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Efficiency Evaluation of Solar Concentrator without Tracking System Type of Compound Parabolic Concentrator (CPC)

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Abstract

It is useful to analyze any optical system theoretically before proceeding with its design in order to ensure the effectiveness of the design through computer simulations that are important and useful in designs for the ability to predict the performance of solar concentrator under any conditions. For this design, non-sequential ray tracing mode wasused in the Zimax program with a light source that simulated solar radiation. The purpose of the design of a compound parabolic concentrator (CPC) is to take advantage of the solar radiation that falls on it without the need for an efficiently tracked system within certain limits of the angle of solar radiation fall known as the acceptance angle. That is, obtaining the largest possible number of rays received inside the CPC through reflections in the inner walls of it, which give a large amount of thermal energy to the surface of the recipient, which in turn gets this energy to be used to create electrical energy. The efficiency of receiving reflected solar radiation in this type of concentrator is great compared to other solar concentrators.

Simulated design of solar reflector concentrator has been presented. The concentrator is a type of compound parabolic concentrator (CPC) involved of internal reflector surface (Hollow and within Poly methyl methacrylate (PMMA) polymer material) without tracking system. CPC has the property to overcome problems result from variation of incidence angle of the sun during daytime. Because the tracking system expensive and has technical problems. The efficiency of CPC has been obtained by using Zemax optical design program, for different designs has concentration ratio(c=1,2,3,4,5). That is, the ratio of the output aperture to the input aperture. Taking into account the angle of acceptance that plays a major role in the form of design and its efficiency the results are shown when designing the model with radial aperture of (50mm) and length of (500mm).The design of concentrations ratio is depends on the acceptance angle.

c=5 at normal incident angle (ϴ=0). And it is almost similar if the material is used PMMA within CPC, and degradation of efficiency with increasing the incidence angle.

Keywords: Zemax, solar concentrator, compound parabolic concentrator,acceptance angle, PMMA.

1.Introduction

Energy is a cornerstone of economic construction for all countries, especially industrial field, as the amount of energy consumption has become an indicator of the progress of these countries[1]. The solar concentrators receive the solar rays that fall on it through a large area (entrance aperture) to small active area(exit aperture) (figure 1), where they are focused by lenses or mirrors . Its leads to increase the efficiency that is represents the ratio between the two areas which called the concentration ratio [2].

The material used to fabricate the concentrator varies depending on the usage. For solar thermal concentration, most of the concentrators are made from mirrors; the concentrator is made either of glass or transparent plastic.

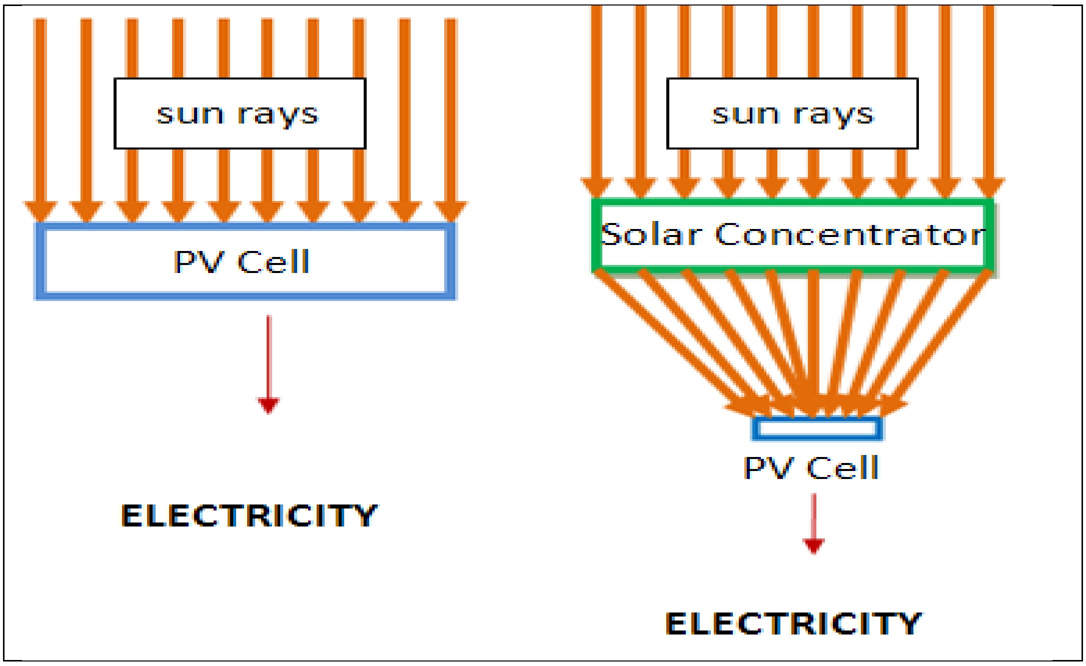

Figure 1: Generating electricity from the sun, with and without a solar concentrator

There are some distinct designs of solar concentrators that have shown importance Contribution to solar energy [3].

The most novel design of solar concentrators is the compound parabolic concentrators (CPC)divided into two types namely: 2-dimensionaland 3-dimensional configuration [4].

The efficiency of acceptance of diffuse radiation in this type is the greatest compared to other solar concentrates(CPC) which is a non-imaging concentrator and that which consists of two parabolas. And one absorber the geometry of the CPC profile depends on the shape of the receiver selected in the current study, (three-dimensional (3D) CPC) [5].

The design of CPC is completely defined with the output radius aperture *a'* and the acceptance of half angle $\theta_i$and it offers the maximum theoretical concentration c. if *a* is the input radius aperture, then:

$$c = \frac{a}{a'} = \frac{n}{sin\theta_i} \quad (2D\ CPC)$$

$$c = \frac{a}{a'} = \frac{n^2}{sin\theta_i^2} (3D\ CPC)$$

$$L = \frac{a'(1+sin\theta_i)cos\theta_i}{sin^2\theta_i} [6]$$

Where n the refractive index of surround area inside the CPC, and L the length of CPC. The importance of relation between acceptance angle and concentration ration of CPC is determined by geometrical design that leads to the amount of efficiency. This relation is illustrated in **Figure (2)** that is shows the directional proportion between acceptance angle and concentration ratio**.**

