DESIGN, IMPLEMENTATION AND PERFORMANCE STUDY OF LOW COST CYLINDRICAL PARABOLIC CONCENTRATOR WITH FLAT HORIZONTAL ABSORBER

Md, Moqbull Hossen, Rajib Ahmed, Dr. Rezaul Karim Mazumder
Department of Applied Physics, Electronics & Communication Engineering, University of Dhaka,
Dhaka-1000, Bangladesh
moqbul_bco@yahoo.com, rajib.ahmed.apece@gmail.com, rkmeteulabd@yahoo.com

Abstract: A low cost cylindrical parabolic concentrator have been designed and implemented from locally available products. The performance comparisons between implemented cylindrical parabolic concentrator and Fresnel mirror concentrator have been done for both cloudy and bright sunny day with flat horizontal absorber. The flat horizontal absorber is mounted with a string of 15 modified grid finger mono crystalline silicon solar cells of size 4.9cm × 4.9cm. The performance of both concentrators is measured in terms of electrical efficiencies and fluctuation of local concentration distributions on a flat horizontal absorber. It has been found that for a bright sunny day the average electrical power output and efficiency of Cylindrical parabolic concentrator and Fresnel mirror concentrators are 21.3 W and 3.4%; 35.3 W and 4.5% respectively. For a semi cloudy day the average electrical power output and efficiency of both concentrators are 13.48 W and 2.7%; 23 W and 3.7% respectively. It has been also observed from the experiment that the local concentration distributions of Fresnel mirror concentrator fluctuated more than that of cylindrical parabolic concentrator. Overall, it has been observed that Fresnel mirror concentrator is more efficient than cylindrical parabolic concentrator.

Key words: Cylindrical Parabolic Concentrator, Fresnel Mirror Concentrator, Electrical Efficiency, Local Concentration, Flat Horizontal Absorber.

1. Introduction

Energy is the basic requirement of modern life-style. As a developing country, Bangladesh has been encountering difficulties in supplying energy to maintain its large population & economic growth. The current demand for energy (6000MW) exceeds the available resources (4500MW). Now, it is the time to think alternative energy source. Therefore, Renewable Energy can be alternative to the fossil fuel. Renewable Energy is clean, green, free, pollution less, endless energy source [1, 2].

Recently there has been growing concern about the shortage of fossil fuels. The present reserve of fossil fuels will be exhausted in near 25 years. In addition, environment changes should be concerned about which is caused by power generation using fossil fuels. Solar energy is the alternative to the fossil fuels and world's growing energy demand. On a typical land area of earth, approximately 1000 W/m^2 of energy photons is available. This energy can be converted into electrical power through solar cells. If intensity of radiation can be increased to the solar cell, the output current will be increased. The intensity of solar radiation to the solar cell can be increased by applying solar concentrator method. PV concentrating systems gain their advantage over flat plate systems from reduced area of PV cells required for a given output power. Research into concentrated photovoltaic has taken place from the 1970s until today. Sandia National Laboratories in Livermore, California was the site for most of the early work, with the first modern photovoltaic concentrating system. Their first system was a linear-trough concentrator system that used a point focus acrylic Fresnel lens focusing on water-cooled silicon cells and two axis tracking [3].

A cylindrical parabolic concentrator consists of a linear parabolic reflector that concentrates light into a receiver positioned along the reflectors focal line. This concentrated energy can be converted electrical power through solar cell. Cylindrical parabolic concentrator systems are the most developed concentrated solar power technology [4].

Fresnel mirror concentrator is made of many thin, flat mirror strips to concentrate light onto a receiver, positioned along the reflectors focal line. Flat mirrors allow more reflective surface in the same amount of space as a parabolic reflector, thus capturing more of the available sunlight, and they are much cheaper than cylindrical parabolic reflectors [5].

The purpose of the present work is to implement a low cost cylindrical parabolic concentrator from locally available products and finally make comparisons between the performance of cylindrical parabolic concentrator and Fresnel mirror concentrator.

2. Design and Construction

For designing a cylindrical parabolic concentrator as shown in Fig. 1, 55° rim angle and 1m aperture were assumed.

Then focus of the cylindrical parabolic was calculated as follows.

Equation for the aperture of the absorber is,

$$W_a = 4f \tan \frac{\varphi_r}{2} \quad (1)$$

In our experiment, and $W_a = 1m$;

Therefore, focus, $F = \dfrac{W_a}{4 \tan \frac{\varphi_r}{2}} = 48$ cm.

