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ScienceDirect
Solar Energy 85 (2011) 1000–1006
SOLAR ENERGY
www.elsevier.com/locate/solener

A new solar concentrating system: Description, characterization and applications

J. Llorente [a,*], J. Ballestrín [b], A.J. Vázquez [a]

[a] Corrosion and Protection Department, National Center for Metallurgical Research (CENIM-CSIC), Avda. Gregorio del Amo 8, 28040 Madrid, Spain
[b] CIEMAT-Plataforma Solar de Almería, Aptdo. 22, E-04200 Tabernas, Almería, Spain

Received 16 October 2009; received in revised form 18 February 2011; accepted 22 February 2011

Communicated by: Associate Editor L. Vant-Hull

Abstract

Solar concentrating systems are usually very expensive and require a large space for their installation. This article presents a new solar concentrating device which is low-cost, small-scale, and has very good features for materials treatment. It consists of two sets of mirrors that reflect solar radiation in two steps with a beam array similar to a Fresnel lens. The power density was measured with Gardon-type radiometers. The results are in good agreement with previous work. The system has a nominal power of 2.5 kW, a measured concentration factor of 1040, and a measured focal diameter of 20 mm (90% of power level).

Keywords: Concentrated solar energy; Solar flux measurement; Solar concentrator; Solar processing; Heat treatments

1. Introduction

Since the late 70s, concentrated solar energy has been used successfully in materials processing, but only in research. During these years, many processes, such as steel surface thermal treatments (Vázquez et al., 1991; Rodríguez, 1997), synthesis of wear and corrosion resistant metal coatings (Sierra and Vázquez, 2006; Ferriere et al., 2006) and modification of ceramic materials have been developed (Costa Oliveira et al., 2005). Today, the usefulness of CSE in all those processes has been demonstrated and first pre-industrial applications are being tested (Cañadas et al., 2006). (See Flamant et al., 1999 for a brief review.)

In solar materials processing, the most commonly used technology is the "solar furnace". It consists of one or several heliostats which reflect solar radiation onto a fixed parabolic mirror which in turn concentrates the rays in its focus in a high power density beam. There are some variations on this, such as secondary concentrators, and off-axis designs. For examples of these systems, see (Lewandowski et al., 1991; Riskiev and Suleimanov, 1991; Neumann and Groer, 1996; Guesdon et al., 2006). All of them require a large site for the heliostats and the parabolic mirror housing, and they are also high-cost systems which are very difficult to operate and maintain.

There are other installations that are comparatively cheaper, smaller and easier to use. A small parabolic dish, for example, can produce very high concentration. But the main disadvantage of this system for materials treatment is the position of the focus at the top, making it necessary for samples to be set face down. This is unsuitable for treatments involving melting of the material, for example. A more suitable device is the refractive Fresnel lens, which consists of a 1 m^2 multifaceted polymeric disk which refracts solar radiation and concentrates the rays on its focus. Concentration factors and temperatures achieved by this system are comparable or higher than those achieved by larger, more expensive facilities (Sierra and Vázquez, 2005; Ferriere et al., 2004). It has been used

* Corresponding author.
E-mail address: j.llorente@cenim.csic.es (J. Llorente).

0038-092X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2011.02.018

successfully in materials processing since the mid 90s for applications such as thermal treatment, TiN coatings on Ti6Al4V alloy (Sánchez Olías et al., 1999) or NiAl coatings on steel by self-propagated high-temperature synthesis (SHS) Sierra and Vázquez, 2005. This paper presents an alternative small-scale, low-cost facility for concentrating solar energy.

