

Improvement of Solar Parabolic Concentrator Thermal Efficiency Correlated To Different Factors

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Abstract: The purpose of this work is the characterization of a solar parabolic concentrator (SPC) designed, constructed and tested in the Research and Technologies Centre of Energy in Tunisia (CRTE) after different modifications realized to the prototype in order to improve the performance of the system. In the first step a modification in the mechanical structure has been done and an optimization of the most performed reflector material has been done by an experimental study of three types of reflectors. In the second step a comparative study of three types of sun tracking systems with two axes is realized to choose the most one. Finally an experimental study is carried out to evaluate the solar parabolic concentrator thermal efficiency after the SPC mechanical and optical optimization. The thermal energy efficiency varies from 40% to 77%; the concentrating system reaches an average concentration factor around 178.

Keywords: Mechanical structure, reflector, sun tracking, thermal efficiency

I. Introduction

The idea of solar-energy concentration is not a new one. The early trials of using solar concentrators go back to the late years of the nineteenth century [1-4]. In the last decades an experimental investigation of a box type solar cooker employing a no tracking concentrator has been done by Negi and Purohit [5] they show that this device can provide improved heat collection and more efficient cooking. The cooker is approximately 10% costlier than the conventional box type solar cooker with a booster mirror. Sun-tracking system plays an important role in the development of high solar concentration applications that directly convert the solar energy into thermal or electrical energy. 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 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 CNRS PROMES laboratory in Odeillo. Using optical measurements made by DLR, they calculated the losses by parabola reflectivity and spillage. Many research works has been done by developing different types of sun tracking systems [8-10]. The aim of this work is to quantify the solar thermal efficiency of the SPC concentrator and after modifications.

II. Description Of The New And The Former Transmission Mechanism

The experimental rig designed and constructed is a solar parabolic concentrator SPC. The experimental system of the solar parabolic concentrator SPC is mainly composed of a parabola provided with an absorber placed by three arms at the focal position. A reflector embedded in a nacelle rotatable around two axes: the horizontal axis (elevation angle) from the support supported by a mast and the second is the vertical axis (azimuth angle) and counterbalancing. The experimental rig is fixed to the ground by a frame.

In order to ameliorate the SPC position accuracy, the previous mechanical structure was modified and the screw-nutactuators mechanical system was replaced by a new reduction gear unit (WG075-40-E-F) transmission mechanism. The new mechanism will permit two rotation movements with advanced mobility degree. The choice of the gear box is related to its design. It is a worm gear speed reducer type which allows a significant rotational speed reduction (upto100) that increases its mechanical torque mean while the non-reversible aspect of the gear provides a position locking for the SPC. All the mentioned characteristics of the transmission mechanism will enhance the position stability and accuracy movement of the SPC. A low rotational speed combined with an important mechanical torque provides a better precision and a good stability of the sun tracking system. Each gear unites driven by a DC motor that puts the parabola mechanism in rotation around the two axes.

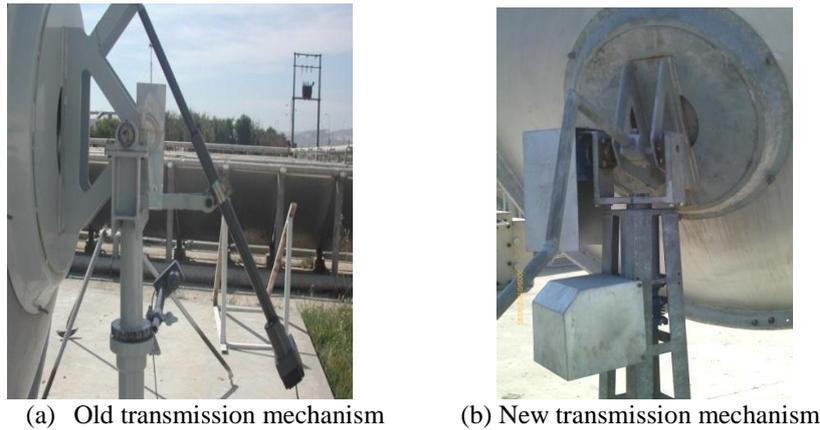


Fig.1. Transmission mechanism modification (a), (b)