So the flat horizontal absorber was kept at the position of the focus. The magnitude of the rim angle determines the material required for the construction of the parabolic surface and refers to "(2)" this can be determined as follow:

$$S = \frac{H_p}{2}\{\sec\frac{\varphi_r}{2} \tan\frac{\varphi_r}{2} + \ln[\sec\frac{\varphi_r}{2} + \tan\frac{\varphi_r}{2}]\} \quad (2)$$

Where H_p = lactus rectum of the parabola (m).

The curve length of the reflective surface can be determined from the above equation and it is found 142 cm.

Fig. 2 shows the cross sectional geometry of a linear Fresnel reflector design. It consists of long narrow flat mirror elements of equal size, d, suitably mounted on a flat base, and a flat horizontal absorber. The tilt of each constituent mirror element is so adjusted that the incident radiation after reflection illuminates a common focus. The design strategy is such that a ray incident normally to the aperture plane and striking the midpoint of each mirror element reaches the point F after reflection.

In order to avoid blocking of radiation reflected from a particular mirror element by adjacent ones, a small gap called shift, is provided between them [6].

In this experiment mirror strips of width 5 cm were used to construct the Fresnel mirror reflector according to the design. The aperture area and focal height of this concentrator were 1.20 m and 1 m respectively. The gap between the mirror strips was 1 cm to avoid blocking of radiation reflected from a particular mirror by adjacent ones. On the other hand, a 5mm thick glass was cut to make 47 pieces of glass of equal size to construct the cylindrical parabolic concentrator. Each mirror strips had length, width and thickness of 80 cm, 3cm and 5m respectively. Normal glass of 60% reflectivity was used which was available in local market and the mirror strips are placed over a metal structure.

In addition, a flat horizontal absorber, shown in Fig. 3, was constructed at the Renewable Energy and Research Centre in University of Dhaka, according to the design shown in Fig. 4 which was used to measure the performance of the concentrator. The absorber was mounted with a string of 15 grid finger space modified solar cells of size 4.9 cm × 4.9 cm each. Copper was selected as absorber material for its high thermal conductivity and resistance to corrosion. Suitable mechanism was incorporated in the mounting structure of concentrator for placing the absorber at the focal height. To protect the solar cell from short circuit and loss of thermal energy the absorbers were covered with 3 mm thick glass sheet from all sides.
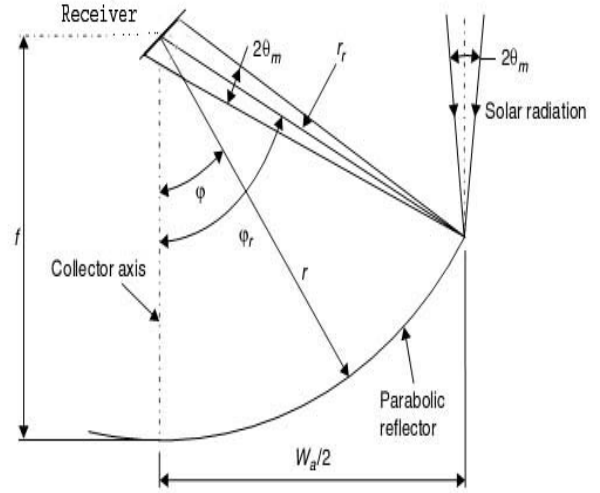

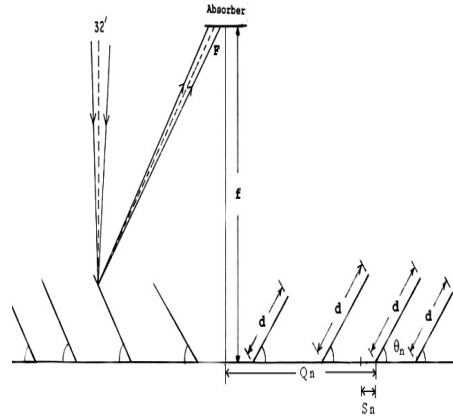Figure 1: Cross section of a cylindrical parabolic concentrator with flat horizontal receiver.

