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Optical and thermal evaluations of a medium temperature parabolic trough solar collector used in a cooling installation

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ABSTRACT

Concentrated solar power technology constitute an interesting option to meet a part of future energy demand, especially when considering the high levels of solar radiation and clearness index that are available particularly in Tunisia. In this work, we study a medium temperature parabolic trough solar collector used to drive a cooling installation located at the Center of Researches and Energy Technologies (CRTEn, Bordj-Cedria, Tunisia). Optical evaluations of the collectors using photogrammetric techniques were performed. The analysis and readjustments of the optical results were conducted using a Matlab code. Therefore, slope errors ranged from −3 to +27 milliradian and the height deviations from the ideal shapes of the parabolic trough collector were 2.5 mm in average with a maximum of 7.5 mm. The intercept factor was determined using both the method of the total optical errors and the camera target method leading respectively to 0.62 and 0.7. Thus, the values of the overall optical efficiency were 0.48 and 0.514. Conversely, a thermal performance testing of the parabolic trough collector was conducted leading to the thermal efficiency and the heat losses evaluations. The instantaneous thermal efficiency reached a maximum of 0.43 but it did not exceed the value of 0.30 when the reflector becomes dirty by dust deposition. This study was also an opportunity for suggesting some recommendations for the enhancement of the PTC performances.

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1. Introduction

In the solar thermal applications needing relatively high temperatures, the energy is optically concentrated before being converted into heat. The sunlight is concentrated in the focal plane, with the aim of maximizing the energy flux on the absorber surface. At present the Parabolic Trough Collector (PTC) can be considered as the most advanced solar thermal technology. It represents the most mature solar technology to generate heat at temperatures up to 400 °C for solar thermal electricity generation [1]. The other kind of PTC is destined to provide heat to processes that need temperatures between 100 and 250 °C. These applications are mainly industrial process heat, such as cleaning, drying, evaporation, distillation, pasteurization, sterilization, cooking, among others, as well as heat driven refrigeration and cooling. Typical aperture widths are between 1 and 3 m, total lengths vary between 2 and 10 m by row and geometrical concentrating ratios are between 15 and 20 [2]. The PTCs of this group are called “medium temperature collectors”.

As far as the importance of the medium temperature parabolic trough solar collector applications, special concerns were attributed by some organizations and researchers to this kind of solar collectors. In fact, the International Energy Agency’s (IEA) developed the Task 33/IV program to improve and optimize medium temperature solar-thermal collectors for solar industrial processes heat. They reported that most solar applications for industrial processes have been used on a relatively small scale and are mostly experimental in nature [3]. In addition, Cabrera et al. [4] performed a literature survey on worldwide applications of the medium temperature PTCs to drive air conditioning and refrigeration facilities. They reported that, despite the relatively important solar fraction given by the PTCs compared to other solar collector technologies, the yearly rate of grow of this type of installations is still low. Recently, Minder [5] presented a medium temperature CSP field for indirect steam generation used for milk process industry in Switzerland. The field area is 115 m^2 and the system uses thermal oil as heat transfer fluid and works up to 190 °C. Besides, Sagade et al. [6] described the experimental results of the prototype parabolic trough destined for process heat applications made of fiberglass-reinforced plastic with its aperture area coated by aluminum foil. They tested the steel receiver coated with black proxy material. They achieved an instantaneous efficiency of 51% and 39%

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Nomenclature

C	the geometric concentrating factor
DNI	the incident normal solar radiation (W/m^2)
F	focal plan position of the parabola
f	focal length of the parabola
p	Parameter of the parabola
S_x	the mirror surface local slope
Tm	average temperature of the receiver fluid (°C)
Ta	ambient temperature (°C)
Xa, Ya, Za	absolute coordinates
X, Y, Z	local coordinates
ΔS_x	the local slope error
ΔZ	the height deviations regarding the ideal collector
$\Delta\alpha$	the slope deviations
α	the surface curvature
$\sigma_{optical}$	standard deviation of the total optical errors (mrad)
σ_{slope}	standard deviation of slope errors (mrad)
$\sigma_{specular}$	standard deviation of specular errors (mrad)
$\sigma_{displacement}$	standard deviation of receiver displacement errors (mrad)
$\sigma_{tracking}$	standard deviation of tracking errors (mrad)
σ_{sun}	Gaussian distribution for the errors caused by the sun shape
σ_{tot}	the standard deviation of the total errors
γ_n	the intercept factor at normal incidence angle
Ψ	rim angles
η_O	the optical efficiency
ρ_m	average specular reflectance of the mirror
τ	transmittance of the glass envelope
α_c	absorptance of the absorber surface coating

