Performance Evaluation of a Parabolic Trough Collector Applying SolTrace and TRNSYS

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Abstract: This work performs an optical and thermal analysis of an artisanal parabolic trough collector, developed by the Research Group on energy, automation and control systems of the Technological Units of Santander. For this, the Monte Carlo ray tracing method is applied through the SolTrace Software and the TRNSYS dynamic simulator. Three configurations with higher proportions in the geometry of the real system are proposed in order to identify the incidence of this parameter in the performance of the device. The results showed that the performance of the device in a hydro-dynamic way is relatively inferior to the hydro-static system, that is, the simulations in SolTrace present higher values than those carried out in TRNSYS. Additionally, the performance of the system is directly affected by the increase in the reflection area. Finally, the geometry that would generate an increase in the performance of the parabolic trough collector is identified.

1 INTRODUCTION

Solar concentrating technology (CSP) is made up of reflector systems that concentrate direct normal radiation (DNI), in a focal point that can be linear or punctual(Lovegrove & Stein, 2021) (Lovegrove & Pye, 2021). They are classified into 4 technologies (Pitz-Paal, 2014): Fresnel linear collectors (LFC) (Tarazona-Romero et al., 2020) (Tarazona-Romero et al., 2021a), parabolic trough collector (PTC) (Moya, 2021), Parabolic Disc (PD)(Schiel & Keck, 2021) and Central Tower (CT) (Vant-Hull, 2021). Linear LFC and PTC systems are known as 2D systems and operate in a temperature range between 100 ° C and 500 ° C (Häberle & Krüger, 2021), while PD and CT point systems are known as 3D systems and have reached a working temperature up to 1000 ° C(Ballestrín et al., 2021) (Meyer et al., 2021).

PTC technology currently presents greater maturity and application at a centralized level than the others. This is due to the fact that it presents higher yields, as well as lower manufacturing, operation and maintenance costs (Barone et al., 2019). On the other hand, its application at a decentralized level is an option aimed at the production of hot water and or steam, for small residential systems in urban or isolated areas, with favorable DNI conditions (González Martínez & Villabona Niño, 2021).

Its design is simple, it is composed of an area of solar reflection, generally made up of highly reflective mirrors that direct the DNI to a linear focal point through which a heat transfer fluid is circulated (Ahlgren et al., 2018). Decentralized systems use pumping systems and simple thermodynamic cycles for their operation (Gowda et al., 2020). Meanwhile, small-scale systems use thermosyphons or small solar pumping units for their operation(Dutta et al., 2021) (Fernández-García et al., 2018).

The development of CSP systems and specifically PTC, is accompanied by design processes and analysis of optical and thermal performance of the units through different methodologies such as(Malekan et al., 2021) (Yang et al., 2020): Monte Carlo ray tracing method (MTCR) (González

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Martínez & Villabona Niño, 2021), numerical simulation (Wu et al., 2021), dynamic simulations (Crespo et al., 2021) and CFD modeling (Kouche & Gallego, 2021). Highlighting the MTCR methodology for its precession and simplicity to analyze renewable systems in a stationary way (Mohammadi et al., 2021) and dynamic simulations, for its analysis under time intervals and desired operating meteorological conditions (Ziyaei et al., 2021).

Eventually, the Research Group on energy, automation and control systems (GISEAC) of the Unidades Tecnológicas de Santander (UTS), developed an artisan prototype of a parabolic trough collector (PTC) under the concept of appropriate technology(González Martínez & Villabona Niño, 2021) (Forero Monsalve & Jaimes Grimaldos, 2021). The device was experimentally evaluated with a steady flow and presented low efficiencies, due to the fact that it was manufactured with local materials and labor, generating a low-cost unit.

Finally, the present work seeks to analyze the performance of a PTC applying the Monte Carlo ray tracing method (MTCR) through SolTrace Software and a dynamic simulation through TRNSYS, evaluating three geometrically different systems to the real PTC, but with the same construction materials, varying the area of reflection. Consequently, section 2 presents the methods and materials used for the development of the simulations, including characteristics of the real prototype and the geometric variations to be simulated. Section 3 presents the results obtained from the simulation process and, finally, section 4 describes the main conclusions of the development of the work.

