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Energy and exergy analysis of a novel gravity-fed solid particle solar receiver

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Abstract

An energy and exergy analysis of a novel solid particle solar receiver is presented based on experimental data and well-known correlations found in the literature. A sand sample from the deserts of the United Arab Emirates has been chosen as the solar absorber and heat carrier material. The intent of the receiver is to be used as a part of a sensible thermal energy storage system for concentrated solar power plants based upon the concept of storing solar heat in sand particles for a later discharge through a specific sand-steam heat exchanger. The results of the analysis indicate low efficiency figures that can be caused by imperfections on the experimental setup and on the original design. Several paths of improvement are discussed in conclusion.

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Keywords: Solid-particle solar receiver; Thermal energy storage; Thermodynamical analysis

1. Introduction

A major problem that prevents solar energy from being used as a mainstream source of power is its dependence on intermittent solar radiation.

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Solutions to this issue have been proposed in the form of thermal energy storage (TES) systems which can assist in leveling the energy output of solar plants so that they are able to provide energy at all times. TES designs can be classified accounting to the energy storage mechanism. A common division is to distinguish between thermochemical, latent and sensible heat storage [1]. This work considers a novel sensible TES system using sand particles as storage medium. In this method concentrated solar irradiation is used to heat sand particles for a later discharge through a sand-steam heat exchanger which supports a conventional Rankine power cycle [2].

Other solar particle receivers have been developed in the past: [3]–[6]. However, in opposition to the receiver analyzed here, none of them is suitable for being used in a beam-down solar power plant without using compressed air to suspend the particles in a cavity. Moreover, the receivers surveyed in the literature either use silicon carbide particles for thermal storage or are engineered for use in thermochemical storage applications.

In the following sections a prototype for the solar receiver is presented and an energy and exergy analysis is performed based on experimental results conducted at the facilities of PROMES-CNRS (Procédés, Matériaux et Énergie Solaire, Centre National de la Recherche Scientifique) laboratory in Font-Romeu-Odeillo-Via, France [2].

Nomenclature

rec	Solar receiver
A_i	Area of the element 'i'
ℓ	Distance between the upper part of the receiver and the focal plane of the parabola
$Q^{*\prime\prime}$	Direct Normal Irradiation
$\dot{Q}_{sun}$	Solar thermal power fed into the receiver
$\dot{Q}_{loss,ref}$	Thermal power lost by reflection
$\dot{Q}_{loss,em}$	Thermal power lost by radiative emission
$\dot{Q}_{loss,cv}$	Thermal power lost by natural convection
ρ	Reflectivity
ϵ	Emissivity
0	Ambient conditions

2. Experimental setup

A prototype for a sand particle solar receiver was built using stainless steel 304 L with the dimensional specifications shown in Fig. 1. The device was mounted on the support system of a solar parabola available at PROMES Laboratory and was placed under the outlet of a sand feeding tube to which a vibrator was attached to facilitate and control the sand flow [2]. Fig. 2 shows a picture of the overall experimental setup with a close-up of the solar receiver on which the sand was flowing under the concentrated solar flux of the parabola.

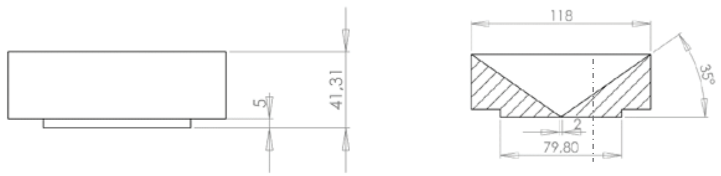

Fig. 1. Dimensional specifications of the solar receiver. Dimensions are in millimeters.