4ème Conférence Internationale des Energies Renouvelables (CIER-2016)
Proceedings of Engineering and Technology – PET
Vol.17, pp.15 - 20

Numerical study of optical parameter's effect on the performance of a parabolic dish system

Hiba Cherif[#1], Anissa Ghomrassi[#2], Jalila Sghaier[#3], Hatem Mhiri[#4]

[#]*Unit of thermal and Thermodynamics in Industrial Processes, National Engineering School of Monastir*
Monastir 5000, Tunisia

[1]hiba.cherif@yahoo.fr
[4]hatem.mhiri@enim.rnu.tn
[2]ghomrassi.anissa@hotmail.com
[3]jalila.sghaier@enim.rnu.tn

***Abstract*— In this paper, a Monte Carlo ray-tracing method is used to predict the solar heat flux distribution on the receiver periphery of a parabolic dish. This software allows us to determine the solar heat flux map for every configuration.**

The impact of the reflectivity of parabolic dish and of selectivity of the receiver on the optical performance has been studied to define the most effective configuration. Three different values of reflectivity ρ are tested: ρ= 0.86; ρ =0.9 and ρ =0.96. It has been found that the solar heat flux increases with increasing of reflectivity ratio. In the other hand, four different values of selectivity are investigated: α/ε=4; α/ε=6; α/ε=7; α/ε=9. It was noted that the concentrated heat flux increases with increasing of the receiver selectivity, so the better receiver is whose selectivity is α/ε=9. This latter is chosen for the possible future studies.

***Keywords*— Parabolic dish; Monte Carlo ray-tracing method; Solar energy; Optical performance; Reflectivity; Selectivity**

I. Introduction

Solar energy is the most abundant renewable energy resource. It is inexhaustible on a human scale. Parabolic dish concentrated solar power is the one of the proven techniques of energy conversion. It is commonly used to concentrate solar radiation and transform it into medium or high temperature heat, citing Dish–Stirling system (Mills)[1] ,solar cooker (Badran et al.)[2] and solar hydrogen production (Furler et al.) [3].

In order to evaluate the optical performance of solar concentrating systems, it is necessary to quantify the focal flux distribution. To realize this objective, there are many different techniques.

The Monte-Carlo ray-tracing method is a method commonly used in the solar energy field for determining the concentrated solar heat flux distribution [4, 5, 6].

Jeter [7] has used an integral relationship in order to calculate the distribution of concentrated flux in idealized paraboloidal solar collectors. Steinfeld et al. [4] used the Monte-Carlo ray-tracing method to investigate the sunshape influence in order to choose the optimal parameters of a cavity receiver in a parabolic dish. Johnston [8, 9] studied the flux mapping the 400 m^2 "Big Dish" by using the COMPREC compound receiver code at The Australian National University.

Doron and Kribus [10] demonstrated the importance of irradiation directional features to volumetric absorbers.

Shuai et al. [6] carried out numerically the performance of a solar parabolic dish system using the Monte-Carlo ray-tracing method in which the effects of sunshape and surface slope error have been considered. Shuai et al. (2010) [11] also presented a numerical study by using the Monte Carlo ray-tracing method to investigated the radiation flux distributions on the focal plane of the solar parabolic dish and in the wall of the cavity receiver/reactor. A measuring system using CCD cameras is developed to determine the focal flux distribution. Moreover, a series of flux measurements are obtained at different receiver's position of the dish vertex of a parabolic dish solar concentrator. Furthermore, the measured flux distributions are compared with a distribution predicted by the Monte Carlo method.

Li et al.[12] has developed an analytical function in order to predict the optical performance of a parabolic dish concentrator with a cavity or flat receiver. Y. Rafeeu et al. [13] have conducted an experimental study to evaluate the thermal efficiency of the parabolic concentrator. They have shown that the efficiency of the latter can be achieved by improving the geometrical precision of the manufacture, by using a reflective film with higher reflectivity and an efficient and more perfect tracking system.

Later, on 2013, an experimental study presented by Skouri et al. [14] has shown that the thermal efficiency of the solar parabolic concentrator depends on the geometrical preciseness of the manufacturing and the material of the reflector and the sun- tracking system. Billy Anak Sup et al.[15] conducted numerical study of solar parabolic dish collector on the geometry and on the flux distribution on the focal region.

Although the existence of bibliographical studies focusing in the parabolic solar dish, few studies discussed solar heat flux reaching the receiver tube and focusing on the effect of optical parameters.

