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Development of a solar cavity receiver with a short-term storage system

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Abstract

The technological progress carried out in the development of high-temperature materials has led to the design of new concentrated solar power plants, like Dish-Micro Gas Turbines (Dish-MGTs). This study proposes a novel cavity receiver for small-scale Dish-MGT plants with a phase-change material storage system integrated inside the receiver container. Such a storage system provides a proper thermal inertia to the component, to level the effects of short-term solar radiation fluctuations which can reduce plant performance and, in the worst cases, damage seriously the MGT. In the paper, results related to CFD steady-state and transient (charge and discharge storage phases) analyses are presented and discussed.

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*Keywords:*Micro Gas Turbine; PCM storage system; Solar Receiver

1. Introduction

Small-Scale Solar Power Plants can represent an interesting alternative to traditional power production systems for the development of off-grid areas located in regions with a high DNI [1]. Several technologies based on the solar source utilization like Photovoltaic Panels (PVs), Dish-Stirling engines and solar Organic Rankine Cycle systems have been developed or are under development. Each of them has its own peculiar advantages and drawbacks [2].

Recently, the availability on the market of new high-temperature materials has made possible the development of

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new Concentrated Solar Power systems as Micro Gas Turbines (MGTs) coupled with solar mini-towers or dishes [3,4]. In Fig. 1 a scheme of a Dish-MGT plant in shown. The main components are a solar radiation concentrator, a high-temperature solar receiver and a recuperated MGT connected with an electric generator. Techno-economic analyses reported in [5-7] show that Dish-MGT systems could outperform Dish-Stirling engines from an economic point of view. Moreover, if equipped with a thermal energy storage, the Dish-MGT system could compete with PVs, cheaper than any other alternative solar plant if a storage system is not taken into consideration.

The most challenging component of a Dish-MGT plant is the solar receiver. In a no-hybridized configuration (without a supplementary combustion chamber), the receiver has to heat up the air coming from the recuperator from about 600 to 800-850 °C at least. Several receivers, most of them based on a cavity concept, have been designed and some prototypes developed [3, 8, 9]. Many technological concerns like material degradation, thermal stress, creep-fatigue potential damage, have been already taken into consideration. Notwithstanding, another relevant aspect has to be highlighted: solar radiation natural fluctuations cause a variability in the impinging solar radiation over the receiver surface. If the receiver has not the proper thermal inertia, a fast variation of the air flow outlet temperature occurs. Such a phenomenon leads to a remarkable system performance drop and, in the worst cases, it could dramatically cause a MGT structural damage. To reduce solar radiation fluctuation effects, the integration of a short-term storage system in a cavity receiver is proposed in the present paper. In particular, a high temperature Phase-Change Material (PCM) storage system has been taken into consideration due to its compactness and its constant-temperature storage feature.

2. The solar receiver: geometry and heat transfer model

For application in Dish-MGT plants, a tubular solar cavity receiver integrated with PCM for a short-term thermal energy storage is proposed. The integrated PCM system stores the thermal energy to reduce air flow outlet temperature fluctuations caused by sudden variations in the solar radiation flux. The receiver consists of a cylindrical container with twelve U-tubes housed inside the structure and submerged in the PCM material. The concentrated solar radiation impinges on the receiver front surface, heating the PCM inside the volume. The PCM is an intermediate medium which can store sensible and latent heat and transfers part of the heat to the compressed air which comes from the recuperator and flows inside the U-tubes. On the basis of previous analyses carried out by the Authors [10 and 11], the receiver front surface has been shaped with a conical cavity. Such a geometry increases the receiver radiation absorption capacity, reducing the hot wall temperature and, consequently, the re-radiation effect.

For the proper PCM choice, many factors have been considered: melting temperature, heat of fusion, volumetric heat storage, liquid/solid void volume, thermal conductivity, compatibility with other materials. Finally, the eutectic metallic alloy Si-Mg (56/44wt%) was selected on the basis of its high melting temperature (946 °C), low corrosive properties, small change in volume, high heat of fusion (757 kJ/kg), good thermal conductivity [12, 13]. Fig. 2 shows the detailed structure of the solar receiver and the most relevant dimensions and PCM properties.

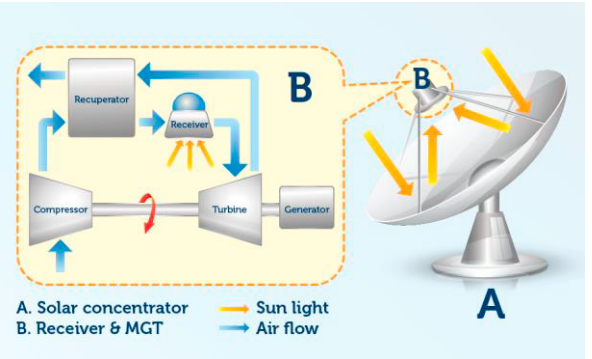

Fig. 1. Scheme of a Dish-MGT concentrating solar power plant [4]