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Absorber design for a Scheffler-Type Solar Concentrator

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HIGHLIGHTS

- Receiver and absorber design methodology based in a solar image in the focal surface.
- Stirling absorber dimensions based in a solar image in the focal surface of a STSC.
- Comparative study of a solar image in the focal surface from different optical model.
- A Monte-Carlo ray-tracing method was used to set STSC cavity receiver aperture.

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ABSTRACT

Ray tracing software, digital close range photogrammetry and the Monte-Carlo ray-tracing method have proven to be precise and efficient measurement techniques for the assessment of the shape accuracies of solar concentrators and their components. This paper presents a new method and results for the geometric aspect of a focal image for a Scheffler-Type Solar Concentrator (STSC) using ray tracing, digital close range photogrammetry and the Monte-Carlo ray-tracing method to establish parameters that allow for the design of the most suitable absorber and receiver geometry for coupling the STSC to a Stirling engine. The results of the ray tracing software, digital close range photogrammetry and Monte-Carlo ray tracing technique in STSC are associated with a Stirling receiver. When using the method to perform simulations, we found that the most suitable solar image geometry has an elliptical shape and area of 0.0065 m^2 on average. Although this result is appropriate, the geometry of the receiver is modified to fit an absorber and cavity receiver to improve the heat transfer by radiation.

1. Introduction

In the search for improved efficiency and profitability of renewable energy, a solar concentrator system must be designed to transfer the maximum amount of available radiation to the receiver, which must be designed to absorb the maximum amount of incident radiation. Optics play a key role in concentrating systems because solar radiation has to be collected through appropriate solar tracking means and transmitted to the receiver with maximum efficiency, ensuring the required level of flux density.

Several studies have been developed to improve receivers for different types of solar concentrators using the Monte-Carlo ray tracing method, ray tracing software and photogrammetry. Joshua et al. presented a study using finite element modelling and ray tracing of parabolic trough collectors for an evaluation of the optical intercept factors with gravity [1]. Men Wirz presented a Monte-Carlo ray tracing method coupled to a finite volume solver to model 3D heat transfer in a parabolic trough solar concentrator system [2]. He et al. presented a comparative and sensitive analysis for parabolic trough solar collectors with a Monte-Carlo ray tracing optical model [3]. Qibin et al. improved the performance of the parabolic trough solar collector system with a solar ray trace method and the finite element method [4]. Lara et al. presented a study with ray tracing for Fresnel concentrators [5]. Ya-Ling et al. studied the optical and thermal performance of a linear Fresnel solar reflectors using molten salt as the heat transfer fluid [6]. Georgiou et al. investigated caustics as an alternative to ray tracing to evaluate heliostat mirrors [7]. Rogers et al. presented ray tracing results for the concentration of sunlight with an immobile primary mirror and an immobile receiver [8]. Karni et al. studied solar receiver design and used a Monte-Carlo ray tracing technique to improve a solar window receiver [9]. [10–12] and presented several studies on the design of receivers in a parabolic dish using ray tracing software to improve the efficiency and design.

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Nomenclature

A	area (m^2)
d	diameter (m)
f	focal length (m)
I	direct solar radiation (W/m^2)
L	thickness (m)
p	distance from the concentrator to the focal point (m)
n	number of pipes (–)
Q	energy flux density (W/m^2)
r	radius (m)
w	width of the focal image (m)
Greek symbols	
ε	subtended angle of the sun
ρ	surface reflectance (–)
φ	intercept factor (–)
θ	inclination angle of the cavity (°)
ψ	rim angle (°)
Subscripts	
abs	absorber
ap	aperture
cav	cavity
Eff	effective
ext	outside
int	inside
rad	radiation
rec	receiver
tub	pipe

The design of fixed focus solar concentrators was recently investigated in [13,14]. In 2013, the Solar World Congress presented a study about ray-tracing for fixed focus solar concentrators [15]. However, no study or methodology exists that can establish the absorber and receiver dimensions and parameters of a Stirling engine coupled to an STSC based on a solar image in the focal plane.