III. Comparative Study Of Three Types Of Sun Tracking Systems With Two Axes

The tracking position of a mobile object has been the objective of several research studies in order to provide the adequate pursuit systems for specific applications. Concentrated solar technologies efficiency relies partially on solar tracking ability and the development of such systems become essential. However, this work contributed towards that goal, with a comparative experimental study of three different sun tracking systems used to ensure the movement of a solar parabolic concentrator around two axes.

The LDR sun tracking system the first sun tracking system is an azimuth–altitude dual axis tracker, which displaced the SPC reflector facing the sun by two screw-nutactuators. It is considered as an active tracking system. This tracker measures the sunlight intensity to determine its position.

First date and time based sun tracking system the date and time based sun tracking system is a programmed dual axes tracker. It is a passive sun tracking system (Fig. 8). The parabolic collector is oriented towards the sun with two direct current (DC) electric motors powered by electrical control unit basing on the signal delivered by a control module.

The second date and time based sun tracking system provided an advanced accuracy (2.5mrad) and a better stability with relatively cheap price (1300 €). It is the adequate follower of this application. The proposed two-axis sun tracking system was characterized by movement stability and a fairly simple and low-cost electromechanical set-up with low maintenance requirements and ease of installation and operation.

Table 1: Cost estimation of different components of each sun tracking system

Sun tracker	components	Cost(€)	Total cost
LDR sun tracking system	Two Screw-nut actuators	250	~1.000 €
	Two LDR sensors	100	
	PIC microcontroller 16F876,	600	
	Two integrated circuit ULN 2003	50	
First date and time based sun tracking system	Two Screw-nut actuators	250	~2.000 €
	Electrical control circuit ECC	140	
	Agilent-3970 with HP control module	1800	
Second date and time based sun tracking system	Two Reduction gear unit (WG075-40-E-F)	300	~1300€
	Two DC motors	100	
	Two electrical control circuit (ECC)	300	
	Programmable logic controller (PLC)	600	

IV. Optimization of The SPC Reflector Material

Fig. 2 gives the variation of the receiver temperature as function of time using three types of reflectors. These experiences are done in 3 days under comparative climatic conditions. An average insulation and ambient temperature equal to 800 W/m² and 25 °C respectively. The first reflector (R1) is aluminum sheet with reflecting coefficient of 0.80; we note that the obtained receiver temperature with this reflector is around 250 °C. Using the second reflector (R2) that is aluminum paper with reflecting coefficient of 0.85, the average absorber temperature is equal to 320 °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 metalized weather able acrylic film. It has a solar weighted total hemispherical reflectance of 94% at air mass 1.5 °. Solar mirror

film offers a number of significant advantages over traditional glass mirrors, including higher reflectance, less weight and improved mechanical properties.

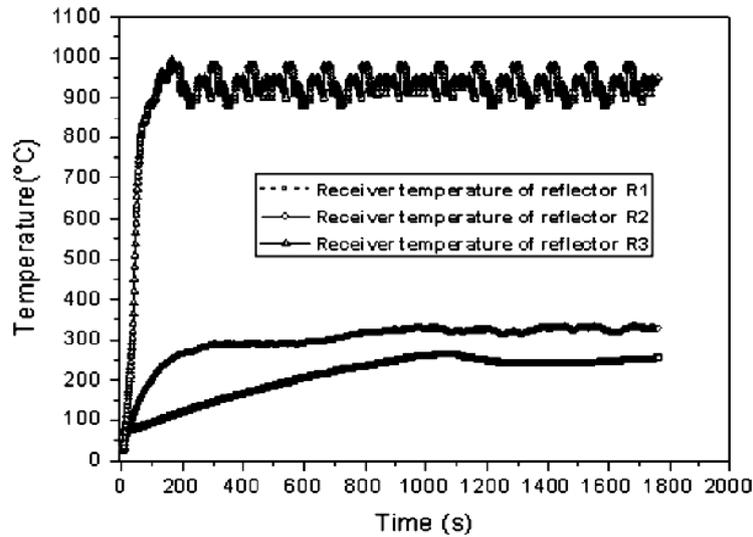


Fig.2. The temporary variations temperatures using three reflectors.

