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Numerical and experimental analysis of a CPV/T receiver suitable for low solar concentration factors

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Abstract

Solar energy conversion is one promising technology to provide the building required energy. Generally, the main used technologies are the PV and thermal flat panels, but this situation provides separately electricity and thermal energy. Electrical and Thermal power combined production is available for the concentrating solar but, usually, this technology is applied to devices working at high concentration factor (over 100), which are large and, therefore, are not suitable for roof installations. At lower concentrating factors (less of 50 suns) small linear, mono-axial, roof integrated devices can be designed and built.The solar receiver plays a key role in the performance of energy generation because it houses the solar cells and itis used to recover the thermal solar power: actually, this is the device where solar energy is converted in electrical and thermal power. The radiation flux distribution on the receiver affects the efficiency of the linear solar concentrator system, because in a mono-axial sunrays are not perpendicular to the receiver. This paper describes the numerical and experimental investigation useful to evaluate the performance of a linear low (20 suns) CPV device and to understand the thermal working condition of the solar receiver. The experimental study focuses to a quantitative analysis of the energy transfer from sun to the water. The numerical activity is a CFD conjugate analysis where the solid volume and the fluids are investigated together; the scope is to individuate how the energy flux cross the device.

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Keywords: CSP, CPV/t, solar receiver test, micro-cogeneration power, CFD

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1. Introduction

In recent years, many CPVsystems and thermal concentrator systems have been developed [1]. Hybrid solar concentrator device(PV/T) have been developed to reduce the silicon needed for photovoltaic electrical energy production and to achieve the simultaneous generationof electrical and thermal energy.

The main idea that are based these systems is to replace the photovoltaic active surface with reflective or refractive surface that are much less expensive. Moreover, by using the replaced materials it is possible to increase the conversion efficiency of the overall system. The solar radiation is focused through mirrors or lenses onto a limited surface of photovoltaic material. In PV/T solar concentrator, the thermal energy production is achieved by recovering of the heat generated by the solar cells; this recovered energy is used to produce hot water (PV/T technology). Solar concentrators allows a better utilization of thermal power and improve the energy generation PV single-crystalline silicon solar cells [2].Solar cell cooling has been demonstrated to increase the PV panel efficiency [3] on standard flat PV panel, however the fluid low temperature limits heat recovery utilization in thermal plants. A thermal solar concentrator operating temperature is higher than 130° - 150° C to allow a good efficiency of the system [4], but this temperature is higher than the highest temperature a PV solar cells can efficiently operate (max 90°C), so the development of PV/T is a trade-off between the production of electrical and thermal energy.

Nomenclature

CPV	Concentrated PhotoVoltaic
CFD	Computed Fluid Dynamics
PV/T	PhotoVoltaic and Thermal
Tilt	Angle between the ground and the panel
CHT	Combined Heat Transfer

The analysed receiver, Fig. 1, is a linear solar concentrating system [5] using low profile linear parabolic reflector to concentrate the solar radiation into a 10 mm high string of mono-crystalline cells [6] with a 20x concentration factor.It is more detail described in Cappelletti et al. [7].

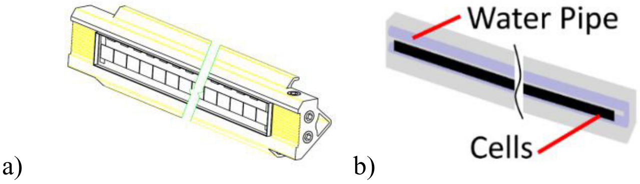

Fig. 1: a) The Solar Receiver. (b) Solid model with the detail of water pipe in the receiver.

The cells are cooled by means of water flowing through counter flow two pipes placed in the aluminium solar receiver; this solution reduces the cell's temperature and provides a thermal energy recovery, this solution is implemented by other system as in Rosell et al. [8]. The linear parabolic mirror concentrator is provided with a mono-axial tracking system and the main direction is Est-West. This configuration involvements a not perfect alignment with the sun of the receiver but it is a known limit of the single tracking axis [9]. A non-zero angles of incidence solar radiation presents the effect of "end-losses" issue [10]. A certain length of the absorber is not illuminated [11] thus there is a cold zone that reduces the heat transfer from receiver to the water. The aim of this work is presenting a combined investigation, experimental and numerical, on the thermal performance analysis of the receiver and understand how the heat transfer work in the receiver.

