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Design and Evaluation of Polygonal Trough Solar Concentrator

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Abstract

In this paper, a solar concentrator is designed in the form of a concave half-cylindrical mirror consisting of polygonal reflective surface plates. The plates are arranged to give a hemispherical shape to the design. These surfaces work to receive solar radiation and focusing by reflecting it to the receiver that is placed in front of the reflecting surfaces. The results are compared with a system consisting of a concave reflecting surface of the same dimensions to obtain a good criterion for evaluating the design performance. The results showed a low acceptance angle for the design for all the samples used due to the geometrical design nature. The optical efficiency affected by the angle of incidence greatly by all the samples used, which differ in the concentration ratio, width and location of the receiver.

Keywords: Solar Concentrator, polygonal trough, incidence Angle, Zemax, Concentration ratio

1.Introduction

The idea of using solar concentrators is very vital in our time, because of the necessity to use renewable energy sources that are alternative to traditional sources,and reduce the effects of using fossil fuels from pollution and global warming. Therefore, solar energy is very important at this time, especially with the development of technologies contribute to the development of tools used in this field.

Solar concentrators are very important in increasing the efficiency of solar systems by increasing the amount of radiation received and reducing the effective area in proportion to the size of the solar system used. The idea of using reflective mirrors came as an effective tool for directing and focusing solar rays of all kinds (spherical, aspherical and plane) [1].

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The use of a reflective polygon surface that forms a concave surface is characterized by ease of design and manufacture. Where possible to replace the curved surface which is difficult industrially. And the replacement of the reflective rectangular panels that combine with each other. In the form of a curved surface, that reflects the light to a specific point (the focus). These panels shall be affixed together with special glue or fixed with a metal backing to take the desired shape.

This design is characterized by a rectangular shape placed in a place that allows receiving the largest possible amount of solar radiation during daylight hours. The design does not require a solar tracker because it is designed to receive and reflect an appropriate amount of solar radiation with a relatively large acceptance angle. This means obtaining relatively large optical efficiency over a wide range of solar incidence on the design [2].

Many studies have generally dealt with solar concentrators and with reflective trough concentrators in particular because of the importance of the topic in the field of solar energy exploitation. A numerical model based on Finite Volume Method (FVM) balance is presented to predict the thermal behavior of a parabolic trough solar collector used for hot water and steam generation. The realistic non-uniform solar flux is calculated in a pre-processing

Task and inserted into the general sample. A numerical-geometrical method based on ray trace and FVM techniques is usedto determine the solar flux distribution around the absorber tube with high accuracy [3].

S. Yanget al. present a dynamic three-dimensional volume element model of a parabolic trough solar collector coupled to an existing semi-finite optical model for simulation and optimization. The spatial domain in the volume element model is discretized with lumped control volumes (i.e., volume elements) in cylindrical coordinates according to the predefined collector geometry. Therefore, the spatial dependency of the model is therefore taken into account without the need to solve partial differential equations[4].

The mathematical model of a parabolic trough collector (PTC) is described in details and tested by comparing the efficiency predicted by the model with the efficiency measured through outdoor tests on a PTC prototype. The model accounts for optical and thermal losses, thus allowing the calculation of optical, thermal, global efficiencies and all working parameters such as temperatures or heat fluxes on all parts of the receiver. The model is presented in details and its implementation in a specific ambient for technical computation is also described [5].

The transparent DAPTSC is improved by applying reflective coating on the upper half of the inner tube outer surface. The optical path length is doubled compared to the transparent DAPTSC; thus, the absorption coefficient of the nano fluids can be reduced accordingly. The coated DAPTSC has an obvious advantage compared to the transparent DAPTSC at an absorption coefficient below 0.5 cm^{-1} for a receiver with inner tube diameter of 7 cm [6].