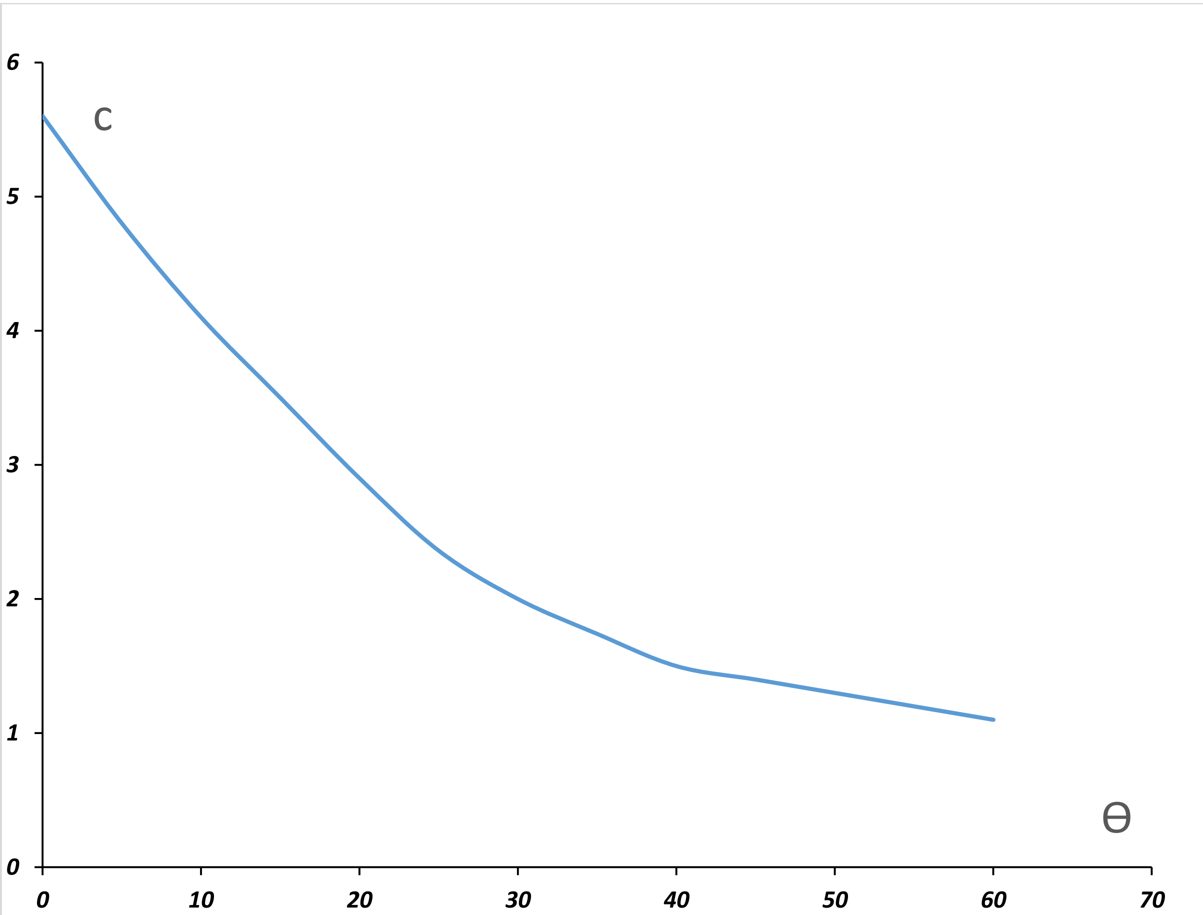

Figure2:Variation of concentration ratio with the acceptance angle

There are many works that are related to solar concentrators, especially with designing CPC. Giovanni Casano et. al. are Design and develop of building a prototype for the CPC, and the immediate efficacy of the model was measured where it was tested when performing an outdoor steady state experiment [7].

Evangelos Bellos et.al. investigate the ability to improve and compare the twoStationary CPC, where they used one reflector and the other two inverters, and found that the performance of a single reflector better than double but double is better in producing heat for all months of the year[8].

Sainath A. Waghm is studies conducted on the effect of the difference in the solar acceptance angle and the shape of the absorbed part on the amount of concentration, where it is noticeable that the increase in the acceptance angle caused a decrease in focus, and led to a decrease in the efficiency of CPC [9].

2.Optical Design

CPC are nonimaging concentrators. They have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a trough with sections of a parabola facing. CPC has circular aperture and rounded walls to achieve a symmetrical collection of solar radiations.

There are different designs for solar concentrators that generally differ in terms of fixation, freedom of movement, the shape of the receiver, and the reflective surfaces used.The adaptive (CPC) has been designed byusing Zemax optical design programas shown **Figure (3)**

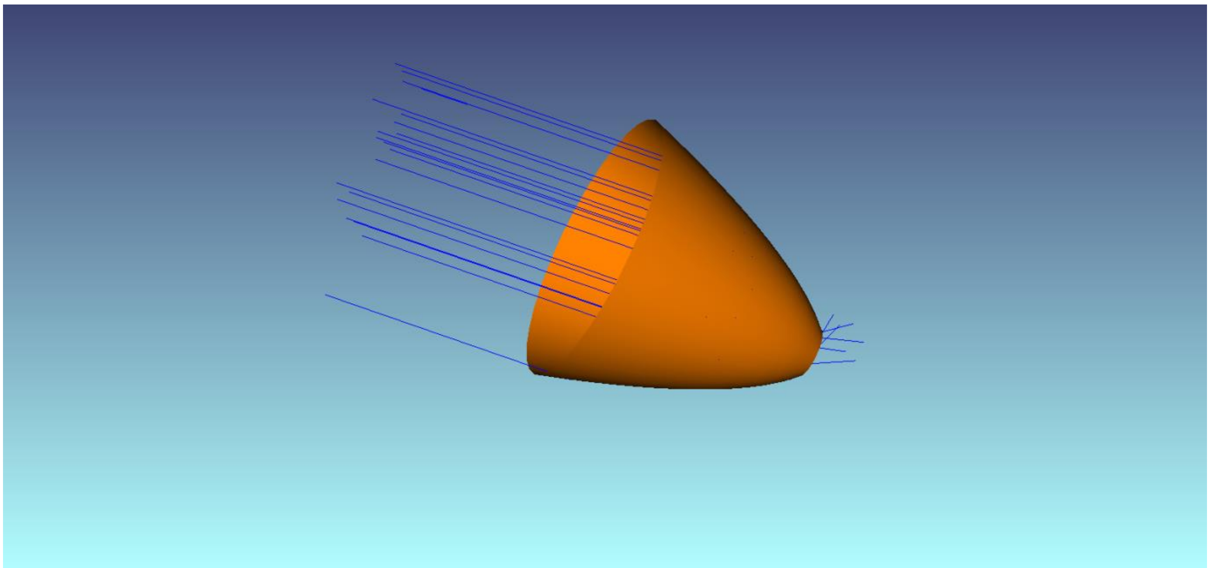

Figure3: layout of CPCdesign by zemax program

The three-dimensional shape of design showing the shape of the solar center consists of a source and an opening aperture and a detector to measure the efficiency, which requires that its shape be similar to the shape of the entrance aperture

