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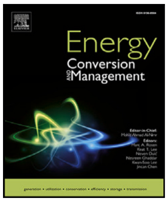

Modeling a solar pressurized volumetric receiver integrated in a parabolic dish: Off-design heat transfers, temperatures, and efficiencies

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ABSTRACT

Concentrated solar power plants are commonly recognized as one of the most attractive options within carbon-free power generation technologies because of their high efficiency and feasible hybridization and/or storage implementation. In this work, a complete heat transfer analysis for an air volumetric receiver coupled to a parabolic dish focused on distributed generation (in the range of kWe) is carried out. It includes most relevant heat losses. Dish collector optical efficiency is computed by means of a ray-tracing software while the thermal performance of the solar receiver is modeled under steady-state conditions using a comprehensive set of equations with a clear physical origin and meaning. Detailed information on the temperatures and heat transfers along the different inner and outer receiver zones are computed with a built from scratch in-house code programmed in Mathematica®. The model considers the main losses from convection, conduction and radiation and through the surrounding insulator. The resulting thermal efficiency mainly depends on the incoming solar irradiance at the glass window, the receiver geometry and the type of materials considered, as well as on the ambient temperature. Explicit numerical results are given at two locations under different meteorological conditions. Optical efficiencies reach values of about 84%. For irradiance values around 800–900 W/m^2, at the receiver outlet, air can reach temperatures of about 1200 K and receiver thermal efficiency is over 80%. It is expected that this model (precise but not too expensive from the computational viewpoint) could help to identify the main efficiency bottlenecks, paving the way for optimization when designing this type of concentrated solar plants through further coupling with a power block, as Brayton or other cycles.

1. Introduction

Key elements in any concentrated solar power (CSP) system are the solar collector and the solar receiver. The solar collector is an optical subsystem designed to collect and concentrate in an efficient way the direct solar irradiance towards the solar receiver. It is characterized by an optical efficiency that measures the fraction of solar power that effectively reaches the solar receiver window. Nowadays, most research works make use of ray tracing Monte Carlo software to compute its optical efficiency [1]. Monte Carlo methods applied to solar ray tracing are based upon the generation of a huge number of photons over the aperture area of the solar collector [2]. The pathway of the photons is built through reflection laws and it is computed if they strike on the receiver aperture. From this, estimations of the optical efficiency of the collector with a good precision and also of the distribution of incident energy flux onto the absorbing surface [3] can be calculated.

The solar receiver can be considered as a special type of heat exchanger with the aim of converting the input direct solar irradiance into heat. The receiver thermal efficiency is essential to obtain high efficiency in the overall CSP plant and so, to increase commercial interest. Many experimental or simulation studies have been conducted in order to propose optimized designs to account for the high complexity of the heat transfer processes in the solar receiver, as it can be seen in the comprehensive review by Sedighi et al. [4].

An interesting application of CSP systems is the possibility of producing distributed electricity at the scale of kW$_e$, close to the consumption place. Solar dishes, for instance, are capable to perform this task easier than other systems because of their modularity [1]. A collecting parabolic dish reflects the input solar radiation into a solar receiver located at parabola focus, where it is transferred to a fluid running a thermodynamic cycle as power block [5]. Particularly,

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