In this paper, the radiation flux distribution on the receiver periphery is studied using the Monte Carlo ray-tracing method. The effect of optical parameters like a reflectivity, selectivity on the radiation flux distribution has been studied in order to define the most effective configuration.

ISSN 2356-5608

II. THE CALCULATION OF SOLAR HEAT FLUX DISTRIBUTION

A. Soltrace modeling

SOLTRACE is a software tool developed at the National Renewable Energy Laboratory (NREL) usually used in the field of solar applications to model the ray propagation process and to analyze the performance of optical systems. SolTrace can also be used to model many general optical systems citing solar power tower, solar parabolic dish, parabolic tough collector and linear Fresnel reflector

In this code, an optical system is structured into "stages" in a global coordinate system. A stage is freely defined as a part of the optical geometry in which a ray will not be returned by the ray on the rest of its path through the system once exits the stage. A stage is constituted of "elements". Each element consists of a surface, an aperture shape, an optical interaction type and a set of optical properties. The location and orientation of stages are specified in the global coordinate system while the location and orientation of elements are defined in the coordinate system of the particular stage in which they are specified.
This software calculates the sun position in azimuth and elevation and identifies an appropriate unit vector.
The next step is to specify optical properties of each element. In this case transmissivity, reflectivity and optical errors are properties defined for every stage.
The following step consists to define the position of each stage in the global coordinate system. After that, numbers of rays launched is specified and calculation is run in order to extract results.

B. Validation

In order to ensure the efficacity of soltrace to predict the heat flux map in the focal point of receiver tube, a validation of the model predicted with experimental results from the literature is made.

The validation of this simulation method was performed by comparing the numerical results calculated by SOLTRACE and experimental data of Johnston [5].

A direct normal irradiance of 1000 W/m^2 and a Gaussian sun shape are supposed in this study.

We consider the same hypotheses as considered by Johnston [5]. The solar heat flux distribution at the focal plane of a parabolic concentrator is compared with that obtained by Johnston [5], as illustrated in Fig. 1.

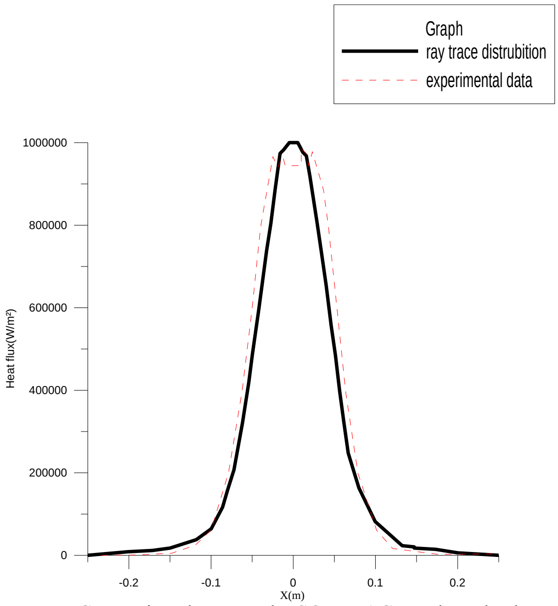

Fig. 1 Comparison between the SOLTRACE code and Johnston's [5] results of focal flux distribution on a 0.5m diameter absorber

As can be seen in Fig.1, a good agreement is achieved between numerical results and Johnston's experimental results.
The results are statistically significant with a very high R-squared value (above 0.98763) and very low P-value (in a range of $0 \leq P \leq 2.10^{-8}$). These prove that the MCRT method used in this study is possible and the numerical results are reliable.
The solar heat flux reaches a peak of approximately 10^6 W/m^2 in the central region. It is demonstrated that the concentrated solar radiation heat flux is reaching quickly the focal point. Outside the central region, the solar heat flux is very low because the absorber receives only direct radiation.
After verifying the validity of the model on Soltrace, we could say that the MCRT method can predict the distribution of solar flux on a receiver placed in the focal point of a solar dish. This model may be applied in any configuration of this system.
It is concluded that it is appropriate to use SolTrace for determining heat flux on the receiver in order to determine the surface temperatures.

C. Heat flux distribution details

The parabolic dish is used to reflect and to focus the sun's rays onto the receiver so that the solar heat can be absorbed by this latter.