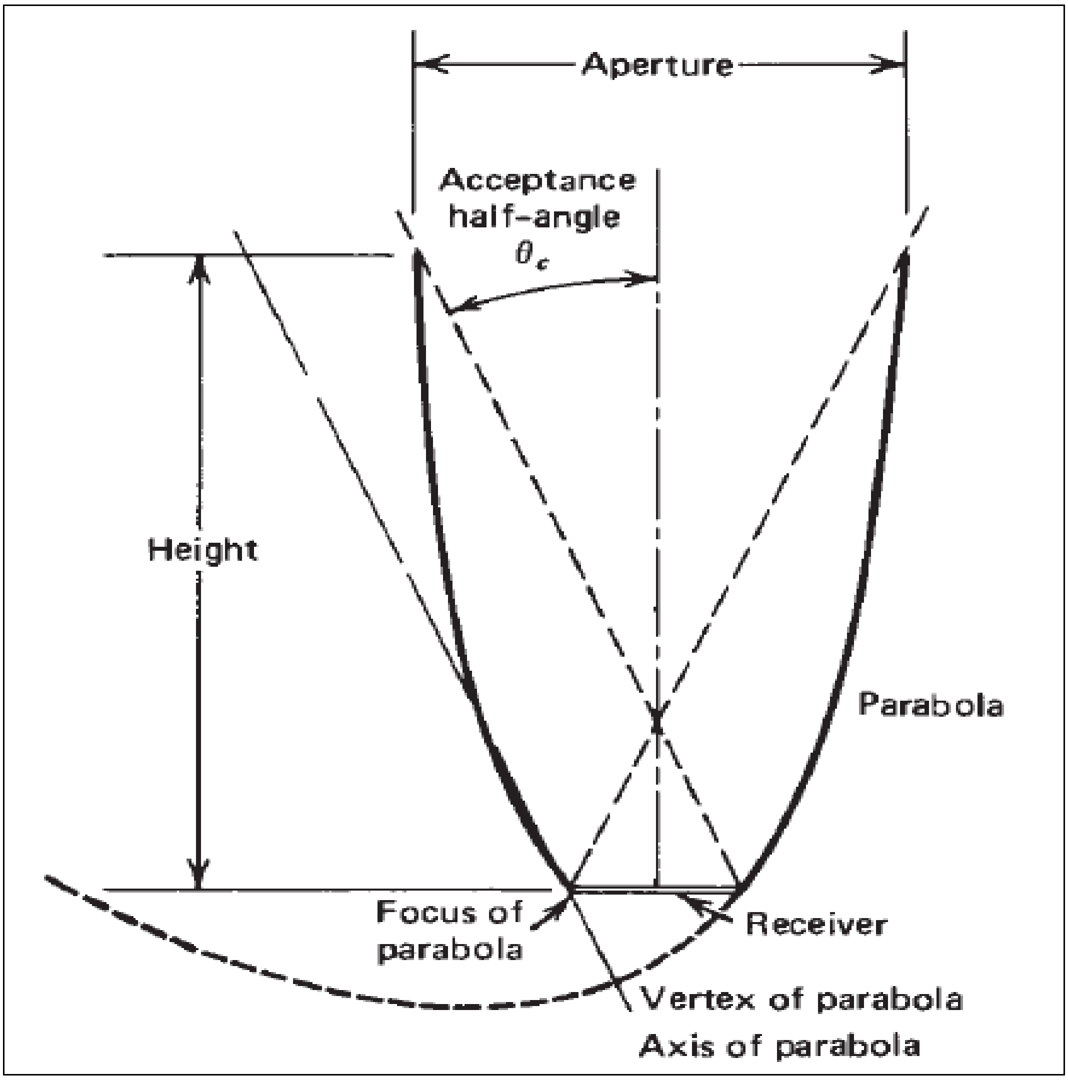

Figure 4: The basic concept of a solar center with a compound parabolic concentrator [10]

In Zemax there are two types of ray tracing mode: sequential and non-sequential ray tracing mode. The second type is used in the design. The sequential irradiation tracking system consists of a source and an optical path and a recipient that the rays can hit each surface more than once without arranging (non-sequential) up to the target. It consists of a source, so this mode is used for non-traditional optical system, such as solar concentrators which is the window of non-sequential ray tracing mode in Zemax that is called (lens data editor) consisting of rows, and each one of the rows represents an element of optical system. The columns of (lens data editor) represent parameters of the system elements, every element has specific parameters differfrom others.

The material that is used in CPC walls is mirror, radial entrance aperture of (50mm) and length of CPC (500 mm). The acceptance angle varies according to the design of each concentrator, that is the largest angle of incidence of sunlight on an optical system achieving efficiency at least (80%), the acceptance angle depends on the type of system being used and the refractive index of the material from which it is formed.

3.Results

To evaluate the optical design performance, must using appropriate tools that give clear picture of optical design activity. The most important tools that give this feature are detector.

The detector viewer can gives the number of rays that strike its which means number of ray reaching exit aperture. Therefore gives the amount of optical efficiency.

Figure (5) shows the distribution of striking rays on the detector at different incidence angle for CPC of concentration ratio (c=3). The **Figure** shows the priority of case one (figure (6-A)) of normal incidence angle (θ=0) compared with other cases, because of nature of geometrical shape that reflects most of incident rays and redirect it to exit aperture. Anyway other cases (B, C, D) give acceptable values of ray distributions, that insures the activity of concentration design despite of increasing of incidence angle.

