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Plate micro-fins in natural convection: an opportunity for passive concentrating photovoltaic cooling

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Abstract

The raise in temperature is a non-negligible issue for concentrating photovoltaics (CPV), where the sunlight is concentrated up to thousands of times and a large amount of heat is collected on the solar cells. Micro-fins have been identified as one of the most promising solution for CPV cooling: despite its potentials, the number of publications on this subject is still limited. The present paper resumes the state-of-the-art of the research on micro-fins, in order to identify the most convenient fin geometry for CPV applications. The results of the investigation conducted in this work show that, compared to a conventional heat sink, micro-fins can improve the thermal performance and, at the same time, lower the weight of a system. For this reason, they are particularly beneficial for tracked systems, such as CPV, where a reduced weight means a reduced load for the tracker. The heat transfer coefficients measured through an experimental setup are used to predict the performance of a micro-finned CPV system in natural convection: an optimized fin array is found able to enhance the mass specific power up to 50% compared to an unfinned surface.

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1. Introduction

The temperature of any photovoltaic cell has to be minimized in order to enhance the electrical efficiency, to limit the thermal stresses, and to avoid mechanical damages [1]. In a concentrating

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photovoltaic (CPV) system, the sunlight is concentrated on a small cell up to thousands of times [2] and the temperature can easily raise above the safety operating range if the heat is not correctly dissipated. For this reason, the temperature of CPV cells working at concentrations above 300 suns is generally maintained within a 50 to 80°C range through the deployment of a cooling system [3,4]. Coolers are generally required to be simple, in order to have a limited impact on the CPV cost. Moreover, a reliable system is essential: any failure can cause damages to the cells and long stops to the power generation. Passive cooling systems have shown high reliability, due to their simplicity and to the employment of natural laws in place of mechanical or electrical power inputs, required instead by active systems. The heat transfer of a surface can be passively enhanced by increasing its extension through the introduction of fins, a widely used solution that has been investigated in numerous studies and are currently employed for many different purposes, such as electronic cooling, industrial processes, and power generation plants [5–7].

The price of cooling systems can be lowered by an increase in efficiency and a drop in volume and mass. Moreover, technologies such as CPV are tracked: a reduction in the weight of the heat sink means a subsequent reduction in load for the tracker and, thus, an increase in efficiency of the whole system. In this light, the micro-technologies represent an attractive solution for CPV cooling: among the present and potential micro-cooling technologies, the micro-fins have been considered as one of the most promising [8]. The present work resumes the outcomes of the previous researches and comments the benefits achieved so far by using the micro-fins in terms of thermal enhancement and mass reduction. The results of a previous experimental investigation are used in a3D model to predict the behavior of a micro-finned CPV system. The work is intended to highlight the recent progresses on natural convective micro-fins and to identity the future research directions towards the design of optimal fin geometries for passive CPV cooling.

2. Literature review

Fins are commonly used to enhance the heat transfer from a solid to the surrounding fluid by extending the thermal exchanging surface[7].It is known that the geometry and the surface temperature strongly affect the thermal behavior of fins in natural convention [9]. Natarajan and his colleagues [10,11]studied the application of fins for passive CPV systems and defined optimized number and geometry of the fins to maximize the heat transfer of a 10x CPV. They found that the fin thickness does not have a significant effect on the heat transfer because thicker fins increase the conduction heat losses and, at the same time, suppress the convection heat losses in between the fins. Bar-Cohen et al. [12] proposed a method to design a heat sink maximizing the heat transfer and minimizing the weight. A first investigation on tilted heat sinks has been reported by Mittelman et al. [13]. Five years later, Do et al. [14] proposed a correlation between the fin geometries, the tilt angles and the heat transfer coefficients.

In micro-fins, at least one of the dimensions is micro-scaled. Despite the wide literature available on fins, the studies on naturally convective micro-scaled fins are still limited. Kim et al. [15]investigated vertically orientated micro-fins and demonstrated the impossibility of using the macro-fin heat transfer correlations for micro-scaled systems. Shokouhmand and Ahmadpour [16]numerically demonstrated that the contribution of the radiative exchange cannot be neglected in a micro-fin array. In their study, radiation contributed to dissipate more than 20%of the heat exchanged by micro-fins. Recently, the correlations between the micro-fin geometries and the thermal behavior have been presented [17,18]: the heat transfer coefficients have been found to increase when the fin height decreases, the fin spacing increases and/or the fin thickness increases. Micro-fins are generally obtained by subtractivemanufacturing processes, such as dicing, etching or electrical discharge machining: Micheli et al. [19] experimentally demonstrated that the drop in weight, instead of an enhancement in heat transfer, is