V. Energy Analysis

To determine the concentrated solar flux after all changes made at the parabolic solar concentrator. We used The disk method is based on the determination of concentrated flux using the energy balance by determining the different thermal losses .while 5 type K thermocouples (with ± 0.5 °C accuracy) were used for instrumentation of the receiver disk. The latter were placed in the internal face of the plate at $z = 0.005$ m depth. In Table 2 the radial locations of these thermocouples are reported, and in Fig. 3 their distribution is shown. Two thermocouples are used for each radial position. The thermocouples were channeled through grooves of 0.005 m depth,

Table 2 Characteristics of the disk.

Material of the disk: stainless Diameter of the disk: 0.012m		
Position in the disk	Symbol of the position	Distance from the center of the disk, m
Position 1	P1	0.05
Position 2	P2	0.025
Position 3	P3	0
Position 4	P4	0.025
Position 5	P5	0.05

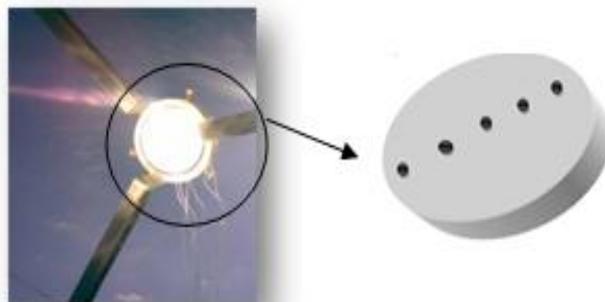


Fig. 3. Disk receiver.

The energy analysis is carried out to evaluate the system efficiency. The energy analysis presented in this section is mainly based on the first law of thermodynamics. The theoretical model employed for the study of the SPC is based on a thermal energy balance. The solar power absorbed Q_a by the receiver of solar parabolic dish system is given by [11]:

$$Q_a = G^* A_a \eta_{op} \quad (1)$$

Where G^* , A_a and η_{op} are solar beam radiation, aperture area of dish concentrator and optical efficiency, respectively. The following equation form can be used to perform an approximated optical efficiency analysis as.

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

Where λ , ρ and $\tau \cdot \alpha$ 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

the useful thermal power gain Q_u can be determined by.

$$Q_u = Q_a - Q_p \quad (3)$$

Where Q_a is the solar power absorbed by the receiver of solar parabolic dish system and Q_p heat losses from a receiver occur due to the temperature difference between the receiver, conductive losses Q_{p-cd} , convective losses Q_{p-cv} and radiative losses.

$$Q_p = Q_{p-cv} + Q_{p-r} + Q_{p-cd} \quad (4)$$

Heat losses from a receiver Q_p occur due to the temperature difference between the receiver and its surroundings and depend on the geometry of the receiver and the collector. In this study, heat losses from the receivers are classified as conductive loss Q_{p-cd} , convective loss Q_{p-cv} and radiative loss by surface emission from the inner surface of the receiver Q_{p-r} . Research has showed that the receiver conduction losses Q_{p-cd} represent a small fraction of the receiver thermal losses [11]. In order to evaluate the conductive loss from receiver, the following equation is used [11].

$$Q_{p-cd} = \left[(1/(1/A_0 h)) + (l/K_t (A_0 A_w)^{1/2}) \right] * (T_r - T_a) \quad (5)$$