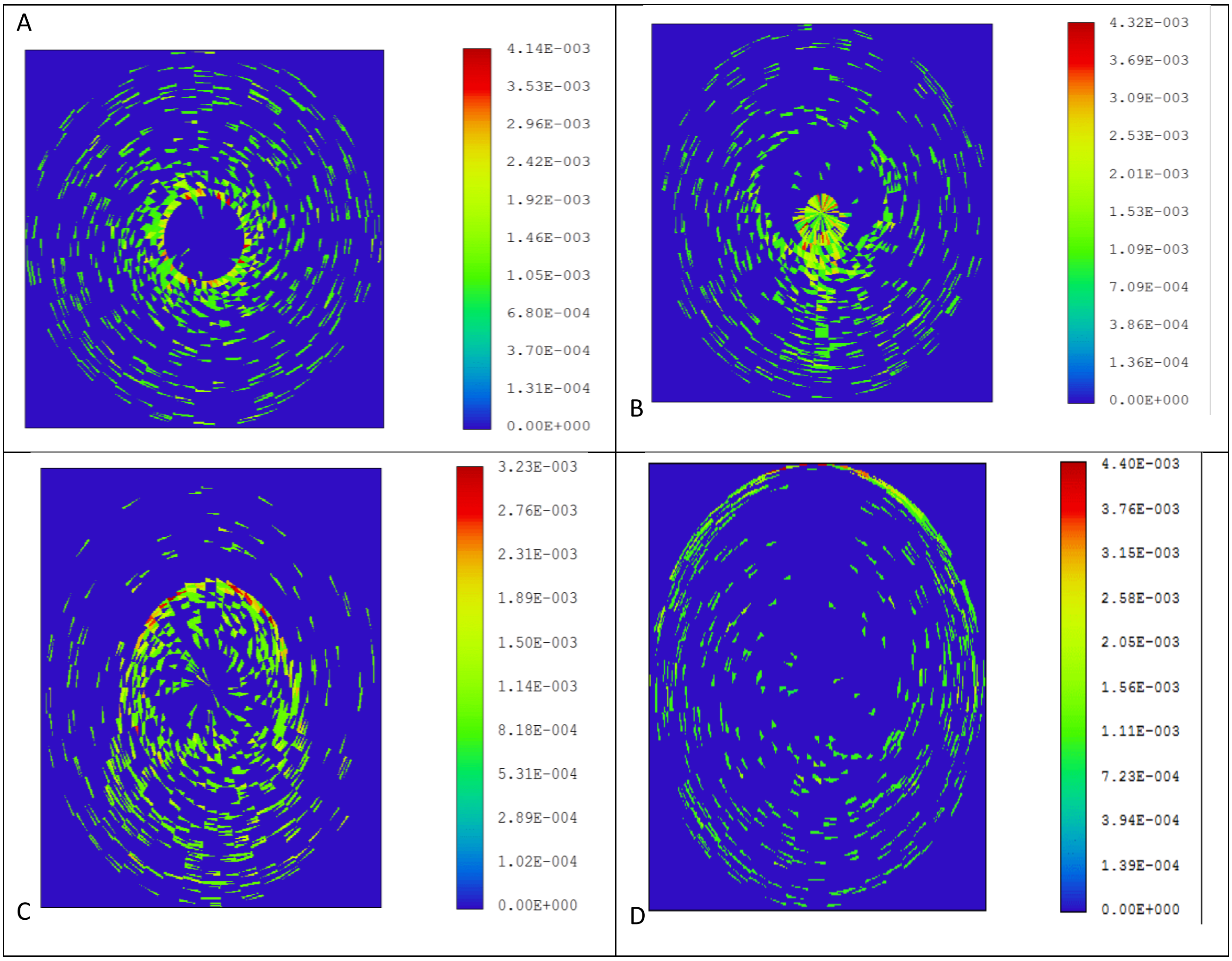

Figure (5):detector viewer;of CPC has concentration ratio(c=3) for variable incidence angles.(A): (θ=0), (b):(θ =5), (C):(θ =10), (D):(θ =15)

At incident angle (θ < 10) the efficiency is almost (η=90%) in the design (c=1, 2, 3, 4), while (η=30%) in the design (c=5). At incident angle (θ = 15) the efficiency is almost (η=85%) in the design (c=1, 2, 3), while (η=10%) in the design (c=4, 5). At incident angle (θ = 20) the efficiency is almost (η=75%) in the design (c=1, 2,), while (η=10%) in the design (c=3, 4, 5) as shown in **Figure (6).**

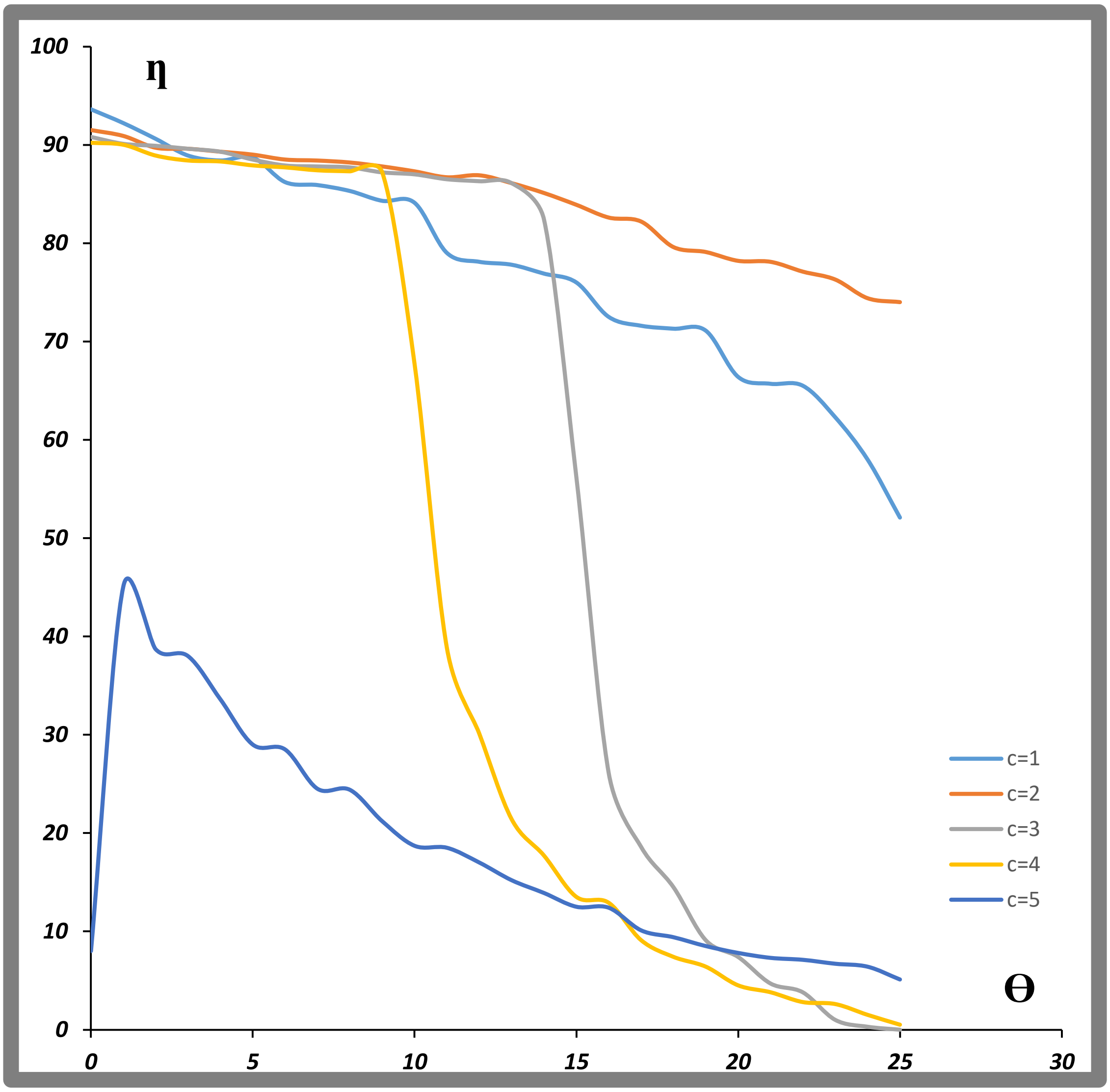

Figure 6:Efficiency at different incident angle of different concentration ratios

Figure (7) shows the irradiance distribution of the intensity illumination on the detector surface for CPC having concentration ratio c=2.Zemax program that provides this feature for one axis, and since reading is symmetrical for the detector, we choose one axis; let it be x axis.