2. Experimental Analysis

2.1. The instruments

The test rig is placed in Florence (IT) (43°47'14" Latitude), where the standard Italian roof is simulated, so the device is oriented to South (0° azimuth) with a 12° tilt inclination, see Fig. 2a. A tank and a submersible pump compose the open hydraulic circuit connected to the device, see Fig. 2b. Two thermocouples measure water in (Tin) and out (Tout) temperature.A National Instrument c-DAQ-9178 performs the temperature data acquisition and it calculates directly the differential temperature. The using of large volume of water (over 300 liters) maintains constant Tin. The using of a reference volume (1 liter) and of a chronograph monitors the water flow rate with 10 minutes sampling.The main date output is the water thermal power that is evaluated by an enthalpy balance, noted the water mass flow rate and the differential Tout- Tin.During the test, theincident radiation date are acquired from the LaMMa weather station [12], it is placed only 2 km from the experiment place so in clear sky condition the data are congruent with the local condition. The elaboration considers the position of the receiver and its incident angle with the Sunrays calculated with the procedure suggested by Marion et al. [13].

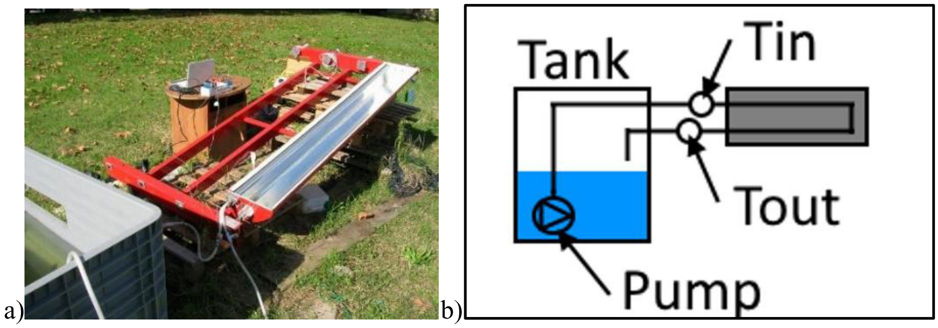

Fig. 2: a) The device during the experimental activity, b) Hydraulic circuit

2.2. The results

The aim of this presented activityfocuses on the thermal efficiency evaluation; this specifics test was is performed at29th October 2014.During the test, the incident radiation was constant in clean sky condition, no cloud, no wind and the air average temperature was about 289K. The average value of direct incident radiation was 713 W/m2. The water mass flow rate was monitored witha measuring every10 minutes and the average value was 0.0147kg/s. The chart of Fig. 3 reports the direct solar input, the heat power output in the water and thermal efficiency. The efficiency is evaluated from the quote of incident radiation is really captured by the receiver because the end-wall effect is important; the 10% of the bottom side of the receiver was shaded. The average thermalefficiency, calculated from the enthalpy balance of the water, it is about 64% and it is congruent with the results of Coventry [14].

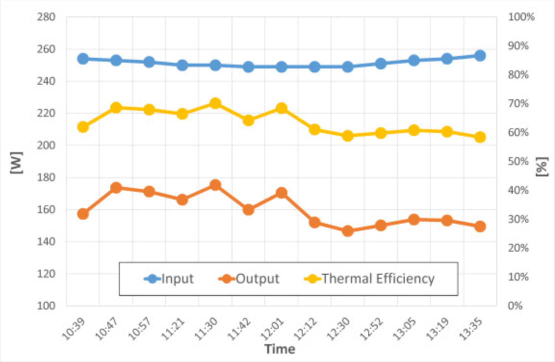

Fig. 3: Input from Incident radiation [W], heat poweroutput [W] and thermal efficiency[%].

3. Numerical Analysis

The aim of numerical instantiation is a blind test on the temperature distribution in the receiver to understand the effects of the flow direction in the receiver.

