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Experimental validation of an optical and thermal model of a linear Fresnel collector system

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ABSTRACT

This paper describes the design and validation of a mathematical model for a solar Fresnel collector. The function of the model is to simulate the optical and thermal dynamics of a Fresnel system for heating water. The model is validated using real data gathered from a cooling plant with double effect absorption chiller located in the School of Engineering University of Seville, Spain (Experimental cooling plant is also described in the paper). Comparison of calculated and plant measured data shows that the error is lower than 3% in the optical model and within 7% in the thermal model.

The model uses a new approach to include a solar tracking mirror mechanism in one axis. This tracking has been designed to maximise the reception of available solar radiation by the absorption pipe. The thermal model used is based around classical models for solar receivers and it is validated with real operating data gathered from a supervisor system.

The Fresnel model has been designed with sufficient flexibility to consider different geometries and thermal parameters, and may be used to simulate the performance of a proposed Fresnel collector system at any location.

1. Introduction

The objective of the work presented in this paper is to simulate the performance of a solar plant with Fresnel collectors using the combination of optical and thermal modelling. Results from the theoretical model are validated with data gathered from an experimental plant.

The optical model developed in this paper brings a new approach to others published optical models that are made by ray-tracing [1], considering other collector geometry [2,3] or for a collector with two-axis tracking [4], where sun rays are perpendicular to collector surface. In this model a collector with tracking mechanism in one axis only is studied, so each collector row is positioned with the objective of reflecting the solar radiation to a pipe. The thermal model for reception pipe is similar to others that have been published in several papers [5–9].

This paper has been divided into five sections. Firstly, in section 2, a general description of facility is done. In section 3, the optical model is explained, its results are necessary for the thermal model, presented in section 4. In section 5, the comparison between real data and model results is done. Final conclusions of study are discussed in section 6.

The diagram of the Fresnel collector plant being modelled is shown in Fig. 1, as well as the system coordinates used in the model. The plant has three main parts: the first part consists of the 11 rows of mirrors located at the lower end of the collector. These mirrors have one axis of rotation. Incident radiation is directed by the mirrors to reflect radiation towards the receiver located at the highest point, which is the second part. Finally, heat energy is gathered from the pipe using a continuous working fluid (water).

2. General description of the solar facility

A solar refrigeration plant has been erected in Engineering School of Seville as a long-term project in partnership with "Gas Natural" to facilitate the integration of both solar energy and natural gas in refrigeration applications. The objective of this project is to identify design improvements for future plants and to serve as a guideline, where the solar collector size and shades, climatology, heat losses, operation control and coupling between chiller and solar collector are the most masterful aspects. The solar collector is coupled with a double effect LiBr + water absorption chiller of 174 kW nominal cooling capacity with an auxiliary natural gas burner. Financial support for this work was provided by Gas

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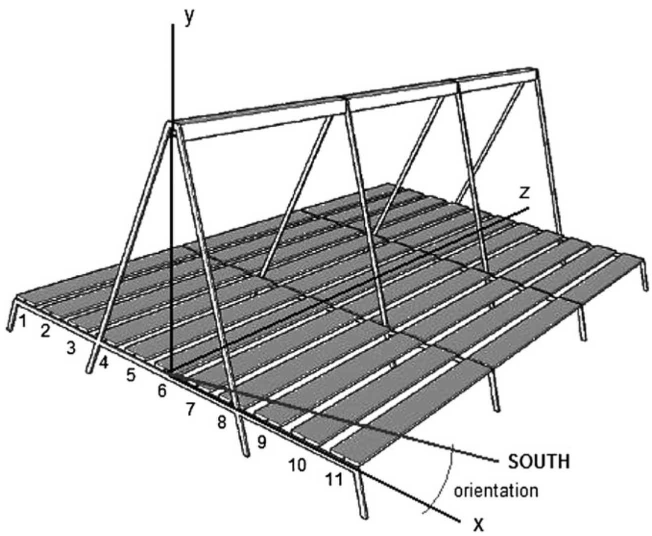

Fig. 1. Reference axis, mirrors rows nomenclature and solar field orientation.

Natural SDG Company, with the participation of AICIA and supported by Corporación Tecnológica de Andalucía [10].