Detector viewer shows variation of irradiance distribution in all incidence angle especially in the first case (**Figure7.A**) at (θ=0). While another case shows slightly irradiance distribution.

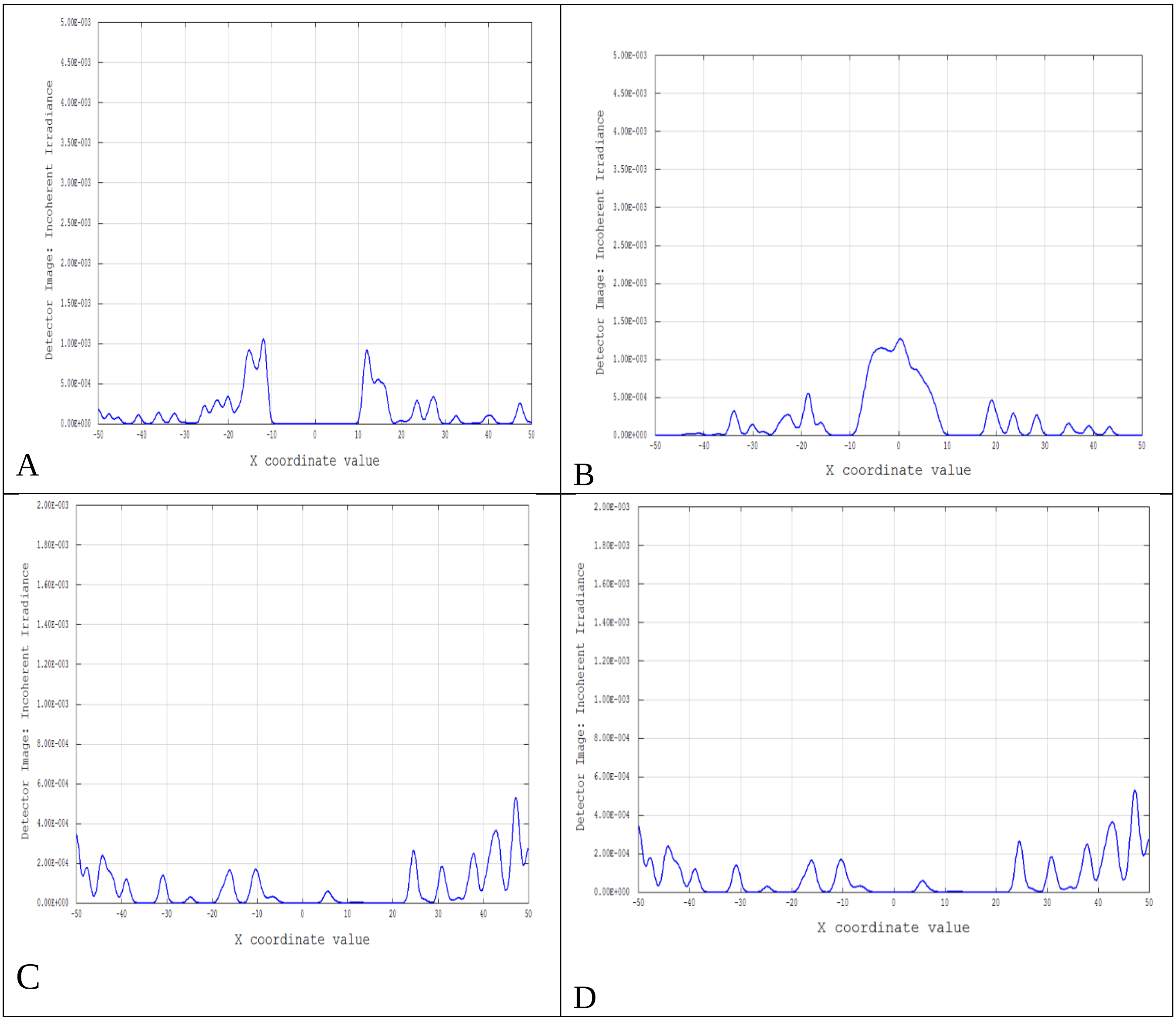

Figure (7):detector image of incoherent irradiance of CPC(c=2); (A):θ=0.(B): (θ=5).(C):(θ=10).(D):(θ=15)

By making a comparison of the CPC design in case of hollow and filled by Poly methyl methacrylate (PMMA) material inside it. One of its advantages is that it has a high transparency, so it is used in greenhouses, making lenses, prisms, and solar cells [11]

PMMA, also known as acrylic, is a transparent thermoplastic. It is often used in sheet form due to its properties such as lightweight and shatter resistance as an alternative to glass. It often serves as an economical alternative to polycarbonate whenever extreme strength is not desired. Due to advancements in technology efforts have been made to increase the impact resistance and scratch resistance of this material [12]

When using PMMA| material filled CPC have concentration ratio (c=2). The efficiency values for angles of incidence is (θ=0 - 25). The efficiency shows slightly degradation by increasing incident angle in the two samples. But is noticeable that the priority of hollow CPC sample in efficiency (**Figure 8**).