To determine the outside convective heat transfer coefficient by wind h_w , the following correlations recommended by McAdams [11] for the flow of air across a tube can be used.

$$\left\{ \begin{array}{l} h_w D_0 / k_{air} = 0.40 + 0.54 (v_w D_0 / \nu_{air})^{0.52} \quad \text{for } 0.1 < v_w D_0 / \nu_{air} < 1000 \\ h_w D_0 / k_{air} = 0.30 (v_w D_0 / \nu_{air})^{0.6} \quad \text{for } 1000 < v_w D_0 / \nu_{air} < 50000 \end{array} \right\} \quad (6)$$

The convective losses in the receiver represent a significant fraction of the total losses in a dish system. Convective losses are a function of cavity temperature and geometry, aperture orientation, diameter, and wind velocity. Convection loss Q_{p-cv} of the receiver system can be calculated using the Newton's Cooling Law.

$$Q_{p-cv} = h_{cv} A_c (T_r - T_a) \quad (7)$$

The radiation losses in the receiver contribute to a significant fraction of the total losses in the receiver and in the total dish system. Unlike convection losses; radiation losses are relatively constant throughout the day once a steady-state temperature has been reached for the heater head temperature. Radiation loss Q_{rad} of the receiver system is given by:

$$Q_{rad} = Q_{rad.ref} + Q_{rad.emit} \quad (8)$$

The radiation losses due to reflectance $Q_{rad.ref}$ of the cavity surfaces depend of the cavity receiver effective absorptance, and it is given by the following equation:

$$Q_{rad.ref} = (1 - \alpha_{eff}) Q_a \quad (9)$$

The effective absorptance is given by the following equation [11]:

Solar radiation is being reflected off from the cavity walls and back through the aperture. The general equation for net radiation exchange [31, 34] due to emission is given by the following equation:

$$Q_{rad.emit} = \epsilon_{eff} \sigma A_c (T_r^4 - T_a^4) \quad (10)$$

The thermal efficiency of the concentrator η_{en} based on the first law of thermodynamics is defined as the ratio between the useful energy and the direct solar radiation incident on the collector:

$$\eta_{en} = 100 Q_u / I_h^* \tag{11}$$

The mean concentration factor of the system is giving by:

$$C_R = A_c Q_u / A_a I_h^* \tag{12}$$

I_h^* is The direct solar radiation

VI. Results And Discussion

Once the analytical study has been fit to the experimental results, it is possible to evaluate temperatures at different positions inside the disk, and in particular, on the center of the disk (P3). In Fig.4 the temporary temperature distribution inside the disk is presented. As can be observed in this figure, the mean value of the temperature on the surface of the receiver plate (is around 650 °C) is very high, and very different to the ambient temperature (23°C).the most temperature obtained in the disk is in the center, we remark a symmetric temperature distribution .

Nevertheless, the heat losses by convection and radiation are small, due to the size of the spot and the mean temperature of the disk. In fig.10 are summarized the average heat losses from the disk in different positions we note that the convective heat losses towards the ambient are close to 15 % and the radiative heat losses are close to 80 %.it is clear that conduction losses is neglected in thermal balance and radiation losses are so important in concentration technologies. We show that minimum overall losses are in position 3 at the center of the disk.

Experimental results of the energetic efficiency of the solar parabolic concentrator after and before modification using the disk as an absorber are depicted in Fig.6. it reach her maximum at the center of the disk that is around 15 % using the previous prototype and after mechanical, optical and tracking modifications we obtained a performed solar concentrator with average value of the thermal efficiency equal to 70% .

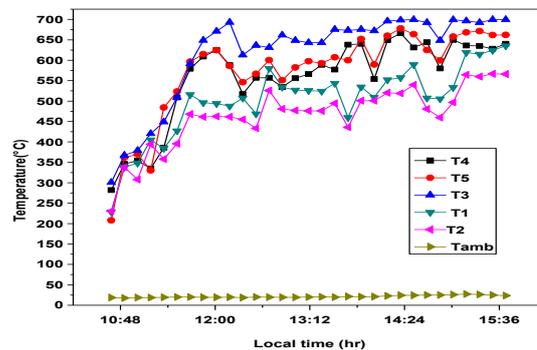


Fig. 4. Temporary temperature variation in different disk positions.

