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Numerical simulation of a trapezoidal cavity receiver for a linear Fresnel solar collector concentrator

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ABSTRACT

A new trapezoidal cavity receiver for a linear Fresnel solar collector is analysed and optimized via ray-trace and CFD simulations. The number of receiver absorber tubes and the inclination of lateral walls in the cavity are checked with simplified ray-trace simulation. The CFD simulation makes possible to optimize cavity depth and rock wool insulation thickness. The simulated global heat transfer coefficient, based on primary mirror area, is correlated with a power-law fit instead of a parabolic fit. The correlation results are compared with heat transfer coefficients available for linear Fresnel collector prototypes.

1. Introduction

When looking at reducing CO_2 emissions, the greatest task in creating viable solar energy conversion systems is that of reducing system cost. The solution to this problem does not necessarily lie on creating the most efficient system, but more on the development of a system that has the lowest lifetime cost per unit of electricity converted from solar energy. A linear Fresnel solar collector concentrator may have a lower efficiency than other concentrating geometries, but the likely reduced cost may well compensate that, providing a solution for cost-effective solar energy collection on a large scale [1]. The linear Fresnel collector concept uses a number of rows of relatively small one-axis tracking mirrors that concentrate the radiation on a linear receiver.

The advantages of linear concentrating Fresnel collectors include their relatively simple construction, low wind loads, a stationary receiver and high ground usage [2].

Some applications allow the use of the shaded area underneath the collector (e.g. for parking lots) and supply basic needs to rural remote communities.

Baum et al. [3] in 1957 were the first to develop the idea of using a tracking reflector field to concentrate solar energy onto a single fixed absorber. However, the first person to apply this principle in a large-scale system was Francia [4] in 1961. In 1991 the PAZ company built a large-scale linear Fresnel reflector at the Ben-Gurion Solar Electricity Technologies Test Center [5]. The system had optical problems due to the construction tolerance of the mirror field, resulting in a very low solar thermal efficiency. Mills and Morrison [6] proposed in 2000 the compact linear Fresnel reflector, using multiple stationary absorbers evenly spaced between the reflector rows. Dey [7] presented a preliminary design methodology and heat transfer calculations for an absorber based on Mills and Morrison [6] concept. The design constraint was the maximum temperature difference between an absorbing surface and fluid inside the tubes. He used a finite element analysis and obtained a temperature difference of less than 20 °C.

Ausra [8] commercialize a compact linear Fresnel reflector based on Mills and Morrison [6] tecnologie. The system uses flat mirrors and several absorber tubes.

The Belgian company Solarmundo installed in Liege, in 2001, a 2500 m^2 linear Fresnel collector prototype for steam generation. This company was integrated in 2004 in the Solar Power Group GmbH [9], Germany, which installed a demonstrator of a linear Fresnel collector in Almeria, Spain, in 2007. The PSE AG, a spin-off company of the Fraunhofer Institute, Germany, manufactures and commercializes linear Fresnel collectors, with several units installed in Europe and Tunisia [10].

Novatec Biosol [11] have installed recently in south of Spain a Fresnel collector solar plant of 1.4 MW. The system uses flat glass mirrors and a CPC cavity with one absorber tube.

In this paper we analyse the optical and thermal performance of a new trapezoidal cavity for a small linear Fresnel receiver, using simplified ray-tracing and computational fluid dynamics. Natural convection inside the cavity, thermal radiation between surfaces

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Nomenclature

D	receiver depth, mm
f	focal length, m
r	radius of curvature, m
T	temperature,°C
Ta	ambient air temperature,°C
$t_{insulation}$	insulation thickness, mm
T_{tubes}	absorber tubes temperature,°C
U	global heat transfer coefficient, W/(m^2 K)
u	global heat transfer coefficient, based to the receiver length, W/(mK)

Greek symbols

α	external heat transfer convection coefficient, W/m^{2}K
φ	angle between optical axis and line from reflector focus, deg
θ	sun incidence angle relative to aperture normal, deg
ψ	tracking angle, deg

and conduction through the walls are simulated, and the overall heat loss coefficient is evaluated. The system uses 10 rows of 4 reflector mirrors with a north–south tracking axis – see Fig. 1. The primary mirrors are cylindrical with different small curvatures. The mirror width is 0.4 m, the length is 3 m, and mirror spacing is 0.15 m. The total mirror area is approximately 48 m^2. The linear receiver is composed of 6 pipes with an inside diameter of ½ inches, placed 2.5 m above the mirrors, inside an insulated trapezoidal cavity, as shown in Fig. 2.