As screenshot of a parabolic dish and a receiver tube is shown in figure 2. A ray traced is also shown in the same figure. This ray coming from the sun is intercepted by the reflector and is reflected in the focal point to be absorbed later by the receiver. The receiver material is copper and the parabolic dish material is aluminum. The reflecting surface is covered with a mirror layer of 2 mm thick. The geometric parameters of the parabolic concentrator system are shown in Table 1 [5].

ISSN 2356-5608

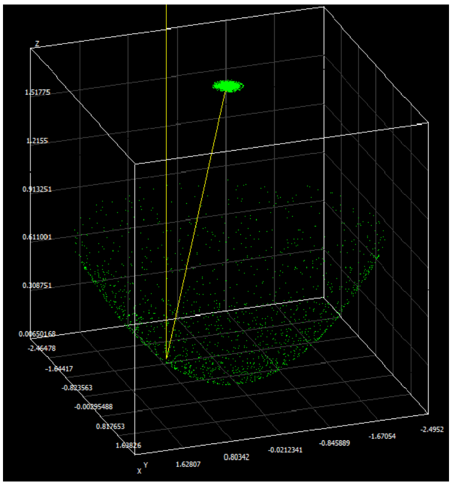

Fig. 2 Schematic of studied parabolic concentrator

Table I geometric parameters of the simulation in this paper

TABLE I

Parabolic dish	Value(m)
Diameter	5
Focal length	1.82

Figures 3a and 3b present the solar heat flux distribution concentrated on the receiver surface. From figure 3b, it's clearly shown that the maximum of solar heat flux is concentrated on the center of the receiver which justified that the receiver modeled is localized exactly on the focal point of the dish. Then heat flux decreases while moving away from the receiver center.

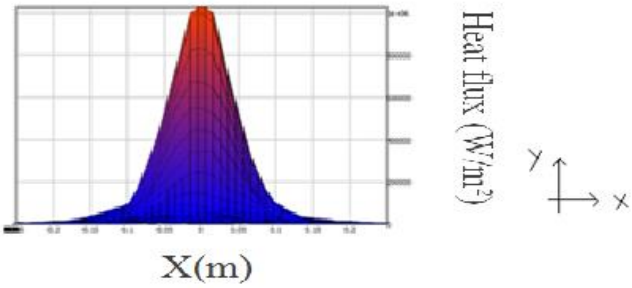

Fig. 3.a Solar heat flux distribution on the receiver surface

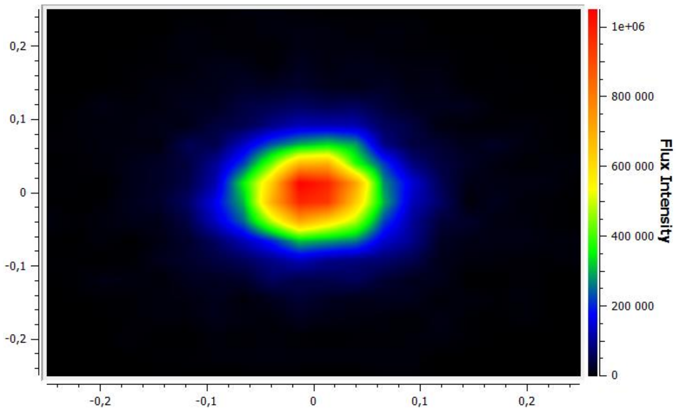

Fig. 3.b Solar heat flux distribution contour in the bottom receiver plane

SOLTRACE are intended for depth analysis of optical performance and give a detailed description of the reflected power from a concentrator.

The application of the Monte Carlo method may be performed in order to determine the optimal parameters for obtaining the maximum value of solar heat flux distribution.

For the reason of the importance of the optical parameter in the improvement of the performance of the parabolic dish, reflectivity of the reflector and selectivity of the receiver are studied in the following section.

In the following a parametric analysis of the effect of the reflectivity of parabolic dish and of selectivity of the receiver on the radiation flux distribution is carried out.

III. Optical Parametric Study

A. Effect of reflectivity of parabolic dish on the radiation flux distribution

The effect of reflectivity of parabolic dish on the radiation flux distribution is studied. Figure 4 shows the distribution of the solar flux Φ on the focal plane for different values of the parabolic concentrator reflectivity. These values are chosen from experimentally studies. The distribution has been calculated in the following conditions: solar radiation 1000W/m^2 and a Gaussian sun shape.

