Optical and photogrammetry study of parabolic dish concentrator

Safa SKOURI [1*], Salwa BOUADILA[1], Mohieddine BEN SALAH [1],Sassi BEN NASRALLAH[2]

[1]The Research and Technology Center of Energy, The Thermal Processes Laboratory, Hammam Lif, B.P. 95, 2050 Tunis, Tunisia

[2]National engineering school of Monastir, street Ibn El Jazzar, 5019, Tunisia.

salwa.bouadila@crten.rnrt.tn

mohieddine2002@yahoo.com

sassi.bennasrallah@enim.rnu.tn

safa.skouri@crten.rnrt.tn

Abstract : Renewable energy generation is becoming more prevalent today. It is relevant to consider that solar concentration technologies contribute to provide a real alternative to the consumption of fossil fuels. Incremental improvements in existing energy networks will not be adequate to supply this demand in a sustainable way. To cure this problem, Tunisia decided to invest in the field of renewable energy and essentially the solar energy, especially that Tunisia has an important solar energy potential about 4,8K wh/day. Recently medium-high temperature application is an important topic in the solar energy field.

The purpose of this work is to improve the performance of mobile parabolic dish was developed and realized in Research and Technology Centre of Energy in BorjCedria Tunisia (CRTEn). In this order an optical and experimental study is carried out and a description of photogrammetry has been done which used to determine geometric error of the system.

Keywords : Photogrammetry, optical study,solar parabolic concentrator.

1. Introduction

The world energy demand is projected to be doubled by 2050 and will be tripled by the end of the century [1]. The actual classic types of energy will not be capable to supply this demand in a sustainable way. The thermal performance of the concentrating collectors is sensitive to the optical and geometric parameters. We can mention numerical and experimental studies of optical SPC parameters have been done to obtain the optimum thermal performance. Authors [2, 3, 4, 5] used Monte Carlo ray tracing method to determine the thermal performance of SPC based on optic and geometric studies and validated experimentally. Zhiqiang et al. [6] presented a procedure to design a facet concentrator the optimum size and position of each facet are determined using Monte Carlo ray tracing analysis to achieve the most concentrated flux. Nepveu et al. [7] presented a global thermal model of the energy conversion of the 10 kWel Eurodish dish/Stirling unit erected at the CNRSPROMES laboratory in Odeillo. Using optical measurements made by DLR, they calculated the losses by parabola reflectivity and spillage. A nodal method is used to calculate the heat losses in the cavity. The model gives results fitting with experimental measurements. Lokeswaran et al. [8] compared experimentally thermal performance, optical efficiency, heat loss factor and cooking power of solar parabolic dish cookers for both cases with and without porous medium made of scrap material. Optical Analysis of 3-D static elliptical hyperboloid concentrator, using the ray tracing technique has been presented by Ali et al. [9].

2. SPC Optical efficiency

Optical losses of solar concentrator can be very significant due to multiple reflections and refractions, which differ according to the optical characteristics of the reflector. The following equation form Eq. (1) can be used to perform an approximated optical efficiency analysis as.

$$\eta_{op} = \gamma \, \lambda \, \rho \, \tau \, \alpha \, \cos\theta \qquad (1)$$

Where λ, ρ and $\tau\alpha$ are the factor of un-shading, dish reflectance and transmittance–absorptance product, respectively. γ is the intercept factor of receiver, which is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device. θ is the incidence angle of solar beam into the dish which is equal to zero degree, therefore the Eq. (1) can be written as:

$$\eta_{op} = \gamma \, \lambda \, \rho \, \tau \, \alpha \qquad (2)$$

In practice, there are optical errors associated with the operation of the collector that will affect the intercept factor in addition to the fact that solar rays are incident from different directions covering the solar disk. The intercept factor can be given in terms of collector geometry and optical errors as [10]:

$$\gamma = \int_{-\infty}^{\infty} d\theta F(\theta) \frac{1}{\sqrt{2\Pi}\sigma_{tot}} \exp(-\frac{\theta^2}{2{\sigma_{tot}}^2}) \qquad (3)$$

σ_{tot} is the standard deviation of the total errors it can be written as:

$$\sigma_{tot}^2 = \sigma_{optical}^2 + \sigma_{sun}^2 \qquad (4)$$

$$\sigma_{optical}^2 = \sigma_{slope}^2 + \sigma_{specular}^2 + \sigma_{displacement}^2 + \sigma_{tracking}^2 \qquad (5)$$

Where $\sigma_{optical}$, σ_{slope} , $\sigma_{specular}$, $\sigma_{displacement}$, $\sigma_{tracking}$ and σ_{sun} are respectively standard deviations of the total optical errors, slope error, specular error , receiver displacement error tracking errors and sun error.