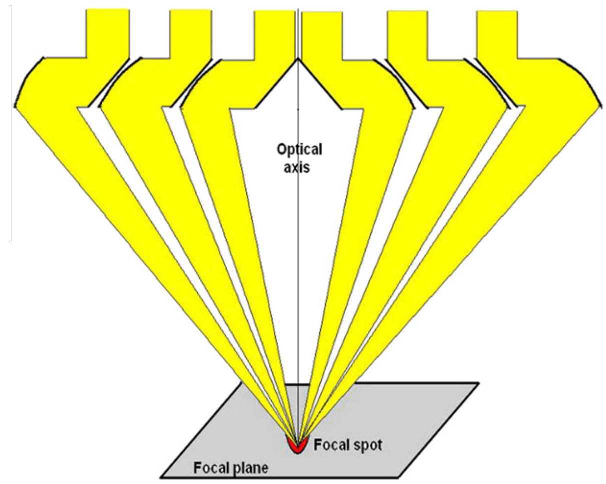

Fig. 2. DRFL beam array.

2. Experimental

2.1. Description of the new system

The new solar concentrating technology is called "Double Reflection Fresnel Lens" (DRFL) (Fig. 1). It is comprised of three main parts:

- Optics, consisting of all the mirrors that reflect and concentrate the solar rays in the focus.
- Electronics, including the solar-tracking timer.
- Mechanics, consisting of the equatorial mounting and the structure that enable the solar tracking of optics by means of the electronics.

The optics consist of 864 mirrors (approx.15 × 12 cm) in nine concentric rings on a circular (Ø = 3.5 m) plane normal to the solar radiation. There are two sets of mirrors. The first set is fixed at a 45° angle from the optical axis with the reflected rays normal to it, and a second set of parabolic mirrors (nominal 8× concentration factor, i.e. the power density in the focus of each mirror is eight times the incident power density) reflects these rays, concentrating them on the focus. The mirrors from the second set have different focal length depending on their position but all of them have an on-axis parabolic shape. Their inclination is varied manually one by one depending on their distance from the optical axis to concentrate all the rays in the center of a ring delimiting the focal plane (Fig. 2). This ring has several holes that can be used to attach accessories for the experiments or maintenance, such as focusing or system orientation (Fig. 3).

The optics are connected to the ring by a tube frame and both are properly counterbalanced to ensure system stability during solar tracking. The base is an equatorial mounting which makes one-axis solar tracking possible. This mounting is oriented by the polar axis at the same inclination angle as the site latitude (40.4° N for Madrid). A curved screw pulls the structure up or down depending on the solar elevation, which varies with the day of the year, and is highest in summer and lowest in winter. This height is regulated by hand once at the beginning of the day and remains almost constant during the day. The entire system is moved by a wheel connected to a small stepping motor controlled by a timer, which regulates the interval and duration of movement. This movement tracks the sun, keeping the position of the focus fixed in the center of the ring.

Some optical analysis can be performed based on Fig. 4. The real dimensions of all the mirrors and the angles they


Fig. 1. A general view of the "Double Reflection Fresnel Lens".

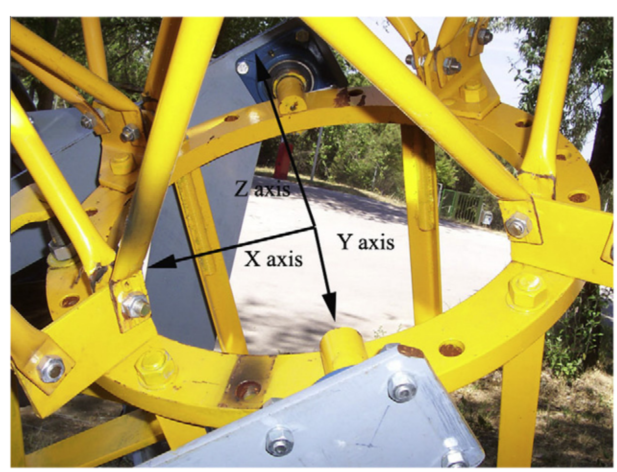

Fig. 3. Detailed view of the focal ring, with holes for attaching measurement or experimental accessories.