3.1. Models

The study is a CHT analysis where the solid volume and the water are modelled and it analyses the heat transfers between the two regions. The used CFD code is ANSYS Fluent® v14.5 [15]; its capability in fluid dynamic cases was assessed and validated in several previous analysis [16], [17].A steady RANS approach was selected and the realizable k-ε closure with standard wall functions for the near wall treatment was selected. The solid domain is showed by

b. An hybrid unstructured mesh of the domain, composed by about 4.63M elements, was generated by the commercial code Centaur TM [18]. The domain is divided in two zone: the solid (2.87 M elements) and the water (1.75 M elements), all two zones are filled by tetrahedrons. The interface between the two volumes is conformer so there is a continuity on node level.

3.2. Boundary conditions

The numerical simulations analyze two configurations of the receiver; the difference is only on the water flow direction: the actual and inverted. The imposed boundary condition are referred an investigation point of the previous experimental activity, so all the noted information are imposed. The incident radiation is imposed as heat input on the receiving surface (241W).On all external surfaces a heat output is imposed to simulate the all thermal loss (-71W). This value is calculated from the test results as the difference between the power input (incident radiation) and the water power output. The water mass flow rate is 0.0147kg/s and the inlet temperature is 290K. With this boundary condition, the calculated outlet water temperature is about 2.75K as during the test.

3.3. Results

This works focuses on the temperature distribution in the receiver. The images of Fig. 4 show the temperature on the middle plane for the two cases. The maximal temperature in the receiver is about 295K only 2K over the outlet temperature, this permit to works with high water temperature without a decrease of PV performances. The chart of Fig. 5 shows the temperature profiles in the channels; at length "1" there are the inlet and the outlet, at length "-1" there is the U-turn. The maximal temperature of the water is at the middle of return channel, at the outlet the temperature decreases to the U-turn temperature. The inversion of the flow direction influences poorly the temperature profiles, only near the U-turn.

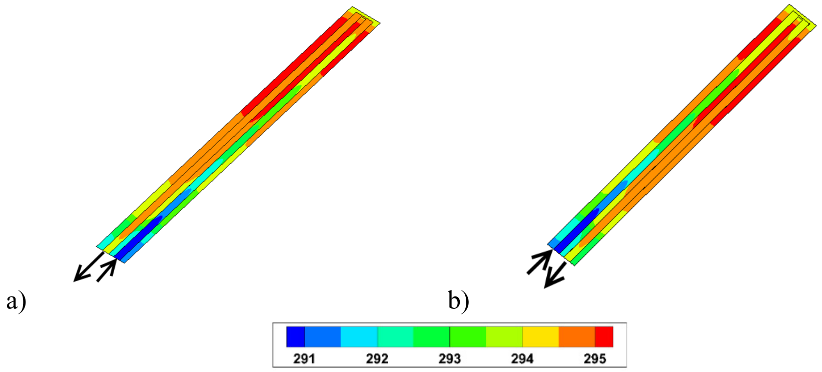

Fig. 4: Temperature in the water channel a)actual flow direction, b)inverted flow

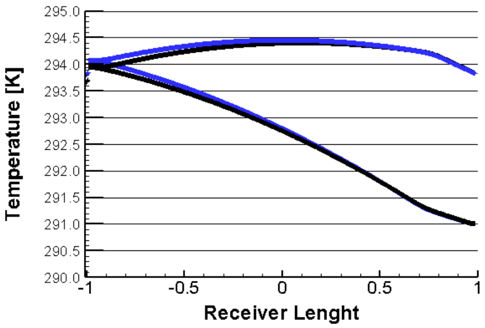

Fig. 5: Temperature profiles in the water channels: Blue actual direction, Black inverted

4. Conclusion

A solar receiver utilized in a concentrating PV/T system is investigated by an experimental and numerical approach to determine its capability to heat water. The unit presents a 64% thermal efficiency calculated on the available sun flux. The maximal outlet temperature is limited by the U-turn geometry of the water channel; actually, during the return way the water transfers energy to the cold zone of the receiver. A one way double channels solution could be preferred for higher temperature, but it increases the difference of temperature in the receiver so it could influences the PV cells operability.

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Biography

Eng. Alessandro Cappelletti, presently Grant Researcher at the Department of Industrial Engineering, University of Florence. His main field is the using of alternative fuels.
At present, he works on the development of innovative PV concentrated solar system, thermal and photovoltaic production on the same device.