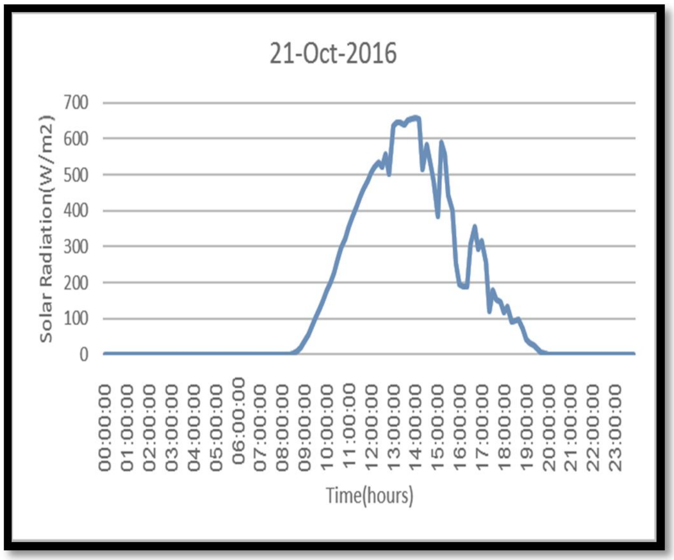




Fig. (6). Measured Hourly Solar radiation for the day21/9/2016 Fig. (7). Measured Hourly Solar radiation for the day21/10/2016

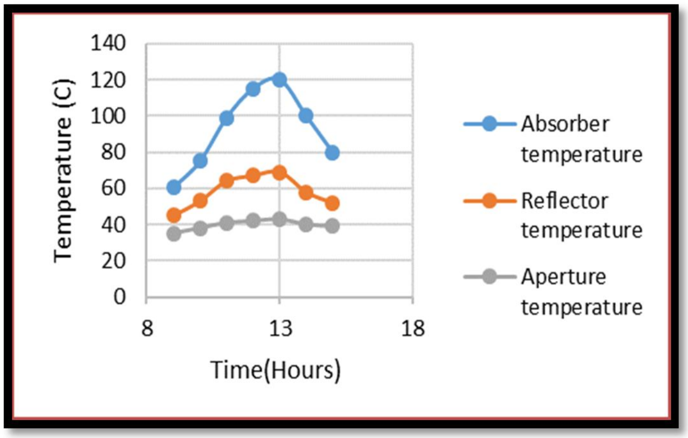



Fig. (8).Maximum absorber temperature in three months

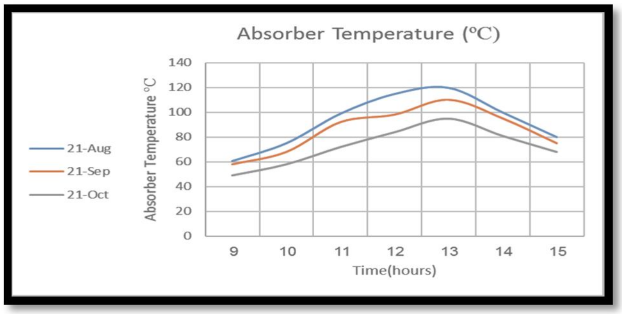



Fig. (9) Absorber temperature variation with time in three mouths (Aug., Sept., Oct.) on 21st day

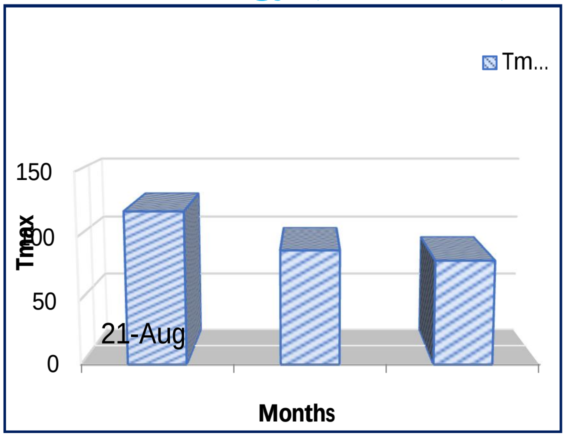



Fig. (10). Development of absorber, reflector and aperture cover surfaces temperatures with time (Aug) on 21st day

## VI. CONCLUSIONS

The following conclusion can be drawn from this study:

*A.* Higher solar radiation is recorded at noon to afternoon (about 13:00 PM).

*B.* Maximum absorber temperature is recorded in August month because of higher solar radiation than other two months (Sept. and Oct.) of (120°C, 95°C and 82°C) respectively.

*C.* Maximum reflector temperature and aperture cover surface temperature are recorded in August month of (69 °C and 43°C) respectively.

*D.* The absorber surface temperature peaks after the maximum solar radiation.

## REFERENCES

[1] H. P. Gary and J. Prakash "Solar Energy Fundamentals and Applications", New Delhi, www.Tata McGraw-Hill. Com, 2005.
[2] H. Tabor, Stationary mirror systems for solar collectors. Solar Energ 2, 27 (1958). H. Tabor, Mirror boosters for solar collectors. Solar Energy 10, 111 (1966).
[3] Winston, R., and Hinterbergerb, H., 1975, "Principles of Cylindrical Concentrators for Solar Energy," Sol. Energy, 17(4), pp. 255–258.
[4] F. Bloisi, D. Ruggi, 1986, "Ideal Concentrators with Polygonal Absorbers", revue Phys. Appl.21 (1986) pp. (163-167) Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/rphysap:01986002102016300.
[5] Abdul-Jabbar, N. K., and Salman, S. A., 1998, "Effect of Two-Axis Sun Tracking on the Performance of Compound Parabolic Concentrators," Energy Convers. Manage. 39(10), pp. 1073–1079.
[6] Norton B, Eames PC, Yadav YP and Griffiths PW, 1997, "Inverted Absorber solar Concentrators for Rural Applications". Ambient Energy, Vol. 18, No. 3, pp 115-120.
[7] Lixi Zhang, Chunlei Li, "The Research of Solar-heated Generation System Using CPC Collector", Proceedings of the International Multi Conference of Engineers and Computer Scientists 2008 Vol II IMECS 2008, 19-21 March, 2008, Hong Kong.
[8] Rabl A (1976b) optical and thermal properties of compound parabolic concentrators. Solar Energy 18: 497-511.
[9] R. Winston, "Principles of Solar Concentrator of a Novel Design", Solar Energy, Vol. 16, pp. 89-95, 1974.
[10] H. C. Hottel and B. B. Woertz, The performance of flat-plate solar-heat collectors. Trans. of A.S.M.E., 91 (February 1942).
[11] A.Rabl, Report SOL 75-03, Radiation transfer through specular passages (May 1975). Int. J. Heat Mass Transfer, to be published
[12] J. F. Kreider, Performance Study of the Compound Parabolic Concentrator Solar Collector. Environmental Consulting Services, Inc., Report (1974), contained in progress report NSF AER-75-OIO65/PR/75/4.