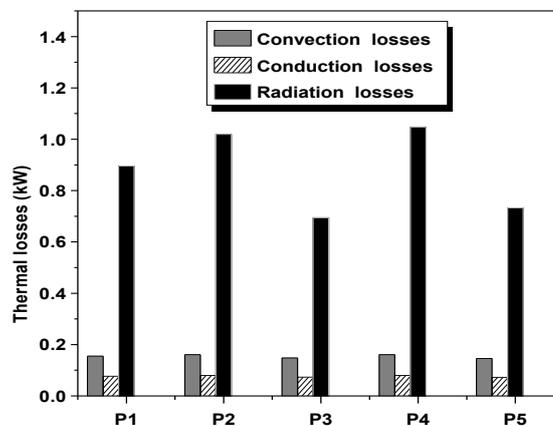


Fig. 5. Spatial variation of the SPC thermal losses.

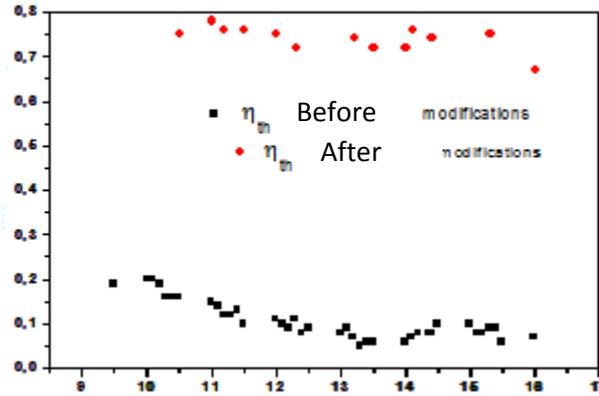


Fig. 6. Thermal efficiency of SPC after and before modifications

VII. Conclusion

This work is a contribution of a solar parabolic concentrator equipped with a programmed sun tracking system, an absorber and measuring instruments. The main findings of the present study to increase the thermal efficiency of the system is that after mechanical, optical and tracking modifications we obtained a performed solar concentrator with average value of the thermal efficiency equal to 70%.

NOMENCLATURE

A_a	Aperture area of dish concentrator, m^2 .
A_0	Area of the outer surface of the receiver, m^2 .
A_{ca}	Aperture area of the cavity, m^2 .
A_c	Total inner surface area of the cavity, m^2 .
A_w	Area of the inner side of receiver, m^2 .
C_R	Mean concentration factor.
D_0	Dish diameter, m .
I_h^*	Direct radiation, W .
$Q_{rad,emit}$	Radiation losses due to emission, W .
Q_u	Useful thermal power gain, W .
Q_{p-cv}	Convection losses, W .
Q_{p-cd}	Receiver conduction losses, W .
Q_{p-r}	Radiation losses, W .
Q_p	Receiver thermal losses, W .
$Q_{rad,ref}$	Radiation losses due to reflectance, W .
Q_a	Solar power absorbed, W .
G^*	Solar beam radiation, W .
D^*	Solar diffuse radiation, W .
T_r	Temperature of receiver, $^{\circ}C$.
T_a	Ambient temperature, $^{\circ}C$.

η_{en}	Energy efficiency of SPC, % .
η_{ex}	Exergetic efficiency of SPC, % .
η_{op}	Optical efficiency, % .
ρ	Dish reflectance
η_{en}	Energy efficiency of SPC, % .
$\tau \alpha$	Transmittance–absorptance product.
γ	Intercept factor of receiver
ν_{air}	Air viscosity, m^2 / s .

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