2.Optical design

The design consists of five reflective panels stacked together to form a curvedconcave rectangular surface. The solar radiation is reflected back to the receiver that is placed in front of the reflecting surface. The receiver consists of a hollow metal tube that contains a liquid with high thermal conductivity (for example, brine). The brine transfers the heat to a thermal

warehouse to be used for the purpose for which the model is designed. The one reflecting plate has dimensions (20 x 500 mm), and it connects with other panels to form a solar concentrator with dimensions (100 x 500 mm) shown in **Figure (1).**
Zemax software program was used in designing the model. It has multiple tools for evaluating design performance, as well as has high design flexibility. An optical detector is used in the program instead of the receiver that has the ability to sense all the rays incident on it.

The model was designed without a solar tracking system because it was designed to receive an appropriate amount of radiation from the sun over daylight hours and with a relatively large angle of acceptance. The reason for this characteristic is due to the geometric shape of the design, which has a large radiation receiving capacity.

There is a set of visual parameters in this model that influence its performance. It was used in this research to evaluate the performance of the model by calculating its visual efficiency with the change of these parameters. These parameters are acceptance angle, concentration ratio, and receiver width.

1- Concentration ratio (Cr)

The concentration ratio in this model depends on the dimensions of the reflecting panels aligned to form the solar center, and on the surface area of the recipient. The concentration ratio represents the ratio between the area of the input hole (the area of the reflective surface) and the area of the output hole (the area of the recipient). This ratio can be changed by changing the recipient surface area and keeping the reflective surface area constant. The mathematical formula for this relationship is [7]:

$$Cr = \frac{A\alpha}{Ar} \qquad (1)$$

Where Aα is the area of the input aperture, and Ar the area of the output aperture.This relationship can be represented by another mathematical formula in terms of the edge angle and acceptance angle, as in Equation (2) [8].

$$Cr = \frac{\sin\emptyset r}{\pi \sin\theta\alpha} \qquad (2)$$

Where ϕr represents the edge angle and θα is half of the acceptance angle.

2-Acceptance angle (2θα)

The acceptance angle is the maximum incidence angle that gives an optical efficiency of (80%) in the solar system, regardless of the type of this system. Therefore, the acceptance angle varies according to the design. Designs that have a relatively large acceptance angle do not need a solar tracking system due to the wide field of receiving solar radiation throughout the day. While the other type of designs that have a relatively small acceptance angle, they need a solar reception system due to their limited work in a small field of receiving solar radiation during the daytime period.[9].

3.Results

The results show a variation in the values of optical efficiency when the design parameters changed, and this indicates its role in affecting the efficiency of the system performance. Optical efficiency curves were used with varying angle of incidence for all results, because the angle of incidence is what determines the efficiency of the system for solar concentrators that operate on the basis of receiving solar radiation.

Figure (2) shows the optical efficiency when the angle of incidence changes for different concentration ratio. The figure shows the decrease in the optical efficiency values when increasing the angle of incidence for all samples. So its highest value is at efficiency (37%) for the sample that has a concentration ratio (C=5). The rest of the samples are followed by a obevios digredation of efficiency values.

Figure (3) shows the change of optical efficiency with the angle of incidence for different samples in the width of the receiversurface, which represents the area of the receiving surface of the rays after reflected from the sample. The figure shows the preference of the sample that has the largest surface area for the receiver. This behavior of the function is due to the increase in the receiving area of the beams on the detector when the width of the receiver is increased.

The change in the position of the receivergreatly affects the amount of radiation received after being reflected by the concentrator, thus affecting the optical efficiency. **Figure (4)** shows the change in optical efficiency with the change of the incidence angle for different samples at the receiversite. If the position of the receiverchanges towards the optical axis, that is, the receiver's movement is near or far from the reflecting surface. Notice that in **Figure (3)** the preference of the sample that has a receiverposition equal to (100 mm) far from the reflecting surface. The efficiency gradually decreases as the receiversite gradually approaches the reflecting surface. This is a result of the concentration of most of the reflected rays at the site (100), because they are close to the focus of the curved surface.