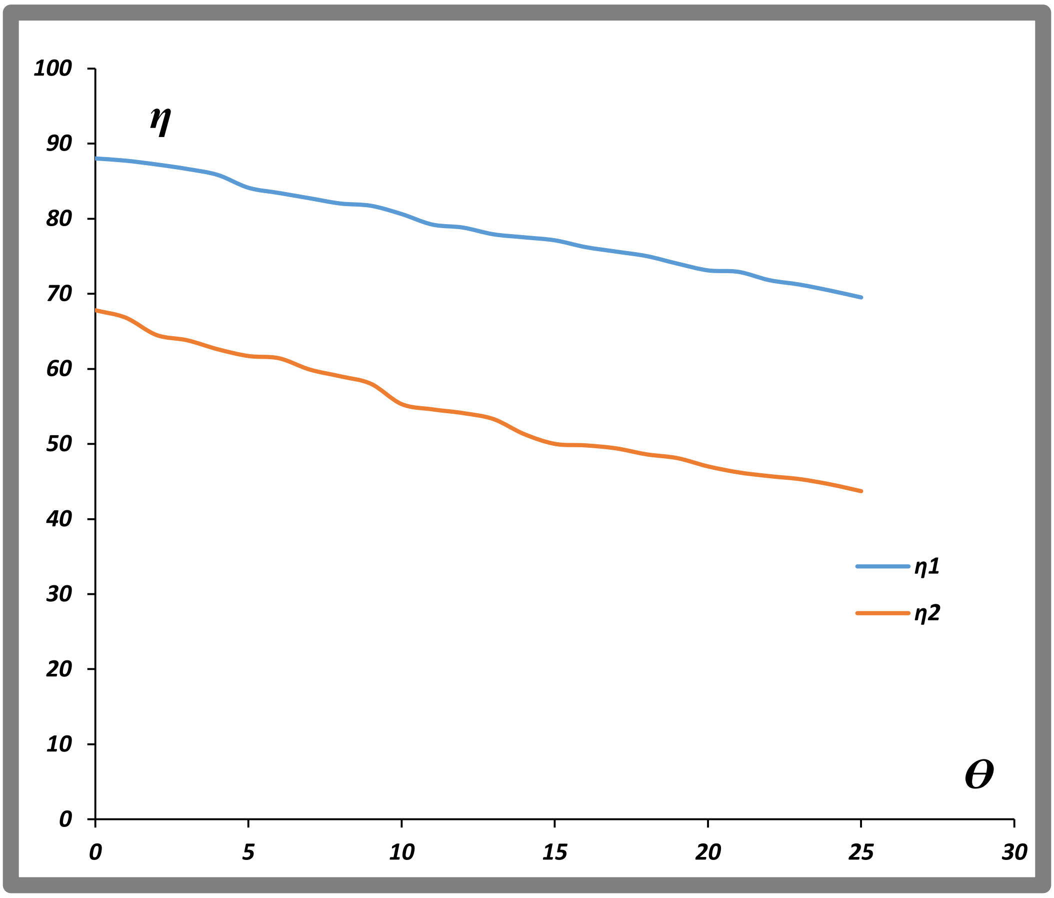

Figure 8: Efficiency of CPC has (c=2) in case of hollow (η_1) and PMMA filled (η_2) sample

In the sample (c=3); the efficiency of hollow sample behaves slightly decreasing when decreasing incident angle in ($\theta<15$), but illustrates sharp decreasing after this angle. The filled sample shows lack of efficiency in whole incident angles (**Figure 9**).

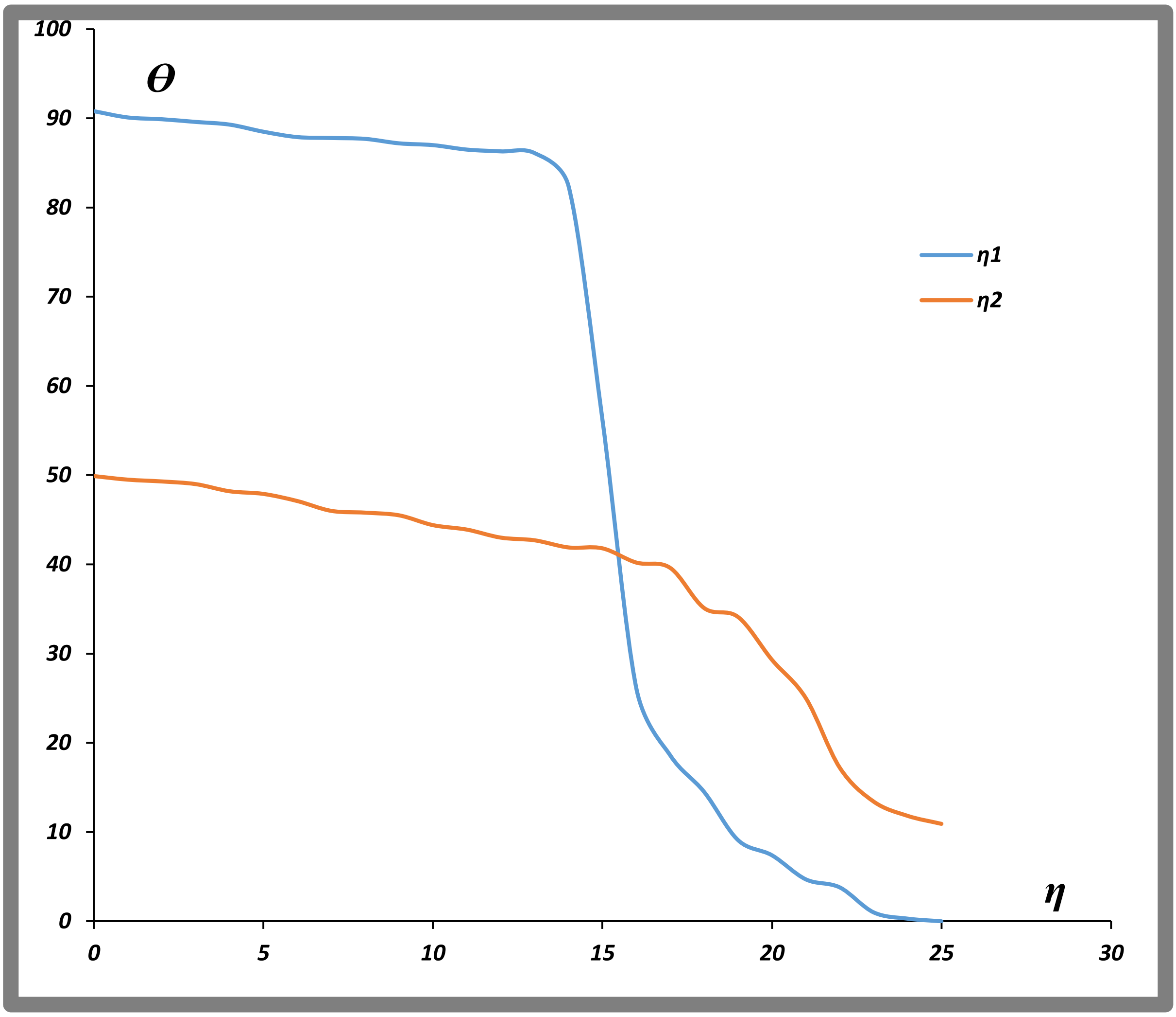

Figure 9: efficiency of CPC has (c=3) in case of hollow (η_1) and PMMA filled (η_2) sample

The sample (c=4) has the efficiency of hollow sample that behaves slightly degradation by decreasing incident angle in ($\theta<10$), but illustrates sharp decreasing after this angle. The filled sample shows lack of efficiency in whole incident angles , especially in ($\theta>15$) as shown in **Figure (10).**