2 METHODS AND MATERIALS

2.1 PTC System Features

Table 1 presents the geometric and optical characteristics of the real PTC prototype that was previously subjected to an experimental process and presented a performance of 36.9% for a steady state of flow. Additionally, the Information in Table 1 allows to feed simulation tools with real data, generating a simulation process based on operating parameters of the real PTC system. Finally, Figure 1 presents the 3D modeling of the real PTC system that allowed defining the geometric parameters presented in Table 1.

Table 1: Original PTC system features.

Variable	
ψ Enge angle	80°
a (Opening width)	550 mm
l (Collector length)	1700 mm
f (Focal length)	164 mm
De (Receiver tube outer diameter)	15.87 mm
Di (Receiver tube Inner diameter)	13.85 mm
Aa (Collector opening area)	0.935 m^2
Ar (Receiver tube area)	0.04985 m^2
Co (Concentration ratio)	11,85 mm
Black paint emissivity	0.98
Black paint solar absorptivity	0.98

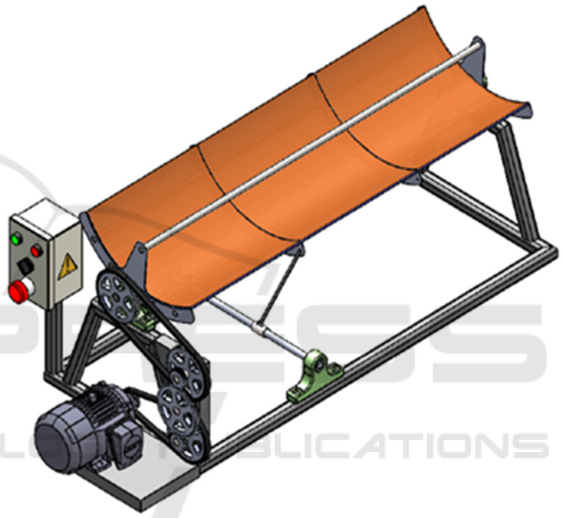

Figure 1. PTC 3D Modeling.

2.2 Geometric Characteristics of the PTC Systems to Simulate

Table 2 presents the three geometries proposed to carry out the simulation processes of the PTC system, where parameters of the reflection area and concentration system are modified.

Table 2. Characteristics of the three PTC systems proposed to simulate.

Characteristics	System N°1	System N°2	System N°3
Receiver tube radius [m]	0.0095	0.0095	0.0095
Receiver tube length [m]	2.0000	2.0000	2.0000
Receiver tube area [m^2]	0.1197	0.1197	0.1197
Sheet width [m]	0.8000	0.7000	0.6000
Mirror width [m]	0.6970	0.6099	0.5227
Mirror length [m]	2.0000	2.0000	2.0000
Mirror area [m^2]	1.3940	1.2198	1.0454

2.3 Geometric Characteristics of the PTC Systems to Simulate

To develop the optical and thermal analysis process, the following tools were used:

SolTrace: it is an open access tool that applies the Monte Ray Tracing methodology based on C ++ code. SolTrace simulates the solar position with respect to a CSP and projects a series of solar rays with a specific DNI, this process allows to identify the intensity of flux on the surfaces of the CSP.

TRNSYS: is a tool that allows to dynamically simulate renewable energy systems and allows evaluating the behavior of the systems in defined time intervals, controlling intrinsic variables in the process and including geometric parameters and optical characteristics of the devices. Figure 2 presents the circuit developed for the analysis of the different proposed PTC systems.