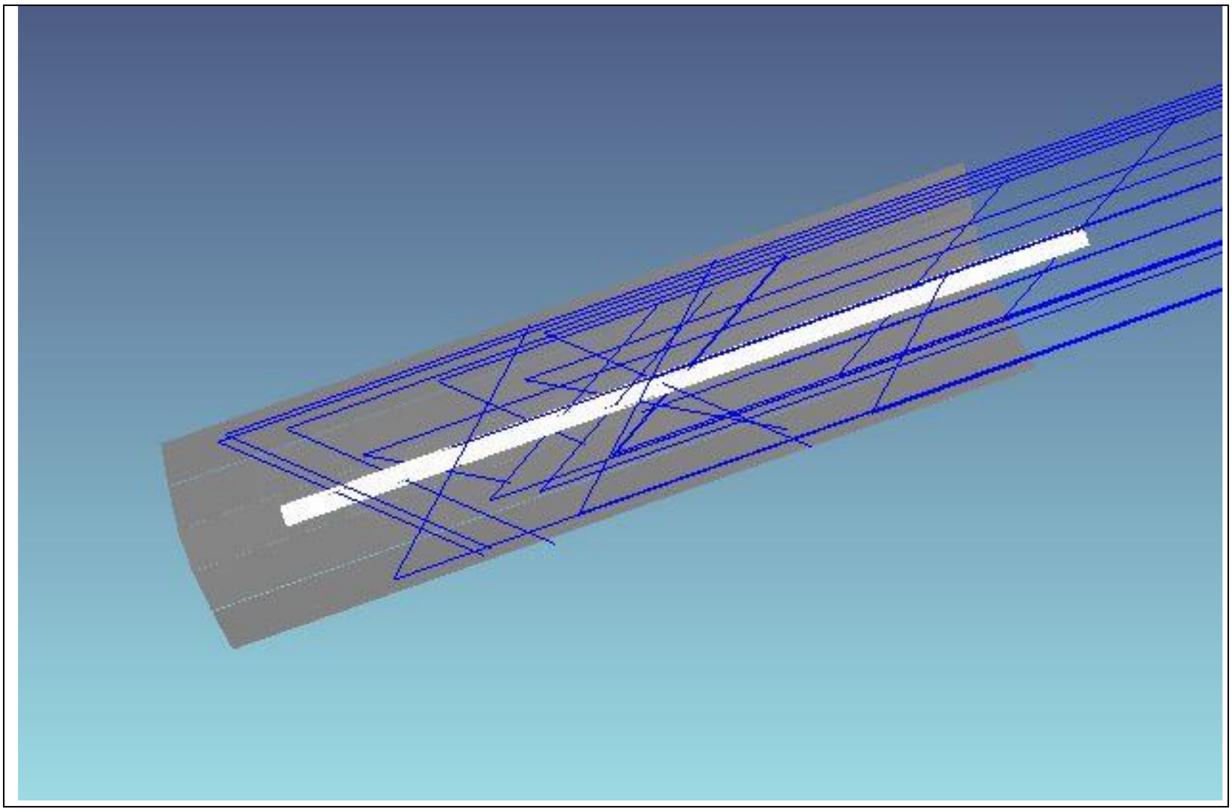

Figure 1. 3-D layout of polygonal trough solar concentrator that designed by Zemax

