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Comparative experiment study on photovoltaic and thermal solar system under natural circulation of water

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ABSTRACT

The hybrid photovoltaic and thermal (PV/T) system can utilize solar energy more effectively and has a higher total efficiency compared with a traditional solar collecting system and a photovoltaic (PV) module. However, there is limited experimental data on how much energy the PV/T system can save when operating with same area of a PV plate and a solar collector simultaneously. In this paper, a comparative test rig had been set up to measure and analyze the performance of PV/T system. There were monocrystalline silicon PV/T solar collector, a traditional solar collector and a monocrystalline silicon photovoltaic plate. The PV/T collector and the traditional solar collector had the same collecting areas and solar cell covered area of the PV/T collector was the same as the area of the photovoltaic plate. The experimental results showed that the daily thermal efficiency of PV/T system was about 40%, which was about 75% of that for a traditional solar thermosiphon system, and the daily average electrical efficiency was found about 10%, which was a little lower than the photovoltaic module. But primary-energy saving efficiency of the PV/T system was much higher than that of the individual PV plate and the traditional solar collector.

1. Introduction

Since the first silicon solar cell was developed in Bell laboratory by Chapin et al. [1], solar cells have received extensive interest due to its simple structure, stable stability, purity and long service time, and their efficiency has increased constantly. However, in practical application the efficiency of the solar cell is much lower than that in standard condition (The radiation density is 1000 W/m^2 and the temperature of solar cell is 25 °C) because of the higher temperature of solar cell which decreases the efficiency.

In order to utilize the solar cell at a low operating temperature, researchers focus on cooling of the solar cell and then take advantage of the heat dissipated from the solar cell. If place some fluid channels at the rear of the solar cell, the fluids flowing in the channels will remove the heat from the cell, hence the temperature of solar cell will get down and then its efficiency will increase. The heat removed by the fluids can be utilized, that is to say the system can provide thermal energy while generating electrical energy. This kind of solar system is called photovoltaic/thermal (PV/T) system. Since Kern and Russell [2] first proposed the main concept of PV/T system which uses air or water as the heat carrier medium, many researchers in the world have conducted theoretical and experimental analysis of PV/T system. Bergene and Lovvik [3] showed that the total efficiency of the PV/T system could achieve 60%–80% through their theoretical research. Huang et al. [4] proposed the concept of primary-energy saving efficiency which was more accurate in evaluating the performance of PV/T system. And they also developed a new PV/T collector type which consisted of collector plate and polycrystalline silicon solar cells. Daily average thermal efficiency of this kind of PV/T system could achieve 38%, and its primary-energy saving efficiency was about 60%. The PV/T system developed by Bjornar and Rekstad [5] had monocrystalline silicon solar cells affixed to the back of a flat-box type solar collector plate which was made of a polymer and had glazing on the surface. They had done experimental research with a low temperature water under different conditions. Hisashi Saitoh et al. [6] affixed monocrystalline silicon solar cells to an aluminum plate with copper tube on the back, and made another PV/T system prototype. They used brine as the heat carrier medium and tested the performance of this system. Zakharchenko et al. [7] made a PV/T solar collector by felting solar collectors with black PVC absorber plate and different kinds of photovoltaic cells. They analyzed the test results and reached the conclusion that there would be better cooling effect on photovoltaic cells and higher thermal efficiency if the area of photovoltaic cells was much smaller than the area of solar collector and the photovoltaic cells was arranged near the

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inlet of the solar collector. Chow [8] developed an explicit dynamic model for a single-glazed flat plate water-heating PV/T collector based on the control-volume finite-difference approach. Furthermore Chow et al. [9] also introduced a dynamic simulation model of a building-integrated PV/T system and compared its predicted operating temperature changes and system daily efficiencies with the measured data acquired from an experimental rig. W. He et al. [10] had experiments on an individual aluminum-alloy flat-box type PV/T system under natural circulation of water and evaluated its performance throughout daily experimental data. Then Chow and He [11] also had an experimental study of facade-integrated PV/T water-heating system with different operating modes in different seasons and reached the conclusion that Natural water circulation was more preferable than forced circulation in this hybrid solar collector system. Kalogirou et al. [12] analyzed and compared industrial application of PV/T solar energy systems from the aspects of locations, load supply temperatures temperature, material of solar cell, requirements of energy and cost of the systems. Charalambous et al. [13] introduced the PV/T system in the aspects of types, theory, models, experimental work, performance and affecting factors comprehensively and systematically in their review. Dubey et al. [14] derived an analytical expression for characteristic equation of combined system of PV/T flat-plate collectors and validated it experimentally for various configurations. The performance of water-heating system had also been carried out.

