Performance Evaluation of a Novel Vacuum Tube PV/T System with Inserted PV and Heat Pipe

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Introduction

Current study mainly focuses on changing the heat transfer medium and PV/T system structure. Although the applications of heat pipes and vacuum tubes in PV/T systems and solar collectors are numerous, most studies have only focused on one of the systems, such as heat pipe PV/T systems, vacuum tube PV/T systems, or vacuum tube solar collectors with inserted heat pipes. Only collecting heat with the collector is not sufficient, and no research has been conducted on vacuum tube PV/T systems that simultaneously insert PV cells and heat pipes.

In addition, vacuum flat-plate PV/T systems have achieved good results in the application of organic Rankine cycles [1-2]. The structure of vacuum tube collectors can also be combined with heat pipes [3] to form a vacuum tube collector with heat pipes, further improving the collector's thermal performance.

This study presents the materials, processes, and parameters of the PV/T system, proposes a vacuum tube PV/T system with inserted PV and heat pipe, establishes the energy transfer process and solves it using self-programmed programs. Experimental verification is conducted under various irradiance and ambient temperature conditions. Simulation and analysis are performed under different flow rate and other parameters, and the results are compared with traditional PV/T systems. Finally, a conclusion is drawn.

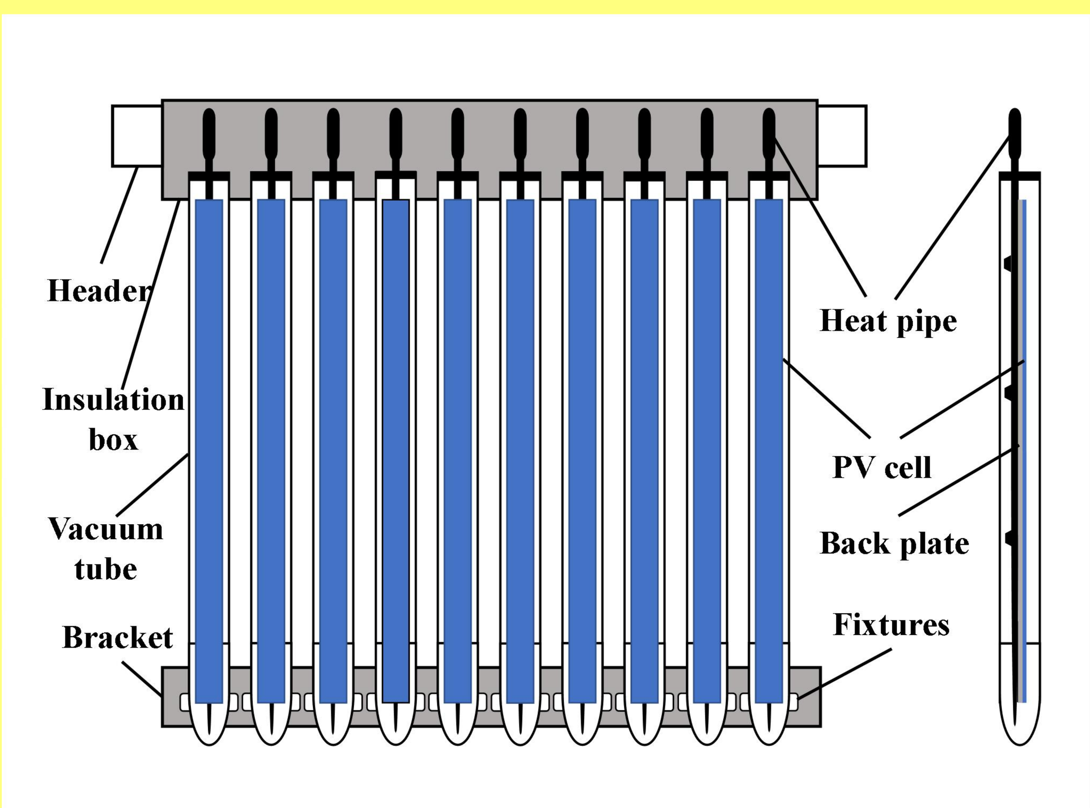

Fig. 1. Vacuum tube PV/T system structure diagram.

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Experimental System

A novel PV/T system is designed, which is mainly composed of heat pipes, glass tubes, photovoltaic cell components, backplane, heat exchange pipes, fixed brackets and heat insulation devices.

Fig.2 is the physical picture of the novel PV/T system. The photovoltaic cell module is tightly bonded to the backplane with thermal conductive adhesive, and the backplane is fixed with a fixing device after being welded to the copper heat pipe. Meanwhile, the backplane also provides support for the photovoltaic module. The glass tube is sealed at the inlet after being evacuated, and the exposed condensation end of the heat pipe is inserted into the header.

The experiments of the novel PV/T system were conducted in an indoor laboratory. The entire experimental setup consisted of a solar simulator, a single novel PV/T system, an IV curve tester, a data acquisition instrument, a pyranometer, a thermometer, and thermocouples.