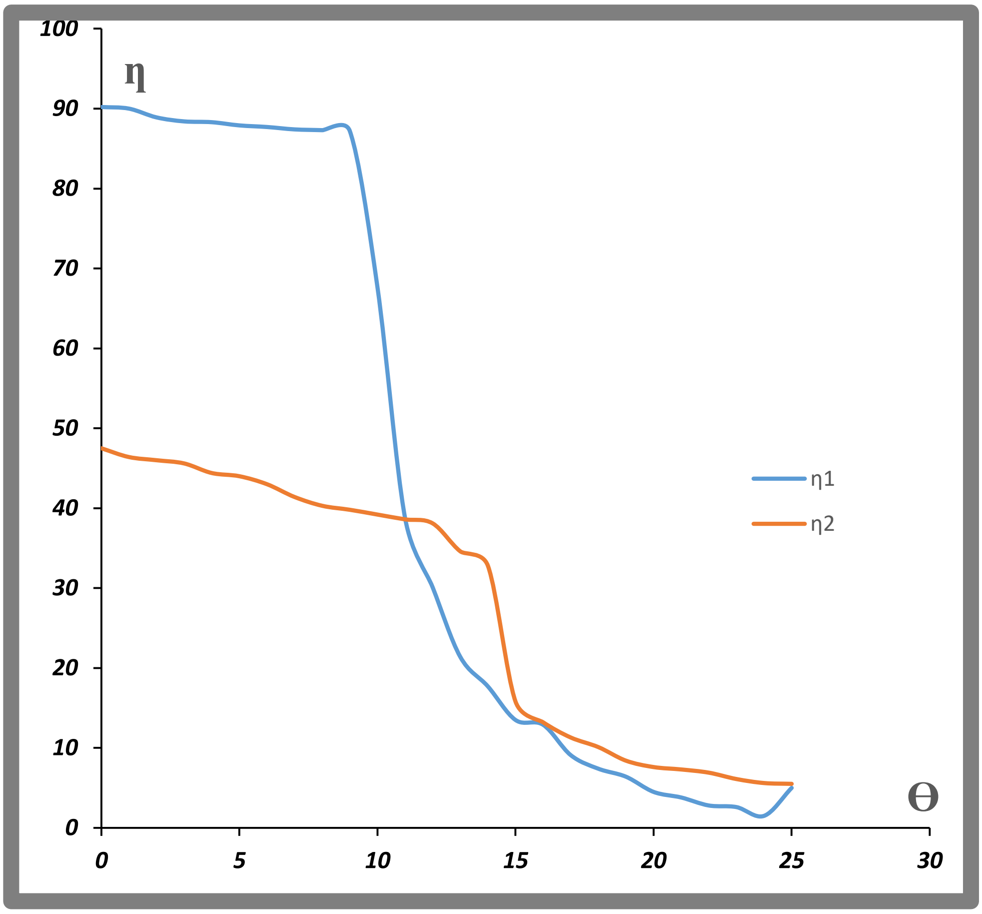

Figure10: Efficiency of CPC has (c=4) in case of hollow (η_1) and PMMA filled (η_2) sample

The samples (c=5); the efficiency of the two samples at normal incident angle (θ=0) have efficiency (10%) and jump in (45%) at (θ=5) and return to lack increasing incident angle in hollow sample. While the filled sample has variation of efficiency by decreasing incident angle (**Figure 11**).

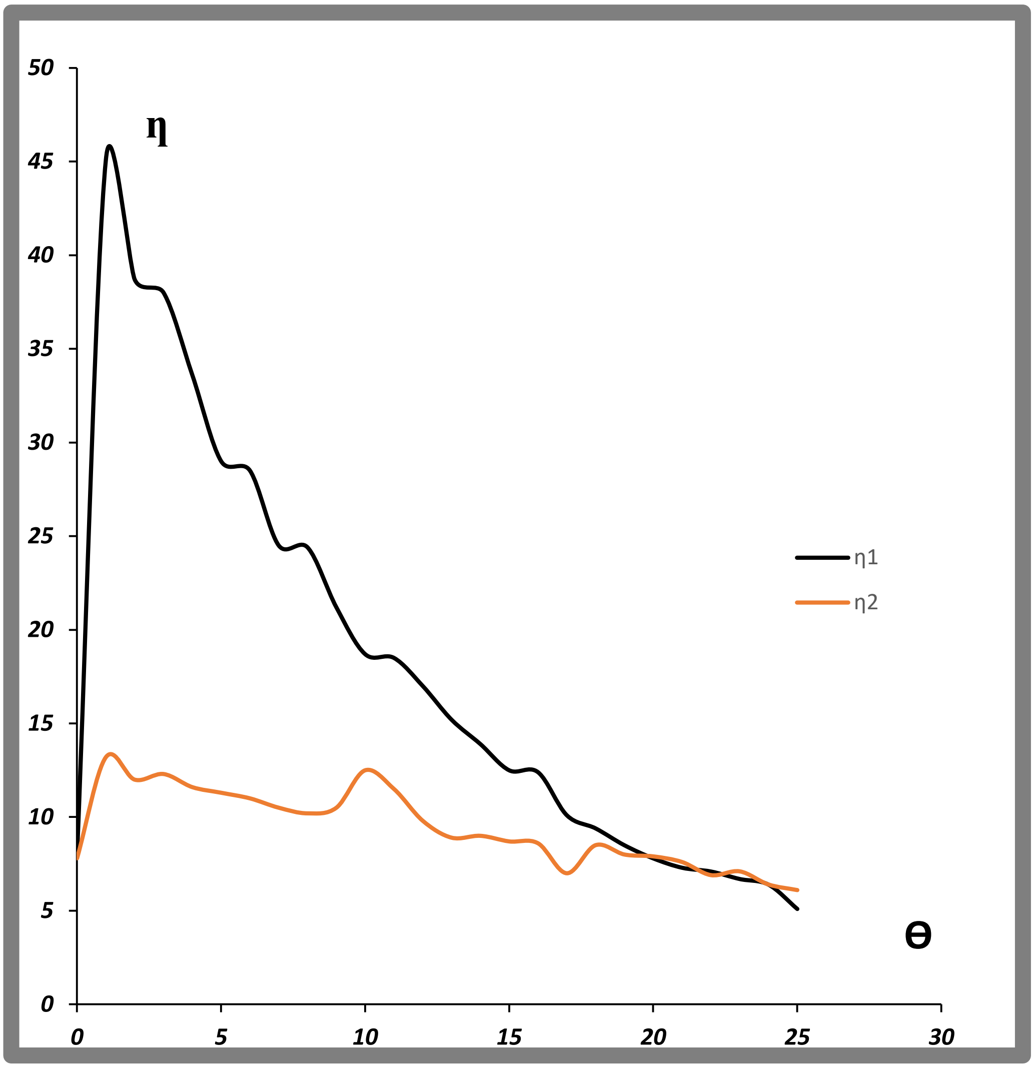

Figure 11: Efficiency of CPC has (c=5) in case of hollow (η_1) and PMMA filled (η_2) sample

Figure (12) illustrates a comparison between of PMMA filled CPC sample that has concentration ratio (c=1, 2, 3, 4, 5). The figure shows priority of sample of (c=1) at all incidence angles.