Figure 2: Linear Fresnel Reflector with flat horizontal receiver

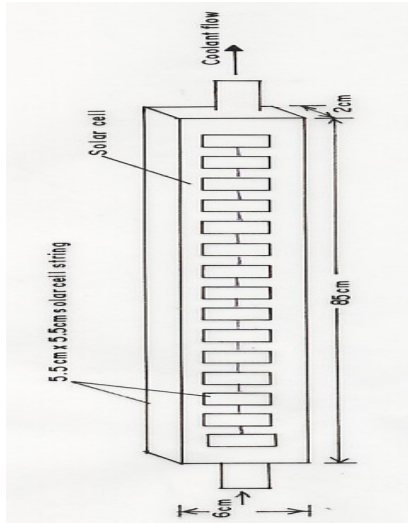Figure 3: Flat horizontal absorber mounted with 15 modified grid finger solar cells

Figure 4: Design of the flat horizontal modified absorber mounted with grid finger solar cells

Figure 5: Cylindrical parabolic concentrator with flat horizontal absorber mounted with modified grid finger solar cells

3. Experimental Setup

Figure 5 shows the experimental setup for cylindrical parabolic cencentator with flat horizontal modified absorber with modified grid finger solar cell at at the Renewable Energy and Research Centre in University of Dhaka.

A reference solar cell of size 1cm×1cm is used to measure the distributions of local concentration ratio (LCR) and concentration ratio (C) on the surfaces of the absorbers. The absorber surfaces were divided into small segments equivalent to the size of the solar cell to be experimented in the study.

The average amount of current obtained by the single reference cell all over the absorber surface due to the concentrated illumination divided by the average current obtained at aperture area of the concentrator for input solar irradiance gives the concentration ratio (C) of the concentrator system. The current obtained at each small segments of absorber surface due to the concentrated beam of light gives the LCR distributions of the concentrator system.

The variation of the current obtained over the every small segments of absorber surface gives the percentage deviation of LCR distributions over the flat horizontal absorber surfaces [7]. To measure the electrical power output from the concentrators, the flat horizontal absorber mounted with a string of 15 modified grid finger mono crystalline solar cells is set up exactly at the focal point [8]. Aperture area of the concentrator multiplied by available input irradiance gives the instant value of input power in W. The output electrical power obtained from the absorbers were taken separately as voltage and current at a regular interval of 30 minutes by a digital multi-meter from 9 am to 4 pm for both semi cloudy day and bright sunny day.

4. Result and Discussion

It was observed that the average distribution of LCR was 7 for cylindrical parabolic concentrator and 12 for Fresnel mirror concentrator on the flat horizontal absorbers in a bright sunny day. Fig. 6 and Fig. 7 present the local concentration ratio distributions over the absorber surfaces. In this experiment the aperture area for Cylindrical and Fresnel mirror concentrator were 0.8 m^2 and 1 m^2 respectively. It was observed that the short circuit current generation by the reference solar cell of size 1cm×1cm at the apertures of both concentrators was 20 mA for a sunny day and it was nearly equivalent to 940 W/m^2 of input incident solar radiation to the aperture from the value of pyranometer. It was measured that the average short circuit current obtained from small segments of the absorber surface from the reference solar cell were 140 mA and 240 mA for Cylindrical & Fresnel concentrator respectively. These values in mili-amperes are equivalent to 6580 W/m^2 and 11280 W/m^2 due to the concentrated beam of lights to the flat horizontal absorber surface in a bright sunny day which was shown in Fig. 6 and Fig. 7. It was observed from the measured data that the local concentration distributions were varied from 0.48% to 3.6% over the flat horizontal absorber surface for cylindrical parabolic concentrator and 1 % to 4.5% for Fresnel mirror concentrator.

Fig. 8 illustrates the comparison of local concentration distributions between the two concentrators in a bright sunny day. It can be concluded form the results that the Fresnel mirror concentrator showed more fluctuation of local concentration distribution than that of cylindrical parabolic concentrator. The fluctuation was due to [8]:

1. The losses at the gaps of the mirror strips of Fresnel mirror concentrator.

2. The distance from the focal height to each mirror strips is not equal and the distances increase from middle mirror strips to the boundary strips.