The vacuum tube heat pipe PV/T system absorbs radiation energy from a solar simulator, converting a small portion of the energy into electricity and the majority of it into heat. Some energy is also dissipated into the environment. The radiation intensity can be varied by adjusting the parameters of the solar simulator, which includes multiple sets of setting values ranging from 630W/m² to 900W/m². The indoor environment temperature can be controlled by an air conditioning system, with the temperature set within the range of 288K±1K and 295K±1K.

Fig. 2. Practical vacuum tube PV/T system.

Simulation

The solar radiation passes through the outer wall of the vacuum tube and is projected onto the photovoltaic cell module. The photovoltaic cell module converts a portion of the solar energy into electricity, while conducting the remaining heat to the metal absorber plate on the back, which converts the solar radiation energy into heat and vaporizes the heat transfer medium in the evaporator section of the heat pipe. The vapor rises to the condensing end of the heat pipe and transfers heat to the working fluid in the header, while it condenses into liquid and flows back to the evaporator section by gravity. This process is repeated, continuously heating the working fluid in the header. Meanwhile, the heated photovoltaic cell module and other components such as the header dissipate some of the heat to the surrounding environment.

For the convenience of energy transfer analysis of the vacuum tube heat pipe PV/T, assumptions are made[4-5].

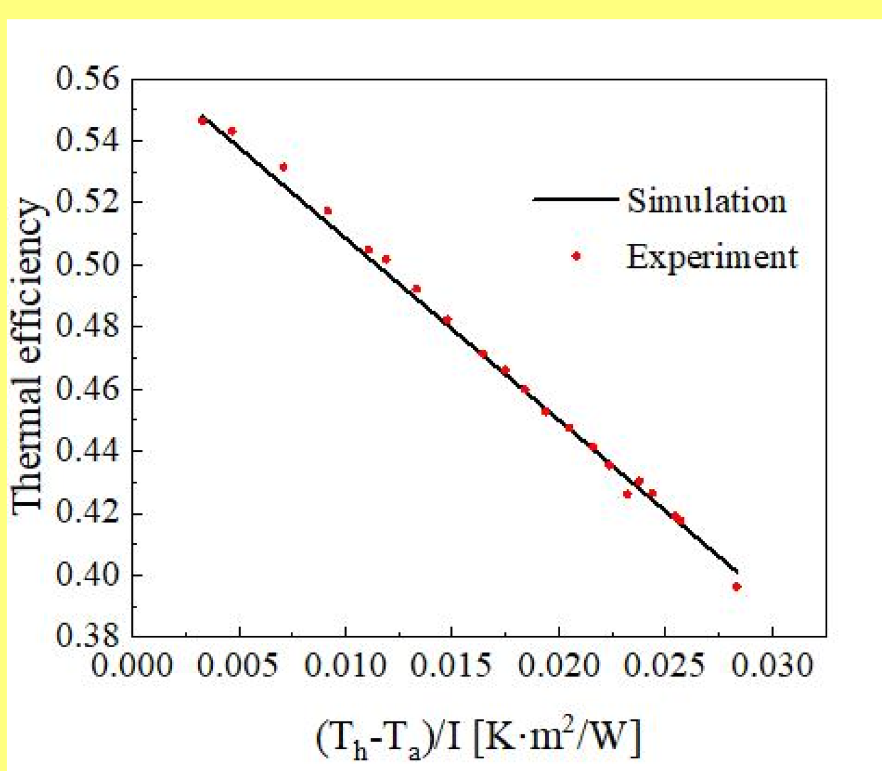

Fig. 3. PV/T system thermal efficiency simulation and experiment.

Results

Fig. 4 and 5 display various curves under different irradiance levels at an ambient temperature of 288K. In Fig.4 and 5, A, B, C, D, and E represent irradiance levels of 830W/m², 780W/m², 730W/m², 680W/m², and 630W/m², respectively. The highest electrical efficiency, thermal efficiency, and overall efficiency reached 11.56%, 48.89%, and 57.22%, respectively. Compared to the flat PV/T system in reference [6], which achieved 9.8% electrical efficiency,27.4% thermal efficiency, and 37.3% overall efficiency, both thermal efficiency and overall efficiency have been significantly improved.

It can be observed that the change in electrical efficiency is not significant, and the instantaneous thermal efficiency increases with the increase of irradiance. Regarding overall efficiency, although the increase in irradiance level will increase heat dissipation losses, it will also bring higher electrical and thermal returns, thus higher irradiance levels are beneficial for improving the system's overall efficiency.

