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Variation of Flux Reflected in Solar Parabolic trough Collectors with Rim Angle

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Abstract

A wide range of solar energy applications can benefit from the parabolic collector, including power generation, heating, and cooling. One of the most important parameters that affect the performance of a parabolic trough collector is its rim angle. This study examines how to rim angle affects the intensity of incoming photons reflected from the collector surface to the receiver. Flux distribution was simulated employing Ray tracing Simulation software. Out of 3000 photons employed in the experiment, 126 to 1608 photons were reflected from the collector to the receiver. A narrower rim angle results in a greater number of photons reflected per aperture width. A smaller aperture width also produces more photons for the focal length range studied.

Paper type: Research paper

Keywords: rim angle; focal length; aperture width; parabolic trough collector; flux distribution.

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Introduction

The solar parabolic trough is a concentrated collector for solar energy. The parabolic trough is used to focus low- and medium-temperature radiation. The concentration ratio, defined as the ratio of aperture area to receiver area, of a parabolic trough is 30 to 100, with temperatures up to 400°C (Barlev *et al.*, 2011). Depending on whether the image of the sun is concentrated on the receiver, concentrating collectors can be characterized as non-imaging or imaging. Parabolic troughs are considered a form of image concentrator (Billy *et al.*, 2015). The thermal performance of a parabolic trough collector with absorber tube misalignment and reflector slope inaccuracy has been assessed using the finite volume approach. For 70mm diameter tubes with absorber tube dislocation, collector efficiency might fall by up to 11% in the presence of slope inaccuracy. (Ramesh *et al.*, 2019). Investigations were conducted on a parabolic trough solar collector. The effect of collector rim angles and non-uniform heat flux distribution boundaries on the interior heat transfer coefficients of an absorber tube was investigated using numerical simulation in ANSYS. Where significant buoyancy effects existed, laminar flow steady-state conditions were considered. A user-defined function in Fluent was used to implement sine-wave non-uniform heat flux distributions and boundary conditions. It was found that the circumferential span of non-uniform heat flux allocations and the collector rim angle both increases the temperature of the absorber tube walls. (Okafor, 2020). As depicted in **Figure 1**, the solar collector is made up of parabolic trough-shaped reflectors and receivers. The receiver is an evacuated tube with heat fluid flowing through and is supported by metal. The line-type receiver is fixed along the focal of the reflector's parabolic cylinder. The parabolic trough reflector is allowed to track the sun with a single-axis tracking mechanism derived from an electric or hydraulic actuator. The outer surface of the concentric cylindrical receiver is glass while the inner tube is made of copper or stainless steel coated with selective dark colour and the annulus is evacuated to reduce the convective heat losses from the receiver-heated fluid (Xu *et al.*, 2015). A parabolic trough collector's cross-section reveals several key components. When incoming radiation contacts the reflector at the collector's rim (where the mirror radius, r_r, is greatest), an angle, φ_r, is created with the collector's centre line. The rim angle is the name given to this angle. In terms of the coordinate system, the parabola's equation is (Sulaiman *et al.*, 2008):

$$y^2 = 4fx \tag{1}$$

where f denotes the focal length defined as the distance between the vertex and the focus along the axis of symmetry and x is the depth of the parabola at its vertex.

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Figure 2 and trigonometry may be used to determine the receiver's diameter (D) required to catch the entire solar image as illustrated by (Kalogirou *et al.*, 1997):

$$D = 2r_r \sin\theta_m \tag{2}$$

Where θ_m is the half acceptance angle (degrees).
Another critical parameter in the parabolic trough is the aperture width, denoted by W_a, which is proportional to the parabola's focal length and the rim angle φ_r (Kalogirou *et al.*, 1997).

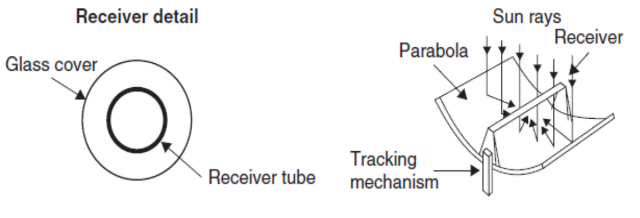

Fig. 1 Parabolic trough collector schematic diagram with cooper receiver (Kalogirou, 2013).

