Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 118 (2015) 286–294

SOLAR ENERGY

www.elsevier.com/locate/solener

Analysis of the influence of the site in the final energy cost of solar furnaces for its use in industrial applications

Ana Monreal [a], David Riveros-Rosas [b,*], Marcelino Sanchez [a]

[a] Centro Nacional de Energías Renovables (CENER), C/ Ciudad de la Innovación 7, Sarriguren 31621, Spain
[b] Universidad Nacional Autónoma de México, Instituto de Geofísica, Av. Universidad 3000, Mexico City 04510, Mexico

Received 11 May 2014; received in revised form 31 January 2015; accepted 25 May 2015
Available online 10 June 2015

Communicated by: Associate Editor C. Estrada-Gasca

Abstract

The potential use of solar furnaces for industrial applications has been an attractive idea in the last years due to their high flux density and the accurate control which satisfies the productive industry requirements and facilitates the implementation of the solar technology within the industrial sector. An important aspect to take into account when designing a solar furnace is the heliostat field layout and its relative size compared to the aperture area of the secondary concentrator of the solar furnace as a consequence of the latitude where the solar facility is located. In this work, the influence of the latitude and atmospheric conditions in the final design and energy cost of solar furnaces for its use in industrial applications has been analyzed. Different criteria have been applied to perform design optimizations for different geographical locations. Results obtained have been discussed and some guidelines regarding solar furnace design and optimization according to the final site location have been indicated.

Keywords: Solar furnace; Heliostat size; Optimization study; Energy cost

1. Introduction

Solar furnaces are devices that, thanks to their optical configuration, have been used for research and development tasks that require high temperatures (Bliss, 1957; Glaser, 1958; Trombe and Le Phat Vinh, 1973; Suresh et al., 1981; Neumann and Groer, 1996; Riveros-Rosas et al., 2010; Villafán-Vidales et al., 2011). A solar furnace provides an enclosed space, partially protected from environmental conditions, for conducting experiments and prototype testing for the use of concentrated solar energy under laboratory controlled conditions (Bliss, 1957; Glaser, 1958). These conditions make solar furnaces suitable for testing materials and receivers for use in solar thermal technologies (Glaser, 1958; Suresh et al., 1981).

However, these systems have not been explored for their use in industrial solar thermal applications and studies with the aim of optimizing the cost of energy obtained with this technology have not been yet conducted. The potential use of solar furnaces for the industry has been discussed for years due to the wide range of advantages derived from its use: free and infinite source of energy (the sun), high energy flux density (more than 5000 suns of mean irradiance) (Bliss, 1957; Neumann and Groer, 1996; Riveros-Rosas et al., 2010), modulation and control of the flux, among others. One limiting issue for commercial use of solar furnaces is the need of a heliostat which redirects the solar radiation from the Sun to the solar furnace

* Corresponding author. Tel.: +52 (55) 56224141; fax: +52 (55) 55502486.
E-mail address: driveros@geofisica.unam.mx (D. Riveros-Rosas).

http://dx.doi.org/10.1016/j.solener.2015.05.032
0038-092X/

aperture and contributes in a significant portion in the cost of this system.

Although sites located in the Sunbelt area (approximately between latitudes 40° North and 35° South) seem to be more suitable for positioning these systems as they enjoy higher irradiations, they require larger aperture areas, and thus a higher number of heliostats, due to the cosine effect. Additionally, the atmosphere influence over solar radiation determines the irradiance level that the heliostat is able to reflect into the solar furnace. The presence of different atmospheric components scatter and attenuate the solar radiation in different ratios for each wavelength as a function of the geographic situation and local climate conditions of each observation site.

The objective of this paper is to quantify the cost of the thermal energy able to be used in a solar furnace system depending on the latitude and the local conditions for each site.

2. Methods

Regions with higher latitudes, where annual Direct Normal Irradiation (DNI) is lower, require lower heliostat sizes in order to obtain a certain percentage from this irradiation due to a lighter influence the cosine effect. On the other hand, atmospheric conditions inherent to locations, like turbidity index and cloud cover, affect the DNI too. As system costs are intensively related to heliostat, the present study tries to analyze the optimum configuration of a solar furnace according to the latitude and atmospheric conditions, considering the maximum solar energy that can be intercepted for each site.

In order to analyze the influence of latitude in the solar field layout of a solar furnace, the analysis was carried out in two steps:

- In the first step, only the latitude effect was evaluated thus omitting possible interferences derived from additional atmospheric conditions.
- In the second step, both the latitude and the influence of local atmospheric conditions have been evaluated through a clear sky model for specific sites at different latitudes. This study only considers clear sky conditions in order to explore this method step by step and filter other possible aspects related to real atmospheric conditions.

The region of Almeria has been chosen as a reference case for the first step. The reference point was located at latitude 37.047°, longitude −2.343° and altitude 462 m. For this reference case, clear sky hourly year data have been created using the ESRA model (Rigollier et al., 2000). Having this location in Almeria region's at a starting point of the analysis, then further clear sky hourly data have been additionally created for four further latitudes with similar characteristics than Almeria (longitude, altitude and Linke turbidity) but with different latitudes (47.047°, 27.047°, 17.047°, 7.047°). This way, it can be ensured that only latitude effects are being evaluated (Fig. 1).

For the second step of the study, local data from the clear sky model ESRA are considered. This allows evaluating the influence of local atmospheric conditions on the cost of energy obtained for a solar oven in each case. Sites of different latitudes, longitudes and altitudes were considered. Selected sites are shown in Table 1 and their spatial distribution shown in Fig. 2.

2.1. Implementation

In order to carry out this work, specific software has been developed under MATLAB® code. This code is capable of calculating the cumulative solar DNI on a solar furnace at a specific site. The cumulative DNI is obtained as a function of the latitude of the site and the aperture area of the solar field.

For the case in study, a simple solar furnace has been designed with its aperture area oriented to the North (see Fig. 3).

This software makes it possible to calculate the amount of solar irradiation intercepted by the aperture area of the solar furnace, redirected by a single heliostat defining the solar field. For the analysis herein performed, the software calculates for each step of the simulation (determined by the frequency of the irradiation data imported to the

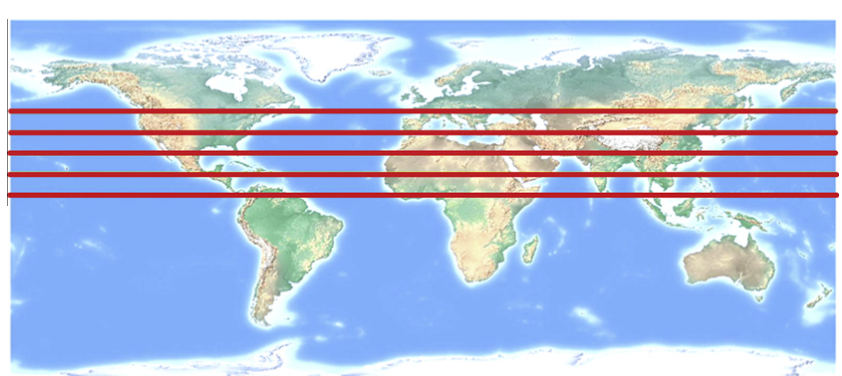

Fig. 1. Latitude for each case from the first step analysis.