The optical performance of the concentrating collector is sensitive to the optical errors. In practice, there are many techniques of optical measurement used to analyze the optical errors and hence determining the intercept factor like photogrammetry.

3. Optical Study of SPC: photogrammetric technique

3.1. Photogrammetric technique

This method determines the exact deformation of the reflector and its geometric error related to the ideal form, as well as the exact position of the absorber. This technique uses a high resolution Camera Nikon D300 set."Targets" should be placed on all the points that need to be measured. Adapters are provided to measure different features such as holes, ridges or other specific points of reference. Subsequently, the object must be photographed from different angles, planes and in different directions. These images are uploaded to the computer and then processed with the management system software. The system automatically calculates the 3D coordinates of all the points with "targets". The calculation is based on the principle of using triangulation between the spaces of the images (photogrammetry) [11].

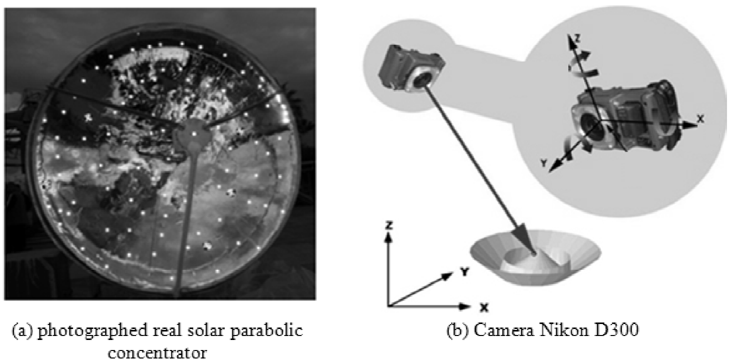

Figure 1:Photogrammetric technique: (a) photographed real solar parabolic concentrator and (b) Camera Nikon D300 [11].

3.2. Geometric study of the SPC

A geometric study of the experimental SPC has been done using the photogrammetry technique.Figure 2 shows the spatial variation of real and ideal parabolic solar concentrator z coordinates. Which show that z_{ideal} is equal to z_{real} for the radial coordinate (r) varied between 0 to 800 mm and from this value we show a slight difference between experimental and ideal coordinates. Figure 3 represents the slope error of SPC for an ideal parabola; all incoming rays parallel to the optical axis (normal rays) will be reflected through the focal point of that parabola. A surface slope error is the angular difference between the measured surface normal and the ideal surface normal of the design parabolic surface. We note that the device presented an average slope error around 0.0002 and 0.0073 rad respectively in the center and in the extremities. The average extremities slope error is more important in one than the other.

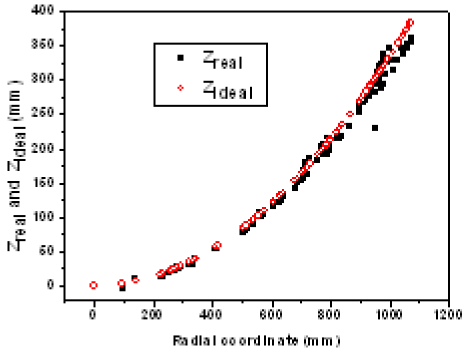

Figure 2: The spatial variation of real and ideal SPC z coordinates.

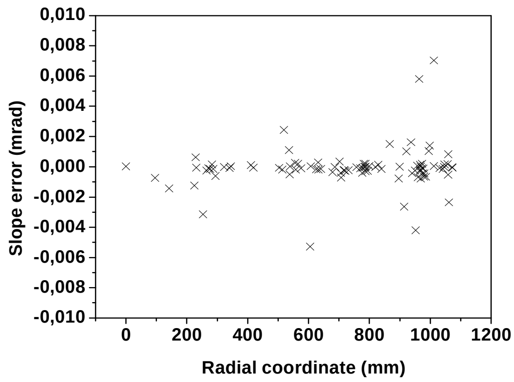

Figure 3: The spatial Variation of the slope error.

Based on Figure 2 and Figure 3, it is clear that this hub is a perfect parabolic shape but it has a slight geometric distortion at the edges. In the present work the deformation does not affect much the thermal efficiency, because we used a small geometry absorbers, but if we want to use another absorbers is proposed to have arms which eases the deformation of the reflector and which can correct these distortions at the edges.