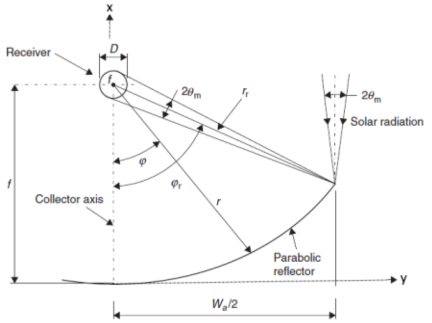

Fig. 2 Parabolic trough geometry (Kalogirou, 2013).

$$W_a = 4f * \tan\frac{\varphi_r}{2} \tag{3}$$

Following Kalogirou, the reflecting surface's curve length is given by (Kalogirou *et al.*, 1997):

$$W_a = \frac{H_p}{2}\left\{sec\left(\frac{\varphi_r}{2}\right)tan\left(\frac{\varphi_r}{2}\right) + ln\left[sec\left(\frac{\varphi_r}{2}\right)tan\left(\frac{\varphi_r}{2}\right)\right]\right\} \tag{4}$$

Where H_p is the parabola's lactus rectum (m), *i.e.* the parabola's opening at the focal point. The collector's surface area, on the other hand, decreases as the rim angle is reduced. This means that using narrower rim angles makes sense because the loss of optical efficiency is minimal and the cost savings in reflecting material are significant (Kalogirou *et al.*, 1997).

1 Materials and Methods

1.1 Modelling

The purpose of parabolic trough collector modelling is to demonstrate the effect of a variety of parameters on the rim angle of the trough parabola during analysis (ASHRAE, 1986). As illustrated in **Figure 3**, a parabolic trough is modelled using Tonatiuh's ray tracing software. Two primary parameters affect the parabolic trough: These are the aperture width (w_a) and focal length characteristics (*f*). Sun radiation is assumed to be perpendicular to the aperture area based on the coordinate set. It was determined that the reflective surface should be a perfect specular reflector with a reflectivity of one. The diameter of the receiver was adjusted to 10cm, and the material used for the receiver was chosen to be specular with a reflectivity of 0. Any sunbath can be used to model the parabolic trough. The simulation interface is used to generate the parabola. After that, the parabola is exposed to a solar collection environment with a specified transmissivity. Before initiating the simulation, the parabola's basic parameter is entered. Before performing the simulation, the parameters are also checked to ensure that the parabola is in the right condition (Joardder, *et al.*, 2017).

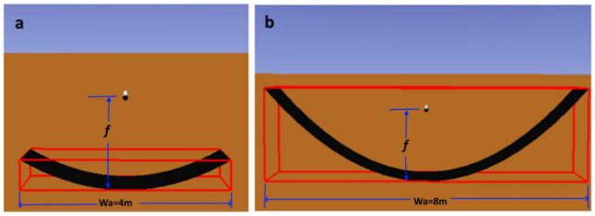

Fig. 3 Model of the parabolic trough in Tonatiuh (a) (W_a=4m); (b) (W_a=8m)

1.2 Simulation ray model

For the construction and optimization of concentrated solar collector configurations such as the parabolic trough collector, ray tracing models are highly useful (Saša *et al.*, 2015). A ray tracing approach is used in this investigation to recreate the sun's radiation within the trough parabola. The parabolic trough's aperture width is adjustable to 4, 5, 6, 7, and 8 meters. Additionally, the focal distance is varied for each run between 0.5, 1, 1.5, 2, and 2.5 meters. In any instance, after the parameters have been defined, the ray tracing begins. The incident flux at the receiver is mapped using two-dimensional coordinate mapping. The simulation seen in **Figure 4** is a ray tracing simulation; each ray represents a photon of light. The reflections of each concentrator element are analytically mapped onto the cylindrical receiver's surface. The concentration on the receiver surface under idealized conditions of collimated solar incidence parallel to the axis of a perfect-surface concentrator is calculated first. The incidence angle is set at 0 degrees. After that, a general solar radiation map is derived.

2 Results and Discussion

2.1 Focused flux distribution

The photons reflected from the concentrator to the receiver are depicted in **Figure 5**. The concentration ratio of the trough design can relate to the number of photons reflected on the receiver. The flux coordinate may be used to determine the flux's intensity, as shown in the diagrams below. The arrangement with the largest parabolic trough has the fewest reflected photons, especially when the focal length is 0.5 meters (128 photons); the configuration with a 4-meter aperture width and a 2-meter focal length has the most reflected photons. To determine the amount of optical concentration, count the number of photons that return from the trough collector and travel to the receiver.

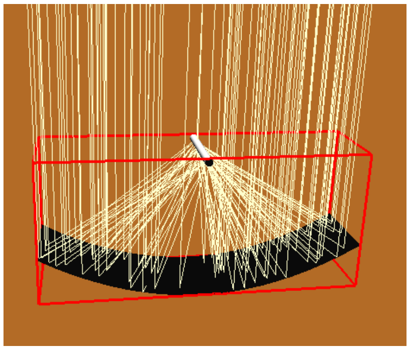

Fig. 1 Ray simulation of the parabolic trough collector.