The maximum temperature achieved in the receiver tubes was fixed through the operating temperature of an organic Rankine cycle (power cycle) driven by the linear Fresnel collectors, designed to operate at 230 °C.

2. Simplified ray-trace simulation

Ray-trace was used for optical efficiency simulations of the concentrating collector. The process consists in following the paths of a large number of rays of incident radiation throughout the system. For reflecting surfaces, the direction and point of intersection of an incident ray with the reflecting surface are determined. The normal to the surface in each point is also determined, and the reflected ray follows the principle that the angle of reflection equals the angle of incidence. Exhaustive ray-trace simulation enables to study the sensitivity of delivered energy to height and width of the receiver, collector tracking orientation, climate, and design modifications. We concentrated our attention in design optimization and behaviour of the receiver cavity, which means that a simplified ray-trace analysis was carried out.

The tracking angle ψ_i of the ith reflector was calculated according to Rabl [12]:

$$\psi_i = \frac{(\phi_i - \theta)}{2} \quad (1)$$

where φ_i is the angle between optical axis and the line from the focus to reflector, θ is the incident angle of the sun relative to the aperture normal.

It is known that the parabolic concentrator is the unique reflector shape that focuses beam radiation into a single point.

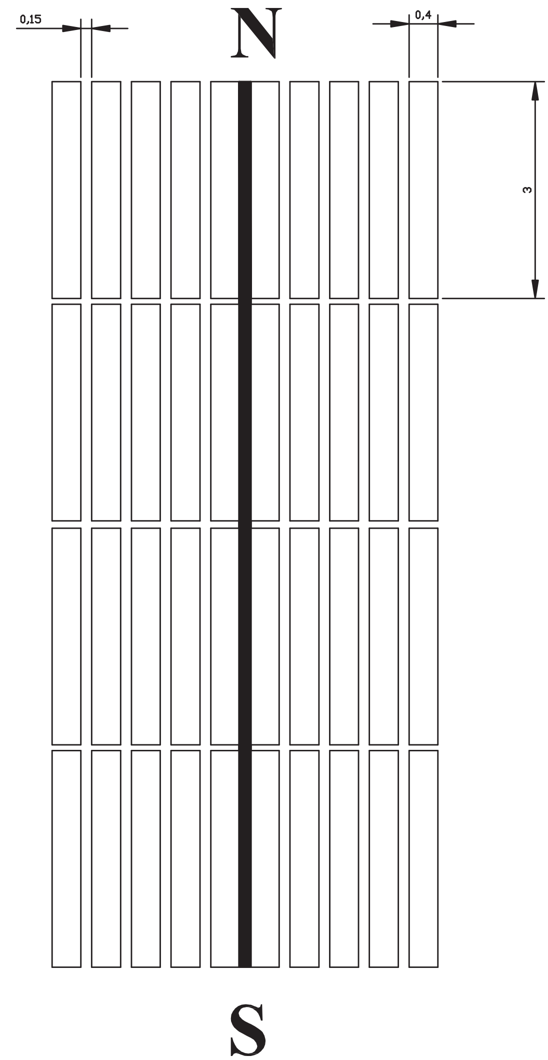

Fig. 1. Schematic representation of the installed collector system – view from above.

However, the manufacture of a parabolic reflector is too expensive. In this system, we adopted cylindrical mirrors with different curvature. The mirror radius of curvature r_i depends on the focal length f of the mirror, and the tracking angle:

$$r_i = \frac{2f}{\cos(\psi)} \quad (2)$$

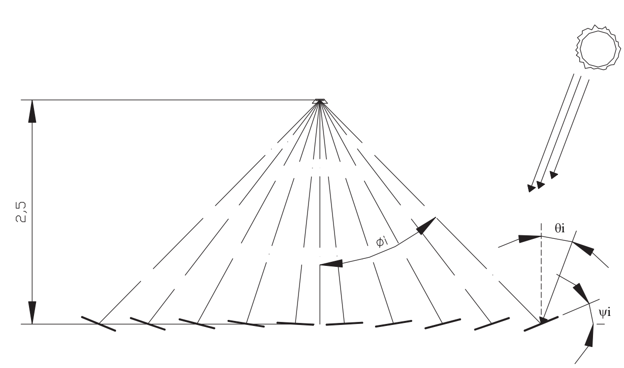

Fig. 2. Schematic representation of the installed collector system – East–West plane view.