Analysis of secondary mirrors for homogenizing a parabolic concentrator's radiative flux over a cylindrical receiver

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1. Introduction

Hydrothermal methods are widely employed for the processing of materials. When a mixture of water and biomass residues is subject to high temperature and pressure, solid, liquid, or gaseous products can be obtained above the water saturation curve. Between 200 and 350ºC, and up to 250 bar, the decomposition and depolymerization reactions are favored, leading to the formation of biocrude [1]. In solar reactors, concentrated solar energy is used to heat a metallic reactor wall [2,3,4]. Parabolic trough concentrators have been proposed for this temperature range [2,3]. A complication with those systems is the appearance of thermal stresses due to temperature gradients in the wall. These stresses add up to those originating from internal pressure [4]. We propose the homogenization of the concentrated radiation flux as an alternative solution in this work. A secondary mirror is used to redirect part of the concentrated radiation to the side of the receiver not illuminated by the parabolic trough. In particular, a CPC, a hyperbolic mirror, and a V-shaped convex mirror are theoretically analyzed as possible candidates for this task.

2. Methodology

Monte Carlo ray-tracing simulations were carried out to study the different proposed optical configurations. These simulations were performed using an in-house developed code written in the Julia programing language. This code was carefully validated against NREL´s SolTrace for the individual concentrators. Different parameters where varied, as the location of the tubular receiver with respect to the focal line of the parabolic trough, the lateral size of the second mirror, and its distance with respect to the receiver. In the case of the V-shaped mirror, the angle of the vertex was also varied, as was the eccentricity of the hyperbolic one. A direct normal irradiance of de 1000W/m^2 was considered and 1,000,000 rays were traced for each configuration. An optimization was carried out for different locations of the secondary mirror by means of a differential evolution algorithm.

3. Results

Of the three proposed secondary mirrors, the less versatile one turns out to be the CPC. Because it is an ideal concentrator, it has no degrees of freedom to change configuration; the acceptance half-angle needs to be set very close to the rim angle of the parabolic concentrator. A smaller acceptance produces strong energy losses and a larger one reduces concentration significantly. Once this angle, and the receiver diameter are fixed, the aperture is fixed, which can strongly limit energy collection.

The hyperbolic and V-shaped mirrors are more versatile because they have more degrees of freedom, allowing more room for optimization trough exploration of configurations. Fig. 1 shows a ray tracing example for a V-shaped mirror. In Table 1, results for different configurations of this geometry are presented. Performance indicators included in Table 1 are the average concentrated flux over the receiver, the uniformity of the flux, and the fraction of lost rays. The uniformity is defined as the ratio of the standard deviation of the concentrated flux, to the average

$$U = \frac{\sigma_q}{q_{\mathrm{av}}}$$

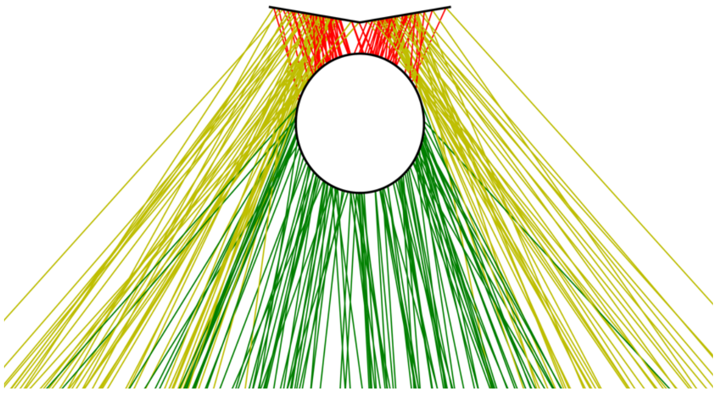

Fig. 1: Ray trace example with a V-shaped mirror as a secondary.

Thus, the lower the value of this parameter, the more uniform is the flux. It can be observed how a very important improvement of the flux uniformity can be achieved with the use of the V-shaped secondary, with little loss of rays and similar average flux, with respect to the case of parabolic trough without secondary.

Receiver displacement [m]	**Average flux [kW/m^2]**	**Uniformity**	**Lost fraction**
0.000 (No secondary)	12.771	1.318	0.006
-0.070	12.081	0.330	0.060
-0.077	12.191	0.339	0.051
-0.080	11.505	0.285	0.105

Table 1: Performance for some optimized cases for V-shaped secondary mirrors displaced from focus.

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