3. It is difficult to track the each mirror strips perfectly to the sun.

But the concentration ratio of the Fresnel mirror concentrator is greater than that of cylindrical parabolic concentrator. Though there were a number of fluctuations of local concentration distributions were observed for both concentrators over the flat horizontal absorber of size 7 cm × 80 cm area, the overall distributions were found to be symmetric for both concentrators and without any sharp fall which might be a threatening illumination level to become a cause of hot spot for solar cell [9].
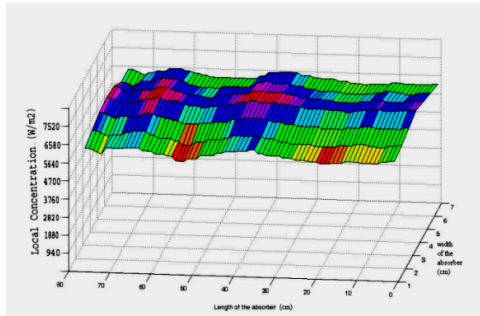

Figure 6: Local concentration distributions on the flat horizontal absorber of cylindrical parabolic concentrator (Aperture area 0.8 m^2) in a sunny day.
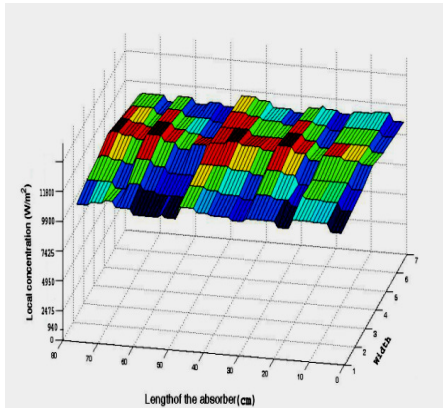

Figure 7: Local concentration distributions on the flat horizontal absorber of Fresnel mirror concentrator (Aperture area 1 m^2) in a sunny day.
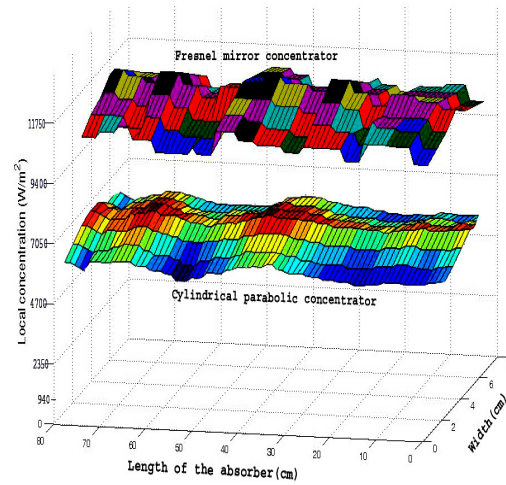

Figure 8: Comparison of Local concentration distribution on the flat horizontal absorber between Fresnel mirror concentrator and cylindrical parabolic concentrator in a sunny day.

Fig. 9 and Fig. 10 show the graphical representations of input power and output power produced by the two concentrators for a bright sunny day. Fig. 11 and Fig. 12 show the graphical representation of input power and output power produced by the two concentrators for a semi cloudy day. The average of the input power and the output power generation from 9 pm to 4 pm of a day for the two systems were computed for the comparison. It was found that the solar cells with 1.2 mm spacing have generated average electrical power 21.3 W for average input power 628 W for Cylindrical parabolic concentrator in a bright sunny day. So the average electrical efficiency of cylindrical parabolic concentrator is 3.4%. The Fresnel mirror concentrator has generated average electrical power 35.3 W for average input power 786.57 W in a bright sunny day. So its average electrical efficiency is 4.5%. It was observed from this result that the efficiency of Fresnel mirror concentrator is 1.1% greater than the cylindrical parabolic concentrator's efficiency. For a semi cloudy day the average electrical power output and efficiency of cylindrical parabolic concentrator and Fresnel mirror concentrators are 13.48W and 2.7%; 23W and 3.7% respectively which were portrayed in Fig. 10 and Fig. 12.