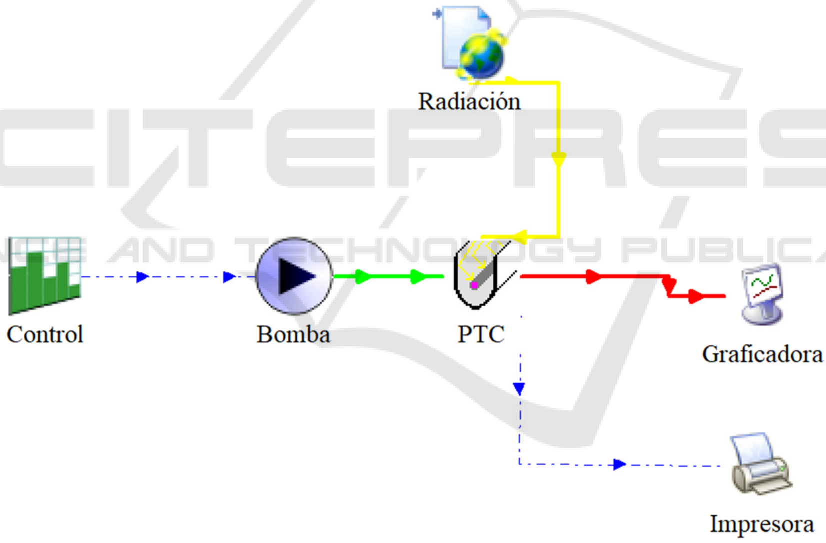

Figure 2. PTC connection diagram.

3 RESULTS

Table 3 presents the results of the simulations carried out in SolTrace and Figure 3 presents the graph of the performance of each PTC in its simulation process, highlighting:

The flow intensities showed higher values in system 1, which presents the geometric design with the largest area of reflection. A decreasing trend of intensity values is reflected as the size of the reflection area decreases.

The system with the highest performance was the system with the smallest reflection area of the three proposed geometries, this is due to the heat transfer losses to which the device is subjected to a greater reflection area as it is an artisanal system.

Systems N° 1 and 2 simulated are close to the performance of the experimental system at 0.5%. System N ° has values much higher than the experimental system.

Table 3: SolTrace simulations results.

Variable	System N°1		System N°2		System N°3		Real Syste m
	Collector mirror	Receiver tube	Collector mirror	Receiver tube	Collector mirror	Receiver tube	
Peak flux	2534.81	70961.6	2236.92	70730.7	2382.14	65260.6	/
Min flux	0	0	0	0	0	0	/
Average flux	187.294	4334.41	195.537	3864.51	190.571	3351.42	/
Performance	36.27%		36.58%		45.46%		36.9%

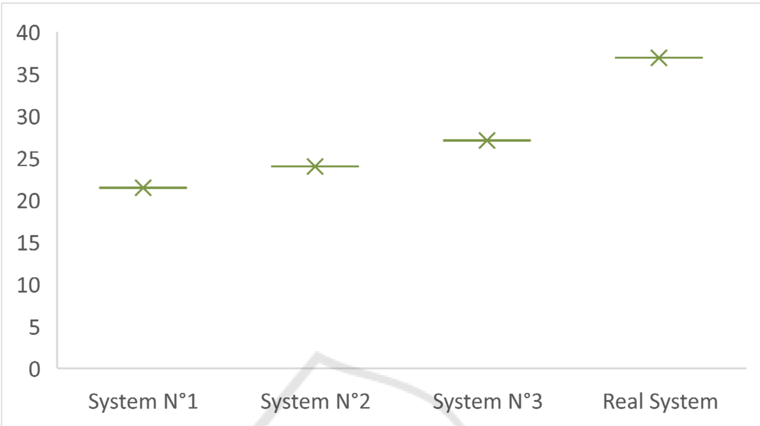

Figure 3: Soltrace Simulation Results.

For its part, Table 4 presents the results of the simulations carried out in TRNSYS and Figure 4 presents the graph of the performance of each PTC in its simulation process, highlighting:

- The system with the highest performance was system 3. There is a tendency to decrease the performance of the unit as the thickness of the material of the reflection area increases.
- The difference between the data obtained by the simulation and the real experimentation is in the range between 10 and 15%

Table 4. TRNSYS simulations results.