For a reflectivity value of 0.86, the concentrated solar heat flux reaches a peak of about 10^6 W/m^2 in the focal point, but with a reflectivity value of 0.96, the solar heat flux reaches a value of 1.2 10^6 W/m^2.

From this figure, it is clear that the solar heat flux that peaks on the receiver is higher at higher reflectivity ratio. It increases from 10^6 W/m^2 to 1.2 10^6 W/m^2 when increasing the reflectivity ratio from 86 % to 96 %. So we can conclude that the peak magnitude of the heat flux distribution is directly proportional to the reflectivity ratio.

ISSN 2356-5608

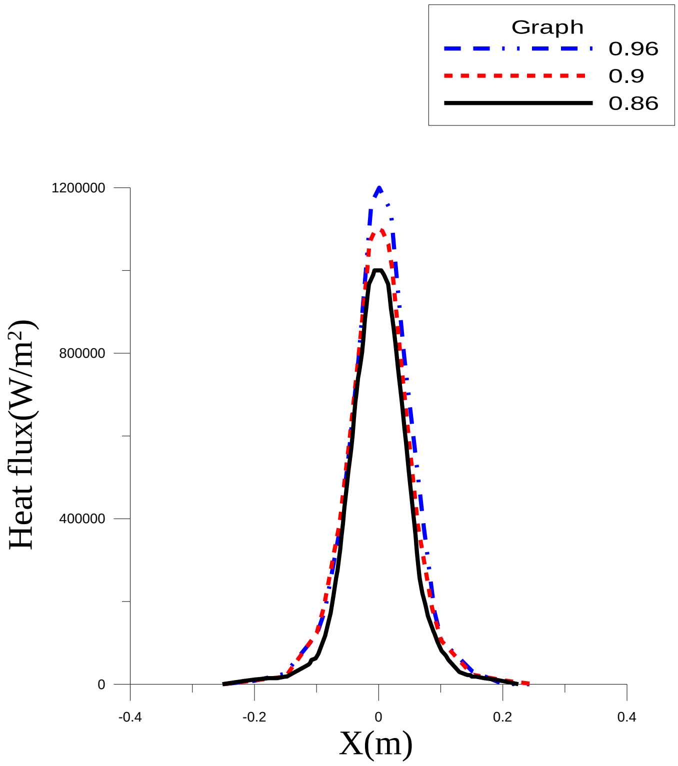

Fig. 4 Solar heat flux distribution in the focal plane with various parabolic dish reflectivity

B. Effect of receiver selectivity on the radiation flux distribution

An important factor that highly influences the optical performance of a concentrator solar system is the selectivity of the receiver.

The selectivity is the ratio of the absorption coefficient and the emissivity of the receiver α/ε. The effect of selectivity of the receiver on the radiation flux distribution is studied. Four different values of selectivity are investigated and tested: $\alpha/\varepsilon=4$; $\alpha/\varepsilon=6$; $\alpha/\varepsilon=7$; $\alpha/\varepsilon=9$. Figure 5 shows the solar heat flux distribution in the focal plane with various receiver selectivity. For a selectivity value of 9, the concentrated solar heat flux reaches a peak of about 1.44 10^6 W/m^2 in the focal point, but with a selectivity value of 4, the solar heat flux reaches a value of 671305 W/m^2. It is clear that the solar heat flux that peaks on the receiver is higher at higher selectivity value. It increases from 671305 W/m^2 to 1.44 10^6 W/m^2 when increasing the value of selectivity from 4 to 9. That's why we can conclude that the peak magnitude of the heat flux distribution is directly proportional to the selectivity.

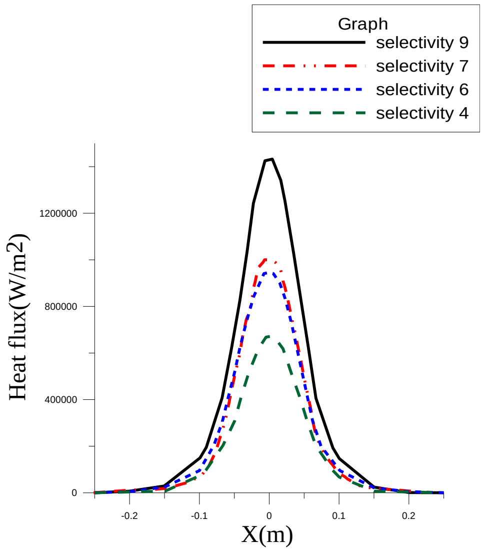

Fig. 5 Solar heat flux distribution in the focal plane of parabolic dish with various receiver selectivities

IV. CONCLUSIONS

In this paper, the application of Monte Carlo ray-tracing method is used to study the concentrated heat flux distribution. Good agreement is achieved between numerical results and Johnston's experimental results. It was found practical to apply SolTrace to determine the heat fluxes in solar applications.