Through the former research, it is known that the PV/T system can utilize the solar energy more effectively and has a higher total efficiency than a common solar collecting system, but the extent is unknown. In other words, it is unknown that how much more energy the PV/T system can collect than common solar collector or the common PV module in the same daylighting area under the same conditions. Especially, the comparative data between the PV/T system and traditional solar system is limited. In order to explore the unsolved problem and the limitation mentioned above, we set two control groups while testing the performance of the PV/T system at University of Science and Technology of China. The control groups are a monocrystalline silicon photovoltaic and a traditional flat plate solar collector. The test PV/T is a new type of PV/T solar collector which has the same material as monocrystalline silicon photovoltaic and is integrated with common solar collector. The solar collect area of the PV/T solar collector is the same as the areas of the traditional flat plate solar collector mentioned above and the solar cell covered area of the PV/T solar collector is also the same as the area of the monocrystalline silicon photovoltaic. In this paper, we clarified the effectiveness of the PV/T system that generates both electric energy and heat, by comparing with the effectiveness of those two control groups mentioned above.

2. Composition of PV/T system and experiment rig design

2.1. Outline of PV/T collector

The core component of PV/T system is PV/T solar collector. Though performance of heat transfer of the tube-sheet type collector is not as good as the flat-box type collector's, the tube-sheet type collector has the advantages of less water capacity and higher pressure bearing capacity, furthermore, it is easier to manufacture. We chose tube-sheet type structure as the absorber plate in the PV/T collector. Figs. 1 and 2 show the front view and the cross section of a PV/T solar collector. A PV/T solar collector is composed of tempered glass, monocrystalline silicon photovoltaic plate, aluminum absorber plate, copper tubes and thermal insulation layer. The tempered glass cover was separated from the PV plate by an air gap. Seven copper tubes were meld to the bottom side of the aluminum absorber plate which was below the PV plate. The thermal insulation layer which was attached to the side and bottom surfaces of the PV/T solar collector was made of asbestos. The water inlet and outlet ends were provided at the lower and upper traverse tubes. The specifications of PV/T solar collector are shown in the Table 1.

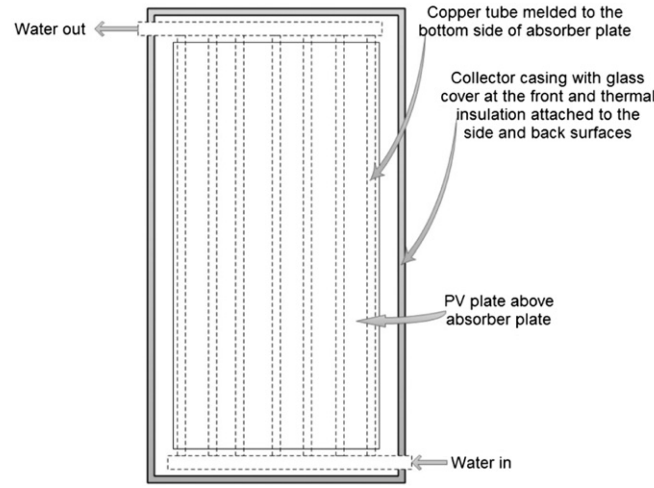

Fig. 1. Front view of the PV/T solar collector.

2.2. Experimental and measurement systems of the PV/T system

Fig. 3 is a system diagram of the experimental equipment. Fig. 4 is a relief image photo of the experimental equipment. The PV/T solar collector carried a thermally-insulated 100 L water-storage tank. Because stratification of temperature was obvious in the storage and in the collector under the natural circulation of water, we set three thermocouples in the storage tank at different altitudes to measure temperature of the water in it. For the succeeding further analysis, each of the temperature of the ambient, the glass cover, the back plate and the water in the inlet and outlet ends was also measured by a pair of thermocouples. Considering that all of the temperatures we measured were in the temperature range of 0 °C–100 °C, we chose the type of copper-konstantan as the thermocouples, whose accuracy were about ±0.3 °C. The temperature of the water was about 10 °C–70 °C, then error estimation of the temperature was about ±0.4%–±3%. The controller controlled the charge and discharge of storage battery and made the output voltage of solar cell near the maximum-power-point. The converter converted direct current into alternating current which was provided to the load conveniently. The operating voltage and operating current of the solar cell had been also measured. The

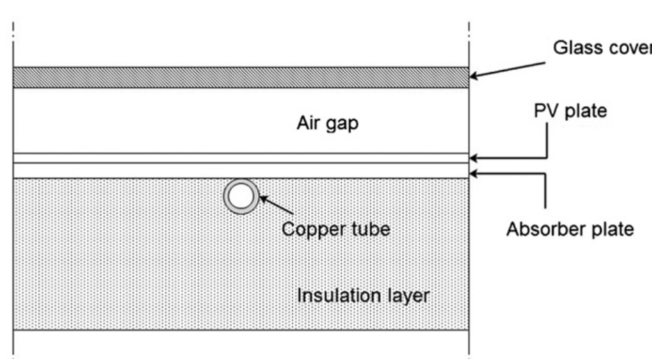

Fig. 2. Cross section of the PV/T solar collector.