Numerical Investigation of a two-inlet PVT air collector

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Abstract. A numerical study of heat and mass transfer characteristics of a two-inlet PV/T air collector is performed. The influence of thermal characteristics and efficiency is investigated as the area ratios of inlet and outlet of the single channel with two inlets are changed. The design of the two-inlet PV/T air collector can avoid the poor heat transfer conditions of the single inlet PV/T air collector and improve the total photo-thermal efficiency. When the inlet/outlet cross-sectional area ratio is reduced, the inlet air from the second inlet enhances the convection heat transfer in the second duct and the temperature distribution is more uniform. As the cross-sectional area of the second inlet increase, the maximum heat exchange amount of the two-inlet PV/T air collector occurs between the inlet and outlet cross-sectional area ratio $L=0.645$ and $L=0.562$.

1 Introduction

Photovoltaic and photo-thermal solar collection system is a combination of photovoltaic modules and thermal energy collection modules. The system can collect solar energy in the form of electric energy and thermal energy. Because photovoltaic-thermal system can further improve the utilization of solar energy, it has become a hot research topic in the field of solar energy in recent years. Since the 1970s, a lot of research and development have been done on photovoltaic-thermal (PV/T) technology. Many innovative systems and products have been proposed. From the early concept, a series of models about photovoltaic-thermal theory were established and introduced, and their applicability was verified by experimental data. In the early research on photovoltaic-thermal solar energy utilization device, Martin Wolf et al.^[1] analyzed photovoltaic-thermal system, showing that the photovoltaic-thermal system is a feasible method and the cost is controllable. In China, Chao Guo et al.^[2] studied the thermal efficiency of photovoltaic-thermal system, and found that the efficiency of heat recovery would increase with the increase of air mass flow. Compared with the solar collector which only has the function of collecting heat, the PV/T system will have a higher comprehensive utilization efficiency. Florschuetz LW et al.^[3] have verified the design of a device using water or air as coolant and given key design concepts and parameters. Air and water are used as the cooling medium of most PV/T systems, and Tripanagnostopoulos Y et al.^[4] found that water-cooled PV/T system had higher thermal efficiency than air-cooled PV/T system. However, due to the high equipment cost, poor operational reliability and difficulty in maintenance of water-cooled PV/T system,

air-cooled PV/T system is more suitable for integrated solar energy utilization with buildings. In the air-cooled PV/T system studied by Adel A H et al.^[5], it was found that the utilization of solar energy was the highest when photovoltaic panels were spread between the glass cover and the back plate. For the study of two-inlet PV/T system, the experimental results from Tingting Yang et al.^[6] show that the two-inlet system with frameless PV plate can increase the thermal efficiency to 5%, while the building integrated photovoltaic/thermal (BIPV/T) system with semi-transparent PV plate can increase the thermal efficiency to reach 7%.

At present, many scholars are engaged in experimental and theoretical research on PV/T air collector system, but there are few researches on PV/T air collector system with two-inlet single channel. This system is characterized by fresh air entering the passage from the central region to enhance the heat transfer efficiency in the central region. By establishing a set of numerical models for a two-inlet single-channel PV/T system and changing the cross-sectional ratio of inlet and outlet, the influence on the heat and mass transfer characteristics are analyzed in this paper.

2 Model construction and validation

2.1 Geometric and physical models

The structure of the two-inlet single-channel PV/T air collector system is shown in figure 1. The system can be divided into two parts. The first photovoltaic panel is parallel to the adiabatic backplate, and the internal air passage is 45mm high. The connection between the second photovoltaic panel and the first photovoltaic

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panel is left with a gap of 12mm high, which serves as the second air inlet. Based on the air passage heights was changed before and after two air passage, both sides and bottom of the collector are adiabatic materials, and the top is a photovoltaic panel without border. There is a forced air exhaust device at the outlet of the back air channel.

Fig.1 Schametic of the PV/T system with two inlets

2.2 Numerical model

Hexahedral structured mesh is used to divide the model mesh in numerical calculation. Air inlet adopt pressure inlet, velocity outlet boundary conditions was used in air outlet, inlet pressure is atmospheric pressure, inlet temperature is 20°C, and the speed of outlet is 2m/s. No slip boundary condition is used on inner wall surface. The sun shines directly on the glass plate and shines through the glass plate on the heat absorption plate. Considering the efficiency of photovoltaic power generation in the system, combined with the heat loss of the upper surface of the photovoltaic photothermal device and the air, the heat absorption plate is defined as the boundary condition of constant heat flow of 300w/m². For the bottom wall surface, its influence on the flow should be taken into account. Therefore, it is more appropriate to set the heat flow density of 80w/m². Other structure surface set adiabatic condition. The turbulence model is based on the standard $k-\epsilon$, and the mesh has good adaptability.