The impact of the reflectivity of parabolic dish on the radiation flux distribution is investigated. We concluded that the increase of the reflectivity ratio leads to an increase in the solar heat flux density concentrated, the peak magnitude of the heat flux distribution increases from 10^6 W/m^2 to 1.210^{6}W/m^2 when increasing the reflectivity ratio from 86 % to 96 %.

The effect of selectivity of the receiver on the radiation flux distribution is also studied. It was noted that the concentrated heat flux increases with increasing of the receiver selectivity. It increases from 671305 W/m^2 to 1.44 10^6 W/m^2 when increasing the value of selectivity from 4 to 9.

Finally a receiver of a selectivity of 9 and a dish with a reflectivity of 0.96 is chosen for the rest of the study in order to allow a high optical performance.

In the following work, Computational Fluid Dynamics CFD simulations will be applied in order to analyse and to optimize the receiver thermal performance.

REFERENCES

[1]] Mills D., 2004. Advances in solar thermal electricity technology. Solar Energy 76 (1–3), 19–31.

[2] Badran, A.A., Yousef, I.A., Joudeh, N.K., Al Hamad, R., Halawa, H., Hassouneh, H.K., 2010. Portable solar cooker and water heater. Energy Conversion and Management 51 (8), 1605–1609.

[3] Furler, P., Scheffe, J.R., Steinfeld A., 2012. Syngas production by simultaneous splitting of H_2O and CO_2 via ceria redox reactions in a

ISSN 2356-5608

high-temperature solar reactor. Energy & Environmental Science 5 (3), 6098–6103.

[4] A. Steinfeld, M. Schubnell, Optimum aperture size and operating temperature of a solar cavity-receiver, Solar Energy 50 (1993) 19-25

[5] G. Johnston, Focal region measurements of the 20 m^2 tiled dish at the Australian national university, Solar Energy 63 (1998) 117-124.

[6] Y. Shuai, X.L. Xia, H.P. Tan, Radiation performance of dish solar concentrator/ cavity receiver systems, Solar Energy 82 (2008) 13-21.

[7] Jeter, S.M., 1986. The distribution of concentrated solar radiation in paraboloidal collectors. Journal of Solar Energy Engineering 108, 219–225.

[8] Johnston G. Flux mapping the 400 m^2 “Big Dish” at the Australian National University. Journal of Solar Energy Engineering, 1995, 117 (4): 290–293

[9] Johnston G, Lovegrove K, Luzzi A. Optical performance of spherical reflecting elements for use with paraboloidal dish concentrators. Solar Energy, 2003, 74(2): 133–140

[10] Doron P, Kribus A. The effect of irradiation directional distribution on absorption in volumetric solar receiver. Journal of Solar Energy Engineering, 1997, 119(1): 68–73

[11] Yong SHUAI, Xinlin XIA, Heping TAN. Numerical simulation and experiment research of radiation performance in a dish solar collector system. Front. Energy Power Eng. China 2010, 4(4): 488–495.

[12] Li Z, Tang D , Du J, Li T,Study on the radiation flux and temperature distributions of the concentrator receiver system in a solar dish/Stirling power facility. Applied Thermal Engineering 31 (2011) 1780-1789.

[13] Y. Rafeeu, M.Z.A. Ab Kadir. Thermal performance of parabolic concentrators under Malaysian environment: A case study. Renewable and Sustainable Energy Reviews 16 (2012) 3826–3835

[14] Skouri S, Salah M, Bouadila S, Balghouthi M, Nasrallah S. Optical, geometric and thermal study for solar parabolic concentrator efficiency improvement under Tunisia environment: A case study. Energy Convers Manage 2013;75: 366–73.

[15] Billy Anak Sup, Mohd. Farid Zainudin , Tanti ZanariahShamsirAli , Rosli Abu Bakar , Gan Leong Ming, Effect of rim angle to the flux distribution diameter in solar parabolic dish collector Energy Procedia 68 (2015) 45 – 52

ISSN 2356-5608