Configuration	Annual average efficiency
System N° 1	21.45%
System N° 2	23.98%
System N° 3	27.07%
Real System	36.9 %

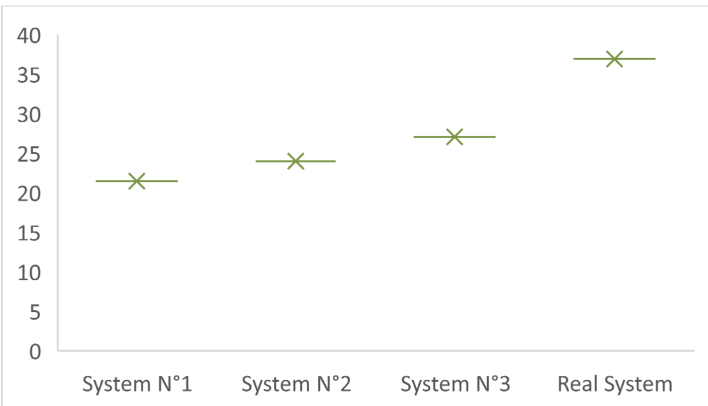

Figure 4. TRNSYS simulation results.

Finally, the two tools reflect that the system with the highest performance is system 3. There is a difference between the values of each tool, but this is due to the methodology applied by each one. For its part, SolTrace is a system that stationary evaluates the operation of the unit, while TRNSYS subjects the system to a dynamic analysis in a defined time interval and given meteorological conditions.

4 CONCLUSIONS

The evaluation of thermal performance was developed based on three improvement proposals, manipulating physical variables such as the width of the sheet, length of the collector, entry angle and radius of the absorber tube, obtaining a considerable decrease in the factors that address critically collector performance. Consequently, it was determined that a collector with a very large area may have a higher incidence of radiation, however, it has higher losses in the system. For its part, a collector with a very small area does not allow optimal use of the heat from the sun's rays.

In addition, the simulation process of the three proposals applying Soltrace highlights:

- The proposed geometry corresponding to the 0.8m sheet width, yielded a result in the thermal performance of 36.28%, observing a decrease of 0.64% compared to the performance of the system presented by the original configuration of the prototype.
- In turn, the proposed geometry corresponding to the 0.7m sheet width, yielded a result in the thermal performance of 36.58%, observing a decrease of 0.34% compared to the performance of the system presented by the original configuration of the prototype.
- Added to this, the proposed geometry corresponding to the 0.6m width of the sheet, yielded a result in the thermal performance of 45.48%, observing an increase of 8.54% compared to the performance of the system presented by the original configuration of the prototype.
- Finally, the proposed geometry that generated an increase in the thermal performance of the system for the simulations in Soltrace, corresponds to the geometry obtained with the 0.6 mm sheet width, being an optimal configuration for the reception of radiation and reduction in heat losses.

On the other hand, the simulation process of the three configurations applying the TRNSYS software highlights:

- The proposed geometry corresponding to the sheet width of 0.8m, yielded a result in the thermal performance of 21.45%, observing an increase of 4.81% compared to the performance of the system presented by the original configuration of the prototype.
- In turn, the proposed geometry corresponding to the 0.7m sheet width, yielded a result in the thermal performance of 23.98%, observing an increase of 7.34% compared to the performance of the system presented by the original configuration of the prototype.
- Added to this, the geometry corresponding to the 0.6 meter sheet width, showed a result in thermal performance of 27.07%, being 10.43% higher than the performance presented by the original prototype configuration.
- Finally, the three proposed configurations generated an increase in the thermal performance of the system for the simulations in TRNSYS, highlighting the geometry obtained with the 0.6m sheet width, being an optimal configuration for the reception of radiation and reduction in the heat losses, thus confirming the results obtained in the Soltrace simulations.

Finally, based on the analysis of the results, it was determined for the three study cases that the configuration with a smaller area of reflection generates a significant improvement in the thermal performance of the system, as can be seen in the results for the Three proposals for geometric improvement analyzed, being a viable configuration to be applied to the current Parabolic Cylinder Collector prototype. It is important to highlight that the three configurations have a greater area of reflection than the current system, so it is concluded that the increase in the area does affect an increase in the performance

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