The solar facility is located on the roof of the building at the Engineering School of Seville. The general geographical coordinates of the system are 37.41° latitude and 6.00° longitude West. Solar field has a deviation of 12° 3′ 1′′ W respect the South (represented by orientation angle in Fig. 1), and rows axis orientation is East–West. The total collector area is 352 m^2 and distributed over 11 rows of primary reflectors. The total number of reflectors is 176, with 16 reflectors in each row. A picture of the solar facility is shown in Fig. 2.

Primary mirrors are made of glass and they are lightly elastically curved (with a curvature radius between 8.6 and 10.6 m) and they have a nominal reflectance of 0.92 [1]. Each row of mirrors is moved by a solar tracking system working in an autonomous way with an electric motor. Each dragging mechanism moves eight mirrors in each row. They are separated by a spacing of 20 cm to the next row to allow for a rotative angle of 180°, and to reduce shadows between them.

As shown in Fig. 2 above the receiver is installed a secondary reflector which consists of a metallic thin wrapper and a polished aluminium layer (nominal reflectance: 0.77) [1]. Its objective is to reflect rays to the reception pipe from primary mirrors. In this way the optical efficiency of the system is optimized. The secondary reflector also protects the receptor pipe from wind, rain and dirtiness.

Fig. 2. General outlook of Fresnel collector.

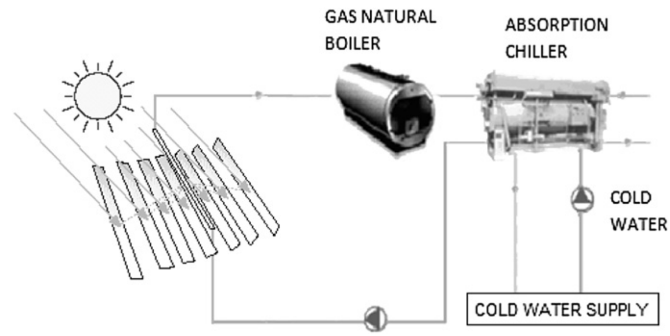

Fig. 3. General diagram of solar cooling plant with the absorption chiller.

The reception pipe SCHOTT PTR® 70 is composed of an absorption pipe and a glass envelope which ensures the vacuum between both. It is placed 4 m over the mirror axis and it has a length of 64 m. The absorption pipe is made of stabilized austenitic stainless steel DIN 1.4541 and it has a nominal absorptance of 0.94. Water temperature is limited to a maximum of 200 °C and the pressure is limited to a maximum of 16 bar. The nominal water flow rate is 13 m^3/h at a nominal operational pressure of 13 bar. The safety pressure relief valve is set to 16 bar to protect the system from over pressurization. The water flow rate can change depending on operation conditions [11].

The solar plant has several sensors:

- Potentiometer: Each mirror row is equipped with a potentiometer to provide a feedback measure of the actual position of the mirror rows during operation. (Accuracy: ±0.1°).
- Solar sensor: There are solar sensors on each side of the receptor to calibrate the mirror rows automatically. These sensors detect the radiation spillage easing the focussing of primary mirrors.
- Temperature sensor: Temperature at input and output of the absorption pipe were monitored using PT100 sensors. If water temperature exceeds the permitted levels, the mirror control system moves the mirror rows to avoid malfunction of the system. (Accuracy: ±0.2 °C).
- Mass flow meter: Located at inlet of absorption pipe. (Accuracy: ±0.05 m^3/h).
- Weather station: Located at 5 m of Fresnel collector. It has an environmental temperature sensor (accuracy: ±0.1 °C), a pyrheliometer and a wind speed sensor.

The absorption chiller is a BROAD BZH15. Its maximum cooling power is 174 kW with a nominal coefficient of performance (COP) of

Table 1
Input and output parameters for the optical model.

MODEL INPUTS	MODEL OUTPUTS
-Day of the year, from 1 to 365 (number 1 is the first of January)	-Solar position
	-Solar time
-Local time (hours)	-Inclination of the mirrors rows
-Direct solar radiation (W/m^2)	-Shadows between rows
-Orientation of solar collector axis respect South	-Stretch and percentage of non-illuminated pipe
	-Optical losses factor
	-Real radiation from the mirrors to the receptor pipe
	-Theoretical radiation without losses