Fig. 13 and Fig. 14 exhibit the comparison of electrical efficiency between two concentrators, which show that the electrical efficiency of Fresnel mirror concentrator is greater than that of cylindrical parabolic concentrator. Electrical efficiency found in this research has been summarized in Table 1 and Table 2.
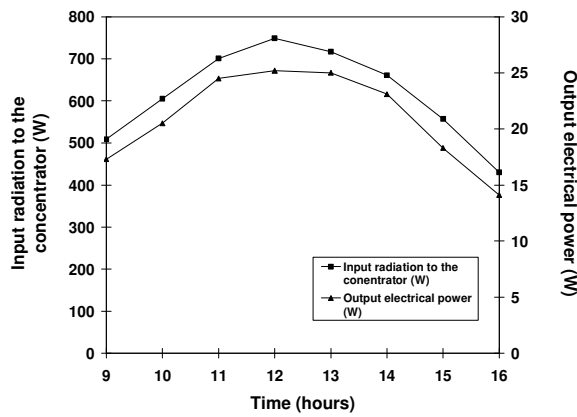
Figure 9: Cylindrical parabolic concentrator with flat horizontal absorber mounted with modified grid finger solar cells
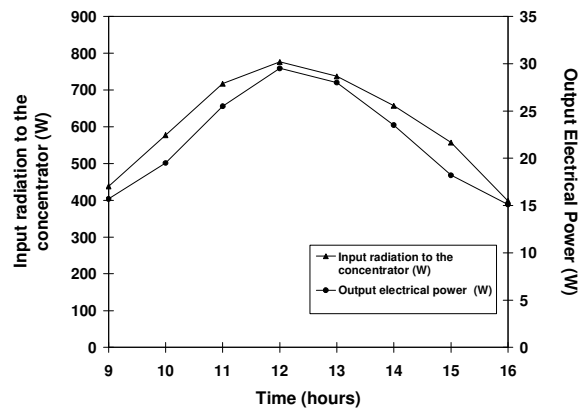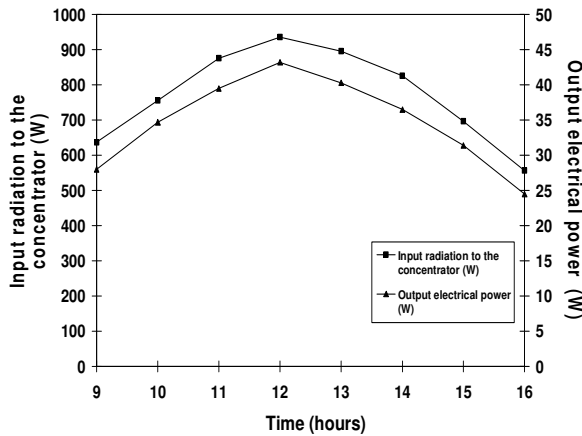

Figure 10: Incident radiation with time and corresponding electrical output of the Fresnel mirror concentrator in a bright sunny day.

Figure 11: Incident radiation with time and corresponding electrical output of the cylindrical parabolic concentrator in a semi-cloudy day.

Figure 12: Incident radiation with time and corresponding electrical output of the Fresnel mirror concentrator in a semi cloudy day.
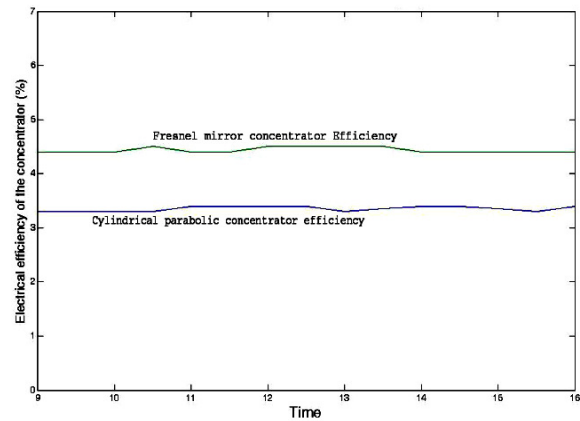

