Solar Thermal Collectors with Low and High Concentration

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Abstract

This paper describes the performance analysis of different concentrating technologies through experimental and numerical modeling activities. Two solar thermal systems with different designs and, accordingly, different concentration ratios have been studied. The first solar device is a stationary CPC (Compound Parabolic Concentrator) low concentrating collector: it is provided with truncated or full CPC reflectors and evacuated tubes. Each evacuated tube is composed by an outer glass envelope and a glass absorber with selective coating in thermal contact, via absorber fin, with a U-shape channel for the liquid flow. The second system is a parabolic trough concentrator (PTC) with two-axes solar tracking: the primary optics consist of a segment of parabolic cylinder which concentrates the direct normal irradiance (DNI) on a linear receiver. In this system, two types of flat receivers have been tested. One receiver has been designed for thermal energy extraction and it consists of a canalized roll-bond plate provided with a semi-selective coating. The other receiver has been designed for cogeneration of electricity and heat (CPVT) and it is equipped with triple junction photovoltaic cells, which are actively cooled by an aluminum roll-bond heat exchanger. The performance of the described collectors has been experimentally characterized at the Solar Energy Conversion Laboratory of the University of Padova (45.4°N, 11.9°E), Italy. The collectors have also been mathematically modeled and the numerical data have been validated against the experimental measurements.

1. Introduction

Solar collectors are distinguished as low-, medium-, or high-temperature heat exchangers. High temperatures are obtained by concentrating solar irradiance via reflecting surfaces [1]. Furthermore, solar collectors are classified according to the geometrical concentration ratio (C), defined as

$$C = \frac{A_{ap}}{A_{abs}} \tag{1}$$

where A_{ap} is the aperture area of the reflector and A_{abs} is the absorber area. For instance, $C = 1$ for flat plate collectors and $C > 1$ for concentrating collectors. Hsieh [2] conducted a theoretical study for the evacuated tube solar collector with U-tubes and a full CPC reflector. Mathematical formulation of optical and thermal processes in CPCs was performed. In his model, any beam of radiation incident within the acceptance angle assumed to reach the absorber. Convection heat transfer coefficient of the working fluid was constant and the contact thermal resistance was neglected. In the work of Kumar et al. [3], theoretical performance of a single-pass metal tubes evacuated tube collector with a CPC reflector was analyzed under different operating conditions. In their model, the energy balance equations for each component (cover, receiver envelope, receiver and fluid inside the cylindrical tube) were solved by using the finite difference technique. Kim and Seo [4] proposed a theoretical and experimental model of the evacuated tube collector with finned tubes and U-tube designs. In their model, the performances of the collectors were studied to find the best shape of the absorber tube. Beam, diffuse irradiation and shade due to adjacent tubes were also taken into account. In linear concentrators, the case of PTC, the thermodynamic limit for the concentration ratio is around 213, as demonstrated by Rabl [5]. In electronics, the mini-channel technology has proved to be reliable and effective in removing high heat fluxes. Its