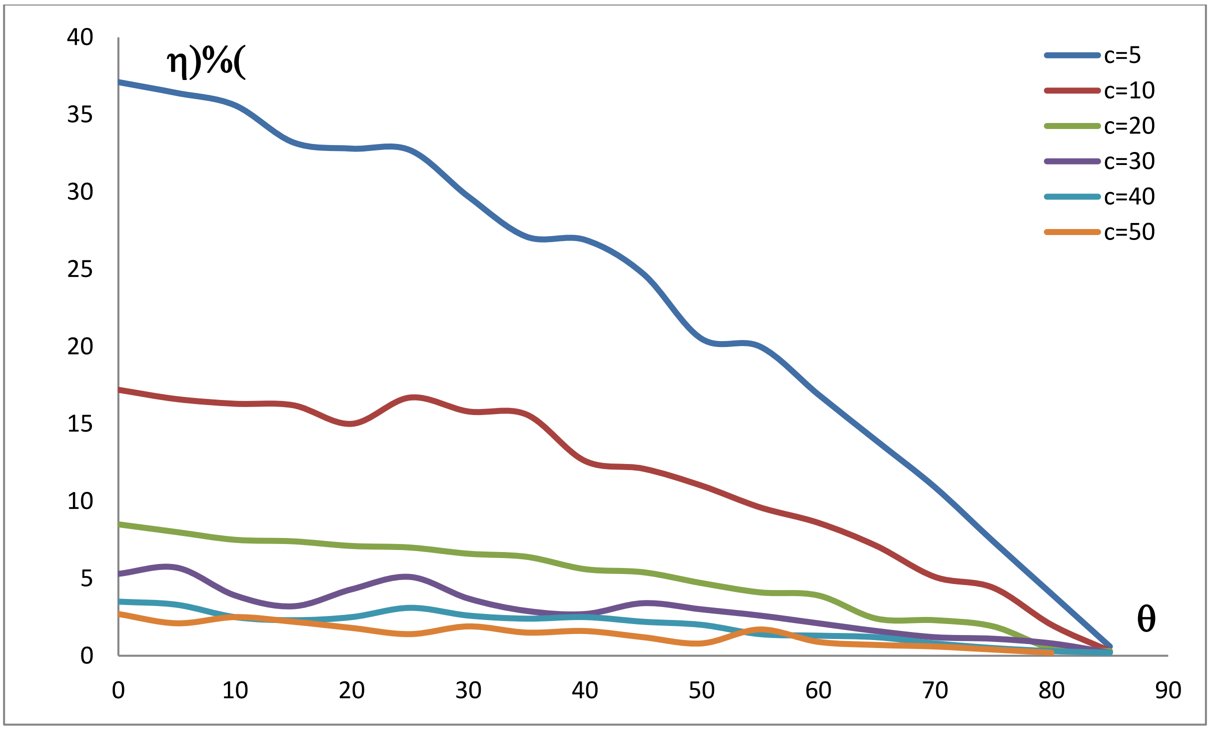

Figure 2. The optical efficiency changing with the incidence angle of different concentration ratio of polygonal trough solar concentrator