Figure 13: Comparison of electrical efficiency between Fresnel mirror concentrator and cylindrical parabolic concentrator in a bright sunny day.
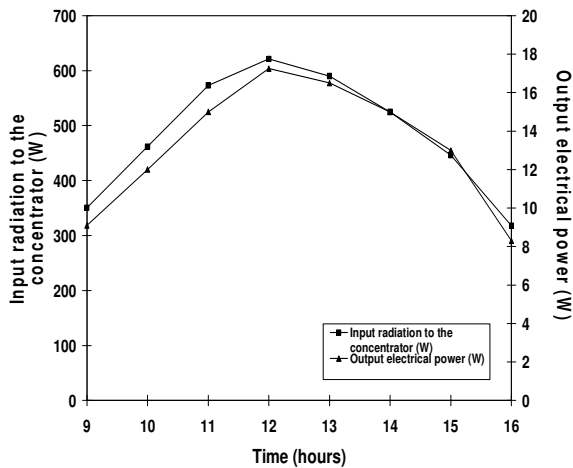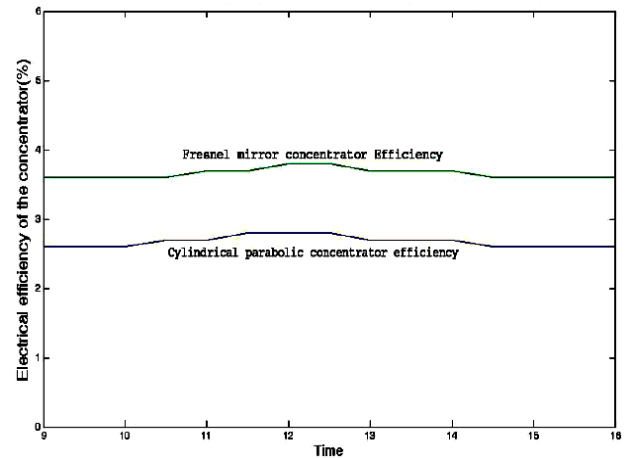

Figure 14: Comparison of electrical efficiency between Fresnel mirror concentrator and cylindrical parabolic concentrator in a semi-cloudy day.

Table 1: Average electrical power generations and conversion efficiencies of both concentrators in a bright sunny day.

Types of concentrator	Types of absorber	Average input power (sunny day) (W)	Output power (W)	Electrical Efficiency (%)
Cylindrical parabolic concentrator	Flat horizontal absorber	628	21.3	3.4
Fresnel mirror concentrator	Flat horizontal absorber	786.5	35.3	4.5

Table 2: Average electrical power generations and conversion efficiencies of both Concentrators in a semi cloudy day.

Types of concentrator	Types of absorber	Average input power (sunny day) (W)	Output power (W)	Electrical efficiency (%)
Cylindrical parabolic concentrator	Flat horizontal absorber	497	13.48	2.7
Fresnel mirror concentrator	Flat horizontal absorber	622	23	3.7

5. Conclusion

From this experiment, it can be concluded that the fluctuations of local concentration distribution of Fresnel mirror concentrator on a flat horizontal absorber was greater than that of cylindrical parabolic concentrator but there was no sharp fall which might be a threatening illumination level to become a cause of hot spot for solar cell.

The outcome of the present research signifies that for both sunny and semi cloudy day the electrical efficiency of Fresnel mirror concentrator is greater than that of the cylindrical parabolic concentrator.

References

[1] Duffe J.A, Beckman W. A.,*" Solar Engineering of Thermal Processes"*, New York: John Willey and Sons, 1980.

[2] http://www.usaid.gov/bd/programs/energy_response.html#more

[3] J. A. Duffie and Beckman, Solar Engineering of Thermal Processes, 3rd ed., New York: John Wiley and Sons, 1991, pp.330-340.

[4] R. N. Singh, S. S. Mathur, and T. C. Kanpal, "Concentration characteristics of cylindrical parabolic concentrators," Applied Energy, Vol. 6, pp. 315-32, 1980.

[5] A. K. Singhal, M. S. Sharma and B. S. Negi, "Performance testing of a linear Fresnel reflector", International Journal of Energy Research, Wiley online library, Vol. 10, pp. 39–46, January 1986.

[6] S. Kalogirou, Solar energy engineering: processes and systems, 1st ed., California: Elsevier Inc., 2009, pp.270-280.

[7] S. Haque, "Small scale periodically repositioned concentrator photovoltaic pumping system for rural application," Dhaka University Journal of Science, Vol. 51, pp. 120-130, July 2004.

[8] J. S. Coventry, "Performance of a concentrating photovoltaic/thermal solar collector," Solar Energy, Vol. 78, issue-2, pp. 211-222, February 2005.

[9] N. Velazquez, O. W. Valladares, D. Sauceda and R. Beltran, "Numerical simulation of a linear Fresnal Reflector concentrator used as direct generation in a solar-GaX cycle," Energy conversion and management, Vol. 51, issue-3, pp. 434-445, March 2010.

[10] A. F. Garsia, E. Zarza, L. Valenzuela and M. Perez, "Parabolic trough solar collectors and their applications," Journal of Renewble and Sustainable Energy Reviews, Vol. 14, issue-7, pp. 1695-1721, September 2010.