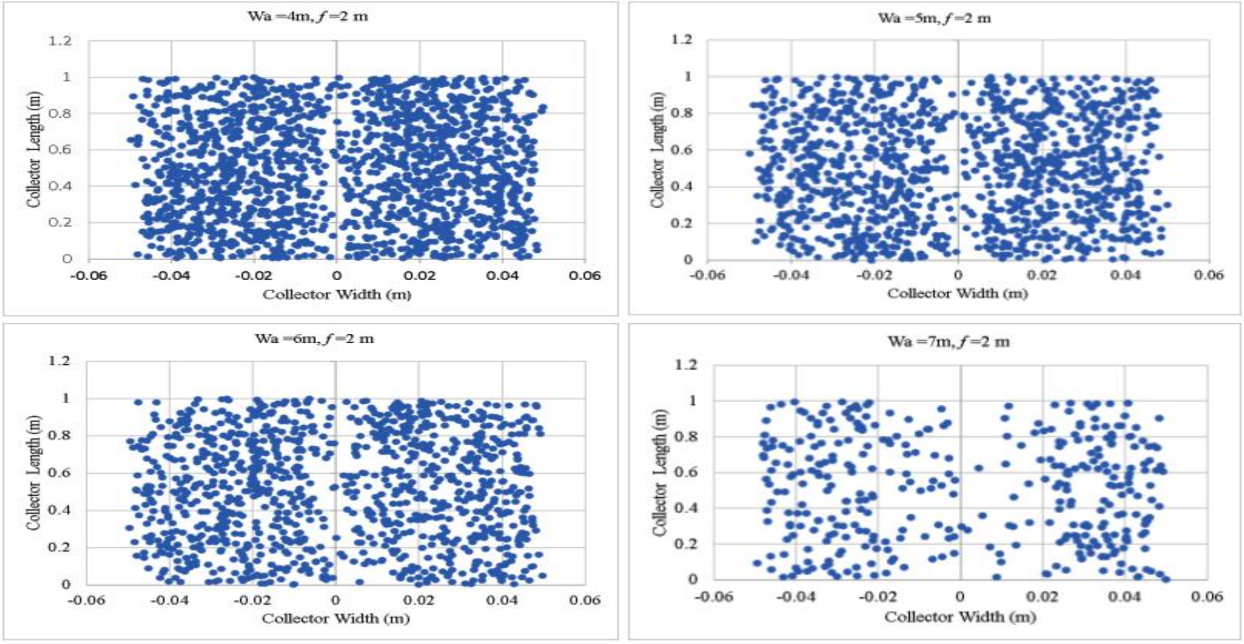

Fig. 5 Reflected flux distribution.

2.2 Solar intensity and rim angle

The intensity of incident solar radiation that is reflected is influenced by the rim angle (i.e., the number of photons reflected changes according to the different rim angles). Indeed, the size of the rim angle determines the quantity of material used to create the parabolic surface (Boultinghouse, 1982). The number of reflected photons may be used to calculate the rim angles. The rim angle and photon count for a parabolic trough with a 4-meter aperture width are shown in **Table 1**. The rim angle and the number of photons reflected on the receiver from the collection are shown in **Figure 6**.

Table 1 Rim angle, number of photons at different focal lengths for trough parabola of W_a=4m

Focal length (m)	Rim angle (degree)	Number of photons
0.5	126.9	324
1	90	514
1.5	67.4	1592
2	53.13	1608
2.5	43.6	454

The results obtained demonstrate that as the aperture width of the parabolic trough lowers, the quantity of photons reflected increases. Additionally, the number of photons per aperture width decreases as the rim angle increases. There is an optimal moment for each aperture width when the number of photons is greatest. For instance, for a 4 meters aperture width, the maximum number of photons occurs at a rim angle of approximately 53 degrees. As the rim angle goes down from 136 degrees to 53 degrees, the number of photons rises at each aperture width. At a rim angle of 64 degrees, there are 1261 photons.

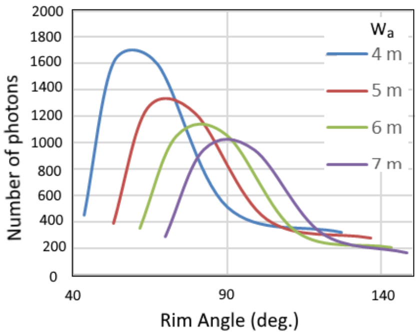

Fig. 6 relationship between the rim angle and the number of photons reflected on the receiver from the collector for different aperture widths.

Conclusions

The rim angle value determines the magnitude of incident solar radiation's reflected flux. Using the rim angle, you can figure out how long the parabolic trough is and how much material is needed to make the parabolic surface. A greater number of photons are reflected per aperture width when the rim angle is narrower. A smaller aperture width generates more photons for the focal length range under consideration. Around 1700 photons were found with an aperture width of w m while 1000 for an aperture of 7m. More studies can be done to illustrate how the rim angle influences the flux intensity and efficiency of the concentrated solar collector.

Nomenclature

D	=receiver diameter	[m]
f	=focal length	[m]
HCE	=heat collection element	[-]
H_p	=parabola's lactus rectum	[m]
r_r	=mirror radius	[m]
Wa	=aperture width	[m]
x	=vertex-to-focus distance	[m]
θ_m	=half acceptance angle	[degree]
φ_r	=rim angle	[degree]

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