3 Simulation results and analysis

3.1 Validation of grid and model

The environmental temperature was set as $T=293K$, and the number of structured grids from 1 million to 1.5 million were used to verify the grid-independence of the model. As the number of grids reaches 1.27 million, the calculated average temperature and average speed of the inlet and outlet remain unchanged. So, 1.27 million

structured grids can obtain the required accuracy and grid-independent solution was found.

Fig.2 Temperature variations in top and middle layers when air is mixed in the second PV/T section

In order to verify the validity of the model, the calculated ten temperature points at the back air passage are compared with the experimental values of Tingting Yang et al.^[6], and the results are shown in figure 2. The distance from the second inlet is set to symbol M, $M=0.03$, $M=0.28$, $M=0.53$, $M=0.77$ and $M=1$. Figure 2(a) is the comparison between calculated and the experimental values of 5 temperature points in the top layer. Figure 2(b) is the comparison between calculated and the experimental values of 5 temperature points in the middle layer. As can be seen from figure 2(a), the calculated value of the temperature distribution at the top of the air passage is in agreement with the experimental result, and the same trend can be seen. There is a little difference between the calculated and experimental values at the the back of top layer. The most important cause of this is that numerical calculation is idealized calculation and in actual experimental condition the heat and mass transfer characteristics of the PV/T air collector are influenced by many factors. Because of the same reason, the heat transfer efficiency will also definitely decrease at the the back air passage. Same conclusion can be seen from the comparison between the

simulated value and the experimental value of the temperature distribution in the middle layer in figure 2(b). To be sure, the calculated value is in good agreement with the experimental value. The average deviations between experiment and calculation of temperature points in the top layer and in the middle layer were 8.7% and 3.4%, respectively. It was shown that the simulation model in this paper can be used for the research of PV/T system.

3.2 The area ratio variation of inlet and outlet

Figure 3 shows the geometric characteristics of PV/T system with two-inlet in single channel. The lengths of the first half of the air passage (length_first) and the second half of the air passage (length_second) are 1020mm. Setting the cross-sectional area ratio of the front and back air passage is L , $L = \text{inlet_first} / (\text{inlet_first} + \text{inlet_second})$. In this paper, the cross-sectional area ratio of the front and back air passage is set as $L=0.847$, $L=0.746$, $L=0.690$, $L=0.645$, $L=0.562$ and $L=0.5$, respectively. The detailed settings can be seen in Table 1.

Fig 3 Geometric feature of air cooled PV/T system with double inlet

Table 1 Cross-sectional area ratio L of six condition

Serial number	Inlet_first/mm	Inlet_second/mm	L
PV_0	45	8.10	0.847
PV_1	45	15.30	0.746
PV_2	45	20.25	0.690
PV_3	45	24.75	0.645
PV_4	45	35.10	0.562
PV_5	45	45.00	0.500

Fig.4 The temperature distribution of 6 cross-sectional area ratios

Fig.5 The velocity distribution of 6 cross-sectional area ratios

Figure 4 and 5 respectively show the distribution of temperature and the distribution of velocity of six kinds of inlet/outlet cross-sectional area ratios. As shown in figure 4, Different area ratios of the inlet and outlet have little influence on the temperature in the front duct. With the increase of the area of the second inlet, the area of the second inlet has stronger influence on the temperature distribution in the back duct, which strengthens the convection effect and makes the temperature distribution more uniform. In figure 5, in the condition of forced ventilation, with the decrease of the cross-sectional area ratio L of the inlet and outlet, the velocity at the second inlet will also increase. The direction of this velocity is not horizontal, but points to the 45° angle coming top from the down. This characteristic is consistent with the experimental measurement conclusion of Tingting Yang et al.^[6]

Figure 6 shows the inlet/outlet temperature difference and the total heat exchange of six kinds of inlet and outlet cross-sectional area ratios. Although the temperature difference between the inlet and outlet decreases with the decrease of the cross-sectional area ratio, the total mass flow increases with the increase of the cross-sectional area of the second inlet. It was found that the total heat transfer reaches a maximum value between $L=0.645$ and $L=0.562$ (L is the cross-sectional area ratio of the inlet and outlet) by calculation. In engineering applications, the two-inlet single-channel PV/T system can control the outlet temperature by changing the cross-sectional area of the second inlet. And in order to obtain a maximize value of the total heat transfer, an optimal cross-sectional area ratio of the inlet and the outlet can be found. At this time the photothermal efficiency is also the highest.

Fig.6 The temperature difference and heat exchange amount of 6 cross-sectional area ratios

4 Conclusions

1. When the cross-sectional area ratio (L) of the inlet and outlet decrease, the area of the second inlet has a stronger influence on the temperature distribution in the back duct. It strengthens the convection effect and makes the temperature distribution more uniform.

2. As the cross-sectional area of the second inlet increases, the total mass flow increases and the

temperature difference between the inlet and outlet also decreases. The calculated maximum heat exchange amount of the two-inlet PV/T air collector occurs between the inlet and outlet cross-sectional area ratio $L=0.645$ and $L=0.562$.

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