In this paper, we developed and applied a methodology to establish the absorber and receiver dimensions of a Stirling engine coupled to an STSC based on a solar image in the focal plane obtained from comparison of the Monte-Carlo ray tracing method, ray tracing software and thermograph camera. The design parameters for an STSC and Stirling absorber were previously reported in 2013 [16,17].

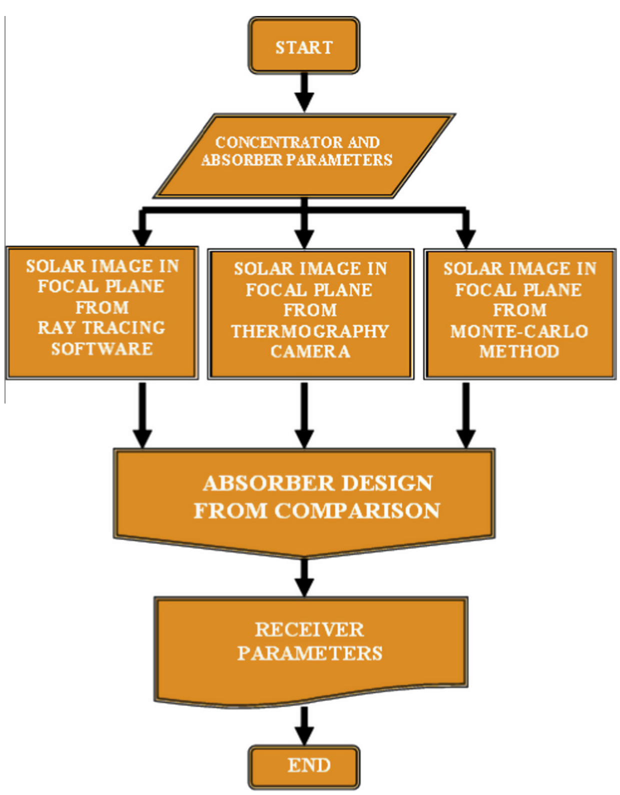

Fig. 1. Flowchart for the absorber and receiver design.

2. Methodology

The methodology used for the simulation is shown in Fig. 1. This methodology consists of three stages: the first is to establish the parameters of the concentrator and absorber, the second stage consists of obtaining the focal image by means of different methods and finally, in the third step, the geometry and parameters of the absorber and cavity receiver are found from the focal image obtained by means of the comparison of different methods and adjustment to the available area.

2.1. Concentrator and absorber parameters

The STSC is illustrated in Fig. 2, and it was previously designed in 2013 [16]. In this study, for coupling with a 3 kWe Stirling engine, the SCTS dimensions are: 3.98 m reflector diameter, 5.04 m focal length and 45° rim angle. The absorber parameters of a Stirling engine were previously established in 2013 [17]. Those parameters were: 0.0064 m^2 absorber area and 0.0063 m outside diameter of the tubes.

2.2. Solar image in the focal plane

The steps of the methodology consist of obtaining the solar image shape and dimensions in a focal plane using different

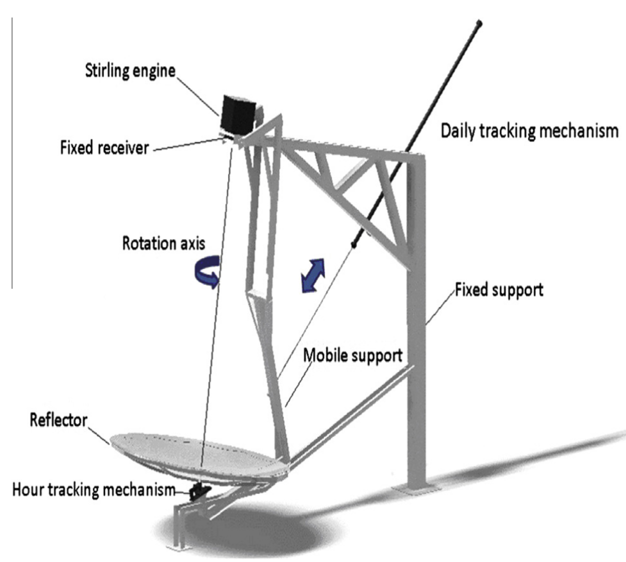

Fig. 2. SCTS Schematic [16].