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Experimental and CFD investigation on temperature distribution of a serpentine tube type photovoltaic/thermal collector

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ABSTRACT

The issue of temperature distribution is significant in the research of PV/T collectors due to the inherent negative temperature characteristics of solar cells. In this paper, a three-dimensional thermal model of a water-cooled flat-panel PV/T collector with serpentine tube is established using the finite element method, which the simulation accuracy is verified by the experimental data. We investigate the effect of multiple factors on the temperature distribution, including tube spacing, absorber materials, inlet velocity and tube row arrangement, respectively. Our results show that reducing tube spacing is the most effective way to increase uniformity of temperature distribution, and using absorber materials with better thermal properties can improve the temperature distribution partly. However, increasing the fluid inlet velocity has little effect on establishing a uniform temperature field though it can reduce the plate temperature. Temperature is hardly affected by the tube row arrangement, and uniform temperature field cannot be obtained with more bends.

1. Introduction

The application of new energy such as solar energy, wind energy and geothermal energy has become more extensive and comprehensive (Zhou et al., 2017; Liu et al., 2018; Hayashi et al., 2018). The PV/T collector is a versatile solar collector that uses a PV panel instead of a specific heat absorber. Thermal efficiency of PV/T collector may be reduced lightly, however, higher overall efficiency of energy utilization can be achieved for solar cells can also output power through the photovoltaic effect at the same time. The electrical efficiency of the PV module is related to the cell temperature. The working fluid can take away the excess heat and improve the photoelectric conversion efficiency of the module.

Since Wolf (1976) proposed the concept of PV/T collectors for the first time; extensive research has been carried out by experimental and theory methods on the performance of the module, among which the water-cooled flat-panel PV/T collectors are the most widely studied. Various simulation software such as ANSYS, TRNSYS, etc. can be helpful to get more detailed results. Khelifa et al. (2016) believe that the PV/T collectors can effectively improve the cells' electrical efficiency, and its overall efficiency is greatly affected by the ambient temperature. The research results of Corbin and Zhai (2010) showed that the electrical efficiency of BIPV/T is higher than that of BIPV by 5.3%, and it can provide enough domestic hot water for use. Nahar et al. (2017) showed that the addition of a absorber plate in the PV/T collector has little effect on the thermal efficiency of the module. Moreno et al. (2017) studied the performance of PV/T collectors under different seasons; and proposed the problems of overheating and insufficient outlet water temperature during the test process. Li and Jing (2017) studied the CPV/T collectors by a coupled TRNSYS and CFD simulation method. They compared the overall efficiency of different cell materials and performed annual output energy assessments.

Temperature distribution has played an important role for solar power generations (Zhou et al., 2015, 2017). Non-uniform temperature distribution affects the normal use of the solar cells, which are the core component of the PV/T collectors, in two ways: (1) cells efficiency loss due to power output loss; (2) the thermal fatigue induced by temperature variation because of large amount of the thermal cycles and stresses (Bahaidarah et al., 2016). Although the study of temperature distribution is often applied to concentrating PV modules, its influence on the performance of PV/T collectors also cannot be ignored.

Previous studies mainly used CFD methods to study the effects of environmental parameters and design parameters on PV panel temperature and outlet water temperature in PV/T collectors (Leone and Beccali, 2016; Boddaert and Caccavelli, 2007; Teo et al., 2012). The value of average temperature alone is used to measure the influence of various factors without paying attention to the temperature distribution on PV panel. In the common water-cooled flat-panel PV/T collector, the

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Nomenclature

A	surface area (m^2)
c	specific heat capacity (J/kg·K)
G	solar irradiation ($W·m^{-2}$)
h	heat transfer coefficient ($W·m^{-2}·K^{-1}$)
k	thermal conductivity($W·m^{-1}·K^{-1}$)
p	packing factor
Q	heat
U	heat loss coefficient ($W·m^{-2}·K^{-1}$)
v	wind speed ($m·s^{-1}$)
W	tube space (mm)
greek	
α	absorption factor
β	solar cell temperature coefficient (K^{-1})
δ	thickness (mm)
ε	Emissivity
θ	tilt angel (degree)
ρ	density ($kg·m^{-1}$)
η	efficiency
τ	transmittance
subscripts	
amb	ambient
abs	absorber
c	collector
el	electrical
g	glass cover
in	inlet
out	outlet
pm	mean value of plate
ref	reference
S	sky
t	tube
T	Tedlar
th	thermal
W	wind

temperature distribution problem of the serpentine tube assembly is more prominent than the parallel tube assembly. In this paper, the influence of parameters on the PV/T collectors is investigated from the perspective of temperature distribution with the method of experiment and CFD simulation.

2. Experimental study

The experimental platform was set up to study the performance of PV/T collectors and also to verify the accuracy of the simulation project. It was conducted in Changsha (112°55′E , 28°13′N), Hunan Province, China. The total annual radiation is about 4030 MJ/m^2, and the experimental time lasted from September to November. The experiment was carried out in an outdoor scene as show in Fig. 1. The schematic diagram of the experiment is shown in Fig. 2.

High-transmittance glass is used on the front side of the PV laminate to isolate the air layer. The aluminum absorber plate is connected to the TPT layer. The cooper serpentine tube is welded behind absorber and the entire back of the module is wrapped with an insulating material. The parameters of the PV modules used are shown in Table 1.

In order to make the experimental situation closer to the actual use in life, the cycle pump P1 is controlled by the difference between the water temperature of the heat exchange tank and the temperature of the PV panel ($T_{e,tank} - T_p$). The water temperature of the heat exchange tank ($T_{e.tant}$) controls the cold water inlet pump P2. At the same time, micro-inverters and energy communication units manufactured by Ap Systems are used to collect the various electrical parameters of the collectors. Experiments are conducted throughout the day. To avoid dealing with excessive useless data, take 8:00am–5:00 pm as the data collection period. The standard uncertainties associated with experimental measurements are shown in Table 2. The key dimensions and physical parameters of the PVT collector are shown in Table 3.

The conditions for judging whether the collector reached the quasi-steady state were as follows:

A. The maximum ambient temperature difference within 15 min does not exceed 1 °C;
B. The maximum inlet temperature difference within 15 min does not exceed 1 °C;
C. The irradiance is greater than 650 W/m^2 in 15 min, and the maximum irradiance difference does not exceed 50 W/m^2.

3. CFD study

3.1. Modeling

The physical model is built exactly in accordance with the structure and dimensions of the experimental collector. It consists of a top glass cover, air layer, PV laminate, absorber, serpentine tube, and water. The PV laminate consists of a conventional 5-layer structure (glass/EVA/

Fig. 1. Experimental set-up.