Subscripts and abbreviations

d	design data
m	measured data
PTSC	parabolic trough solar collector
HTF	heat transfer fluid

with and without glass cover, respectively. Others authors [7–9] studied the thermal performances of medium temperature parabolic trough particularly the thermal characterization of the receiver such as overall heat loss, end loss and thermal emittance of the coating. In order to improve the performances of these kinds of PTC and their usage for industrial process heat, much more investigations in the design, simulation, experimental and evaluating technique ways are still required [10].

As the optical quality in particular the geometric precision of the solar concentrators has a significant impact on the efficiency and thus on the performance of the PTCs plants, many studies were performed on the surface measurement methods of solar concentrators. Thomas et al. [11] and Xiaoa et al. [12] presented a review of available methods for surface shape measurement of solar concentrator. They gave a detailed description of the very used techniques: the photogrammetry, the deflectometry and the Video Scanning Hartmann Optical Test (VSHOT). The most studied measurement technique was the photogrammetry which is a method based on photographic processes and widely used for the 3-dimensional measurement of objects. The use of photogrammetry for the parabolic trough collector shapes evaluations was performed by García-Cortés et al. [13], Shortis et al. [14], Fernández-Reche et al. [15] and Pottler et al. [16]. Digital close range photogrammetry has proven to be a precise and efficient measurement technique for the assessment of shape accuracies of solar concentrators and their components. The combination of high quality mega-pixel digital still cameras, appropriate software, and calibrated reference scales in general is sufficient to provide coordinate measurements with precisions of 1:50,000 or better. The extreme flexibility of photogrammetry to provide high accuracy 3D coordinate measurements over almost any scale makes it particularly appropriate for the measurement of solar concentrator systems. In the last years, close range photogrammetry has become a helpful tool to perform this optical evaluation, mainly due to the commercial availability of high resolution digital cameras and photogrammetry software packages [17].

In this study, we present a medium temperature parabolic trough solar collector used to drive a cooling installation located at the Center of Researches and Energy Technologies (CRTEn, Bordj-Cedria, Tunisia). In a previous study [18], dealing with the description of the cooling installation, the results of the running and the global performances COP were presented. Nevertheless, in this work, we focused on the solar loop of the installation and particularly the used parabolic trough solar concentrator. Optical evaluations of the collectors using photogrammetric techniques were performed. To establish that a parabolic trough concentrator has a good optical quality, it was documented that tolerances must be lower than 3–5 mm, and close-range photogrammetry is an accurate enough technique to measure these surfaces as accuracies lower than 1 mm can be easily achieved [16]. In addition, the reflector of the considered parabolic concentrator is polished aluminum without glass cover which allowed the positioning of the targets exactly on the desired surface contrarily to the silvered glass covered mirror when the targets are placed about 4 mm above the reflector due to the glass thickness [14]. Therefore, the uncertainties of the results are reduced. Theses raisons put together with the low-cost of the technique allowed us to adopt the photogrammetry.

In the following paragraphs of the text, the procedures of images capturing and 3D processing were presented. These procedures use combination of high quality megapixel digital still cameras, appropriate software, suitable targeting and calibrated reference scales to provide coordinate measurements with high precisions. The analysis and readjustments of the optical results were conducted using a Matlab code leading to the slope errors and the height deviations from the ideal shapes of the parabolic trough collector. The intercept factor was determined using the method of the total optical errors and the camera target method. The overall optical efficiency was then performed. Moreover, a thermal performance testing of the parabolic trough collector was presented leading to the thermal efficiency and heat losses evaluations. In addition some recommendations for the enhancement of the PTC performances were suggested.

2. General description of the solar cooling installation

The solar cooling installation is used to supply chilled water to a research laboratory building located in the Research and Technology Center of Energy in Borj Cedria, Tunisia. It consists of 39 m^2 linear parabolic trough solar collectors (PTSC) coupled to a 16 kW double effect absorption chiller, a cooling tower, a backup heater, two tanks for storage and drain-back storage and a set of fan-coils installed in the building to be conditioned. A general scheme of the installation is presented in Fig. 1.

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