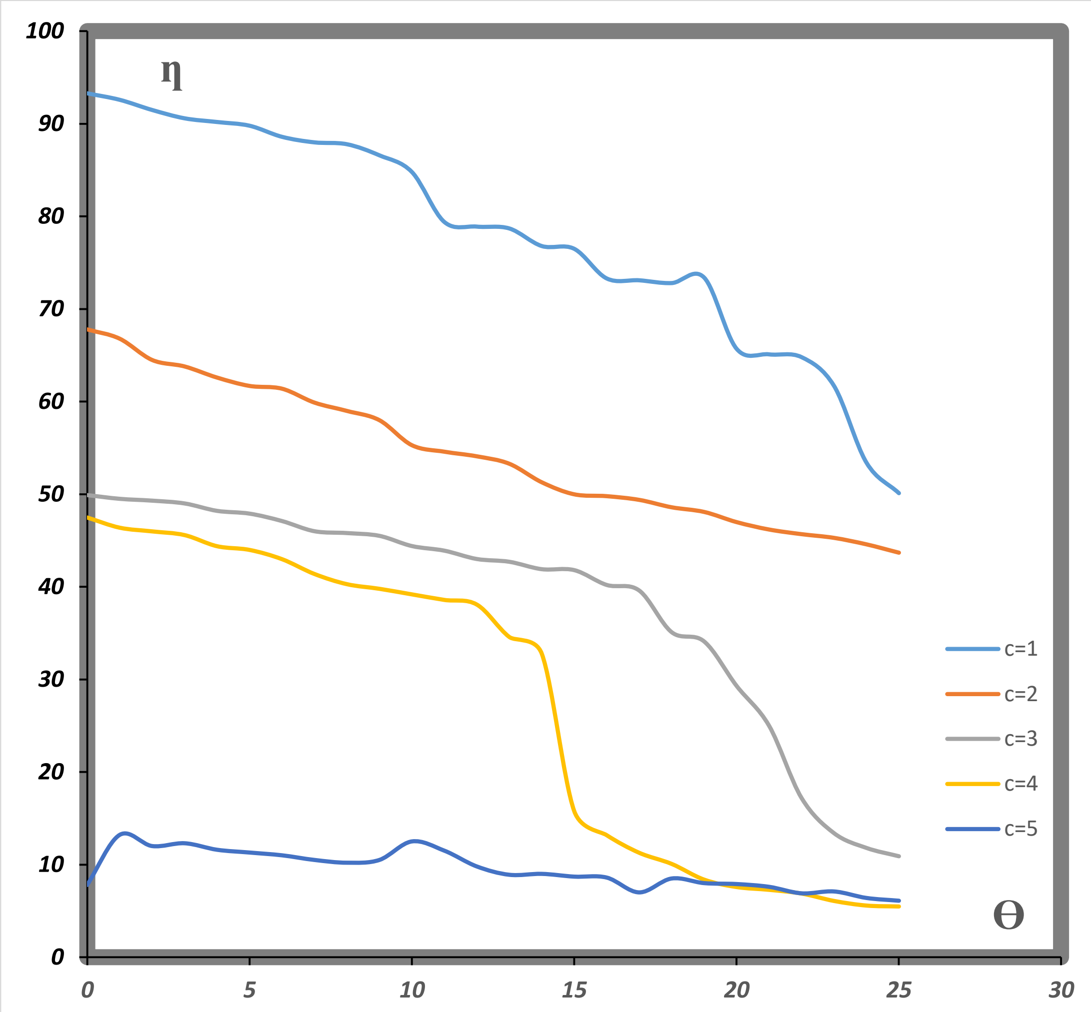

Figure 12: comparison between concentrations (c=1, 2, 3, 4, 5) in (PMMA)filledCPC sample at different incident angles.

4.Conclusion

The results show progressing in the efficiency of hollow samples, other than and progressing (c=2, 3) of hollow samples. The degradation of efficiency value has been presented by increasing the incident angle in whole samples. But the efficiency gives an acceptable values at different incident angles . This givse impression about the utility of CPC design to overcome of solar position variation.

References

1.Al-Rawi, S.S.; Sabri, J.M.; Alani, G.T. Designing and Constructing a demostic compound solar heater. *Tikrit Journal of Pure Science*. **2013**, *1*,*18*,190-195.

2.Shawesh, M. B.; Alraih, M.A.; Khaled, E. A. Performance study, compound concentrator, parabolic compound with flat receiver. *Asmari University Journal of Basic and Applied Sciences*.**2017**, *13*,*2*, 23-42.

3.Muhammad. S.F.;Ramirez,I.R.; McMeekin, S. G.; Stewart. B. G.; Clive, B. Solar concentrators. *International Journal of Applied Sciences*. **2010**, *1*,*1*, 1-15.

4.De, D. K.;Olukunle, O. C. (2015, March). A brief review of solar concentrators. *International Conference on Energy Economics and Environment IEEE*. **2015**, 1-7.

5.Umair, M.; Akisawa, A.; Ueda, Y. Optimum settings for a compound parabolic concentrator with wings providing increased duration of effective temperature for solar-driven systems: a case study for Tokyo. *Energies*. **2014**, *7*,*1*, 28-42.

6.Figari, A. Some features of the compound parabolic concentrator.*Conference Paper*.**2011**,1-4.

7.Casano, G.; Fossa, M.; Piva, S. Design and experimental characterization of a CPC solar collector.*International Journal Of Heat And Technology*. **2017**, *35*,*1*, S179-S185.

8.Bellos, E.;Tzivanidis, C.; Antonopoulos,K. A. Optical performance and optimization of two stationary compound parabolic collectors (CPC). *proceedings of the world congress on momentum, heat and mass transfer*.**2016**.

9.Waghmare, S. Effect of Variable Acceptance Angle And Absorber Geometry On Flux Concentration of Solar Compound Parabolic Collector. *In ICTEA: International Conference on Thermal Engineering*. **2019**, *2019*,1-3.

10.Shawesh, M. B.; Alraih, M.A.; Khaled, E. A.Concentrated solar parabolic fabrication with composite parabola and test Its performance under the climatic conditions of the city of Misurata. *International Journal of Engineering & Information Technology*. **2018**, *4*, *2*, 8-13.

11.Musa, W. A.;Hamad, T. K. The optical properties of Poly methyl methacrylate (PMMA) polymers doped by Potassium Iodide with different thickness. *Baghdad Science Journal*.**2011**, *8*, *2*, 538-542.

12.Pawar. E. A Review Article on Acrylic PMMA. *IOSR Journal of Mechanical and Civil Engineering*, **2016**, *13*, *2* , 01-0