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Gravity-fed combined solar receiver/storage system using sand particles as heat collector, heat transfer and thermal energy storage media

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Abstract

An innovative gravity-fed combined solar receiver/storage system for thermal energy storage (TES) is presented for concentrated solar power (CSP) plants with beam down tower configuration. Sand particles are employed as heat collector, heat transfer and thermal energy storage media in contrast to conventionally used materials such as molten salts or synthetic oils. Relevant properties of two sand samples from the United Arab Emirates (UAE) deserts are examined. A prototype of the receiver was manufactured and its elements were characterized. Preliminary tests on the prototype were performed under the concentrated flux of a 2 kW solar furnace and associated results are presented.

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Keywords: thermal energy storage; concentrated solar power; solid particle receiver; sand.

1. Introduction

Within current complex energy ecosystem, solar thermal energy provides an excellent source of renewable energy to produce electricity in CSP plants. However, to successfully produce electricity on demand, independently from

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solar intermittencies, the usage of TES technologies becomes crucial. Current TES systems allow for higher capacity factors although at the cost of increasing the power plant cost. Available data [1] suggest that the incremental cost can be justified economically. Furthermore, without exceeding a specific storage size, the levelized cost of electricity reduces as the available hours of storage increase [1]. To target the cost reduction of the power plant, this paper focuses in key areas such as the material to collect, store and transfer the energy as well as the receiver itself.

At present, nitrate salts (molten salts) are used as storage media in conventional commercial TES systems and thousands of imported tons of salts are necessary for each plant. Through the development of CSP systems based on other available materials, new innovative and sustainable approaches could be possible. It is estimated that for a CSP plant to be economically feasible at present time, direct normal irradiation levels of 2000 kWh/m^2/year or above are required [1]. This makes many areas in the vicinity of deserts, such as the Arabian Peninsula, suitable for the installation of such plants. For this reason, readily available particulate materials, such as sand, offer good opportunities to develop low-cost central particle receivers and high temperature storage systems, where the solid particles act as the heat collector, the heat transfer and the heat storage media. Silica sand is thermally stable above 800 °C [2], in contrast to molten salts, such as nitrate salts, which are limited to 565 °C due to their degradation [3]. This increase in the operational temperatures leads to higher efficiencies of the power cycle. The sand is also easily movable, permitting a gravity fed system to be implemented.

In the present paper, two sand samples from different desert locations in the UAE were selected and characterized. A central particle receiver system with high temperature storage which employs the analyzed sand is presented. To implement the concept, a prototype unit of the receiver was manufactured and examined at the PROMES-CNRS solar facilities in Font Romeu-Odeillo-Via, France.

2. Material characterization

2.1. Material selection

Two sand samples were collected from different locations of the UAE desert, which had variations in color and particle size distribution. These differences are expected to affect the radiative heat transfer properties of the sand, their thermal and physical behavior and ultimately their performance when integrated in the TES system.

The differences in color are a consequence of the variability of the chemical composition of the sands, on which its thermal properties are dependent. *Jallad et al* [4] performed a spectroscopic analysis of several sand samples recovered in all of the emirates of the UAE and identified the main compounds present in each case. As it was found, the variation in the sand color from the east and central areas of the UAE (sample 1 in Fig. 1), where the samples are light brown, to the west, where the color is closer to red (sample 2), can be explained by the increase of iron oxides in the field. Otherwise, the samples collected in those areas are mainly constituted of calcite ($CaCO_3$) and quartz (SiO_2). Finally, the dark color of the sand in Al Ain close to the border with Oman is explained as these sands were formed by corrosion of the gabbro rocks at the Hajar mountain range with a significant presence of hematite. Fig. 1 illustrates the points of collection.

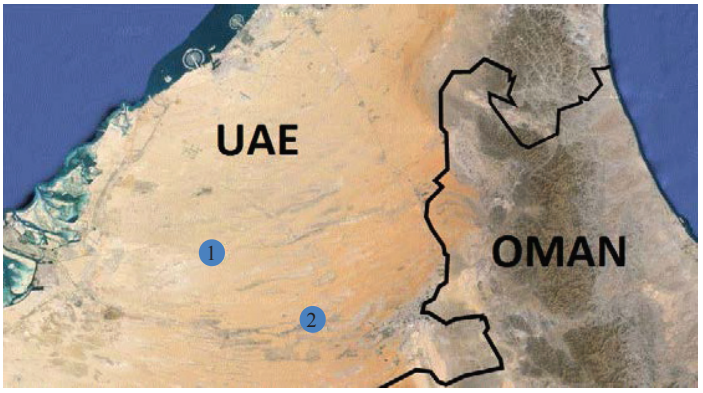

Fig. 1. Points of collection of the sand samples