4. Effect of the reflector material

Optical losses of solar concentrators can be very significant due to multiple reflections and refractions, which differ according to the optical characteristics of the reflector. Three types of reflector are tested to choice the most perform reflector. Figure 4 gives the variation of the receiver temperature as function of time using three types of reflectors.

These experiences are done in three days under comparative climatic conditions. An average insulation and ambient temperature equal to 800 W/m^2 and 25°C respectively.

The first reflector (R1), aluminum sheet with reflecting coefficient of 0.80, we note that the obtained receiver temperature is around 250°C. Using the second reflector (R2), aluminum paper with reflecting coefficient of 0.85, the average absorber temperature is equal to320°C. The last reflector (R3), 3M solar mirror film 1100, which gives an absorber temperature around 900°C. Therefore, the variation average instantaneous temperature obtained using those reflectors, the most perform SPC reflector is the 3M Solar Mirror Film 1100. That is a silver metallized weather able acrylic film. It has a solar-weighted total hemispherical reflectance of 94% at air mass 1.5 [12]. Solar Mirror Film offers a number of significant advantages over traditional glass mirrors, including higher reflectance, less weight and improved mechanical properties.

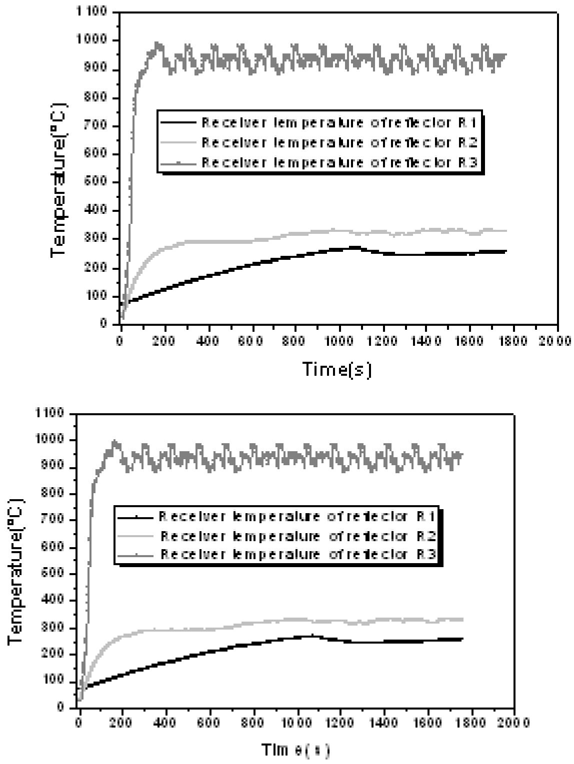

Figure 4:The temporary variations temperatures using three reflectors.

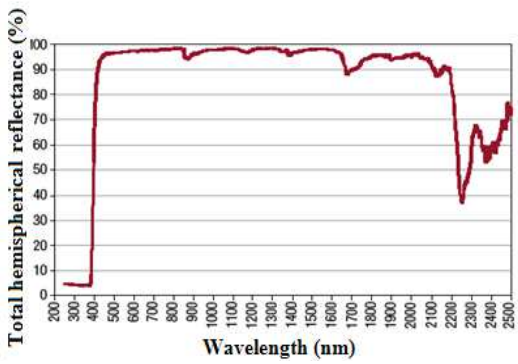

Figure 5: Total hemispherical reflectance variation of (R3) [12].

Table 1:Physical Properties of SPC reflector material [12].

Properties	Typical values
Total solar reflectance(air mass 1.5) %	94
Thickness mils	4.6
Specularity %	>95
Minimum reflective area/ sq. meter	99.8%
Operating temperature range (°C)	(-40°C to 65°C)

5. Conclusion

This work is a contribution of a solar parabolic concentrator equipped with a sun tracking system, a solar heat exchanger and measuring instruments.

The main findings of the present study to increase the efficiency of the system could be recommended as follows:

- Enhancing the geometrical preciseness of the manufacturing. The geometrical effect on solar dish concentrators was clearly shown in the results found by photogrammetry technique which used to determine geometric error of the system.
- Using a perform reflective film with higher reflectivity, greater thermal efficiency can be reached with efficient reflective materials.

Nomenclature

η_{op} optical efficiency

λ factor of un-shading

ρ dish reflectance

$\tau\alpha$ transmittance–absorptance product

γ intercept factor of receiver

θ incidence angle of solar beam

σ_{tot} total errors

$\sigma_{optical}$ total optical errors

σ_{slope} slope error

$\sigma_{specular}$ specular error

$\sigma_{displacement}$ receiver displacement

$\sigma_{tracking}$ error tracking errors

σ_{sun} sun error. interne

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