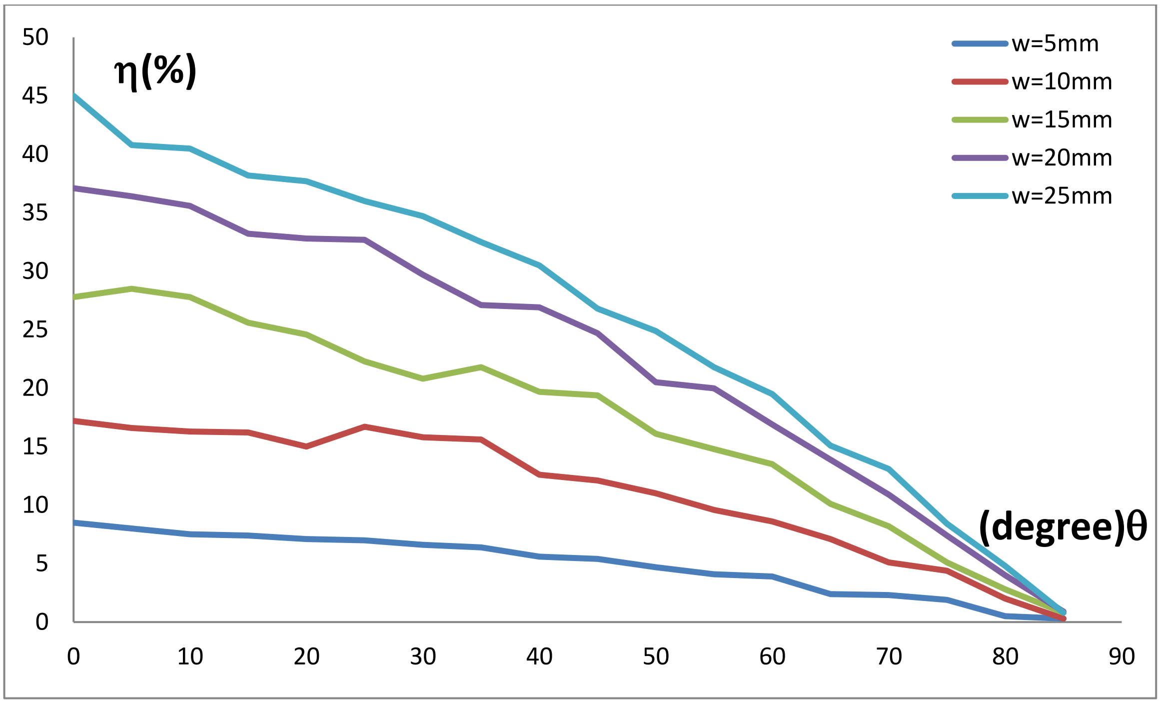

Figure 3. The optical efficiency changing with the incidence angle of different reciever width of polygonal trough solar concentrator

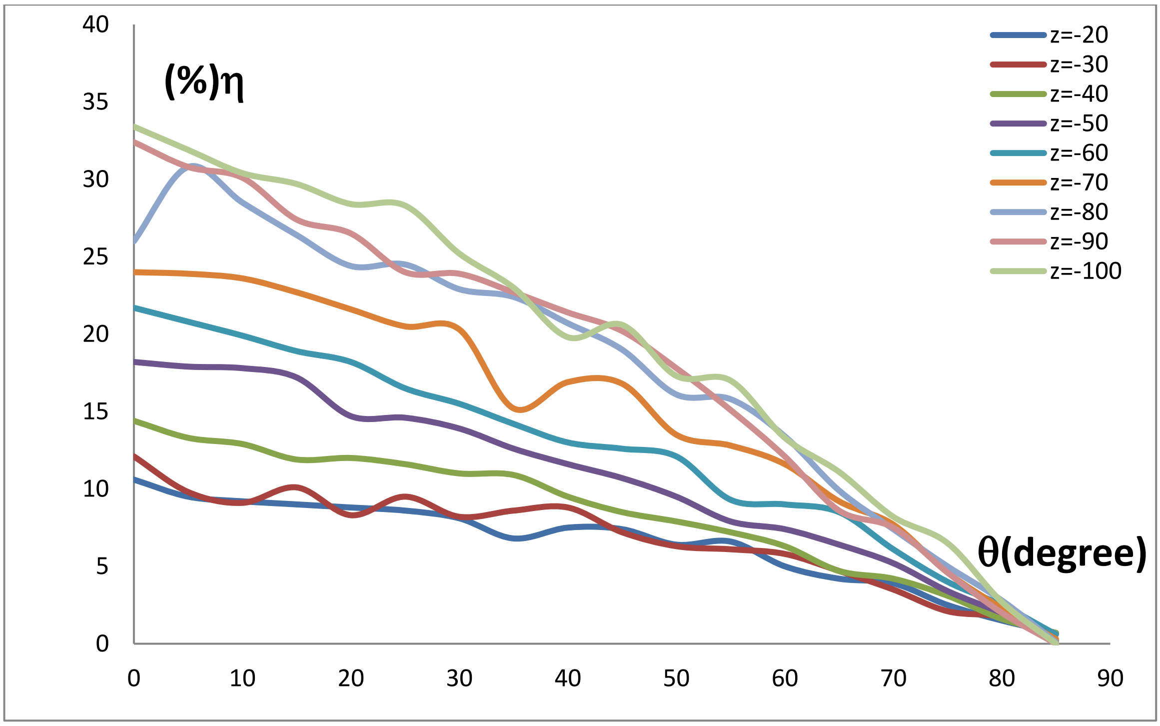

Figure 4. The optical efficiency changing with the incidence angle of different reciever position of polygonal trough solar concentrator

4.Conclusion

The design of the polygon trough solar concentrator gives relatively low efficiency due to the nature of the geometric design that scattered rays after reflection. That is, they do not focus in one location, such as curved surfaces. Despite that, the study showed the preference of the design that has a lower concentration ratio, and the reciever that has a larger width, as well as the ideal location for the recieverat a distance of (100 mm) from the reflective surface. The design is greatly affected by the angle of incidence, so the greater the angle of incidence, the lower the optical efficiency. In general, the design has an acceptance angle of less than (40^o) for all samples used.

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