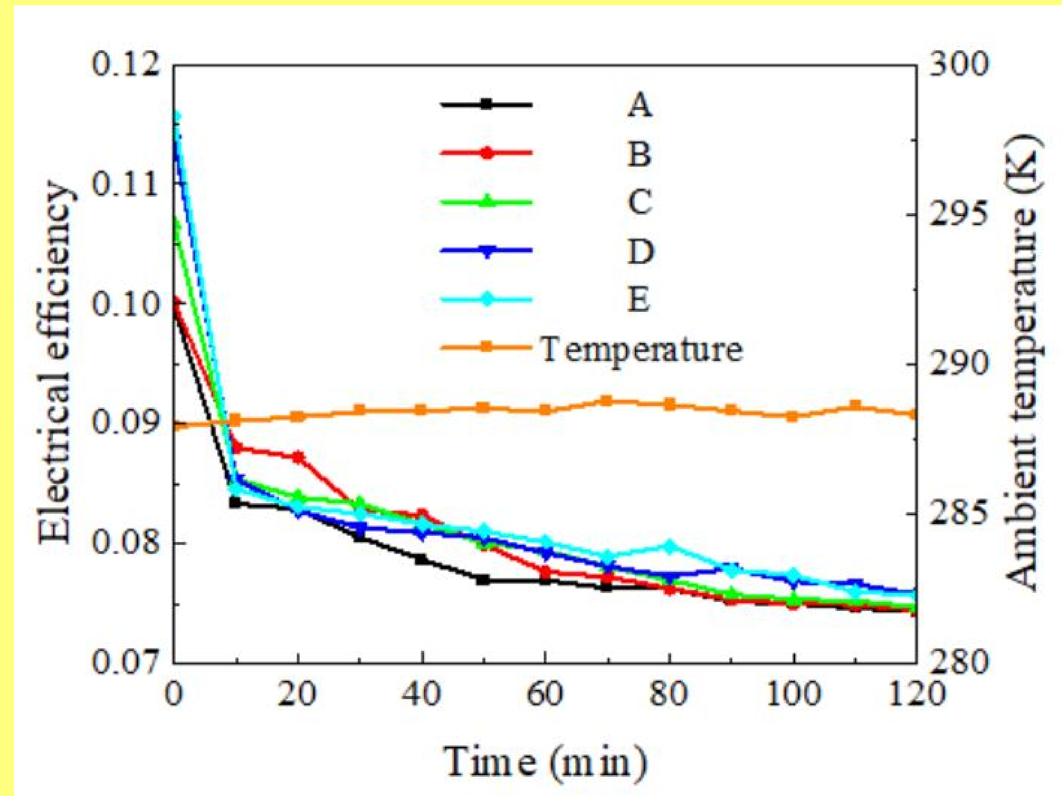

Fig.4. Electrical efficiency.

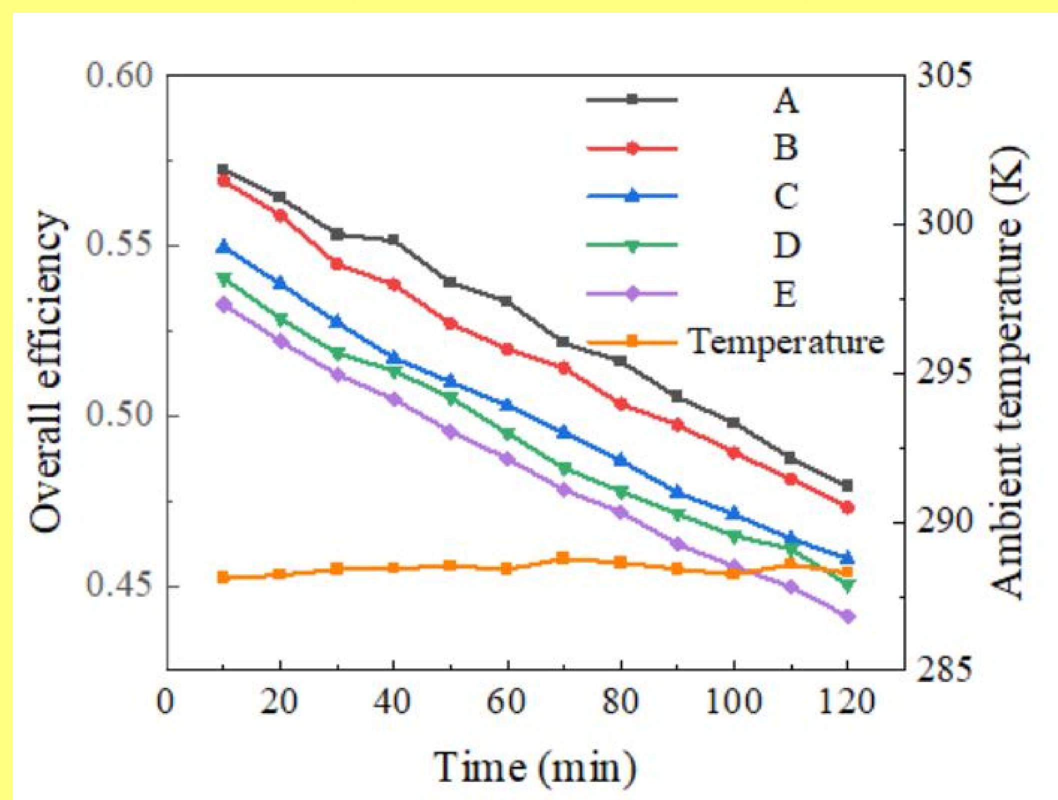

Fig. 5. Overall efficiency.

Conclusions

The main conclusions drawn from this study are:

- The vacuum tube PV/T system with inserted PV and heat pipe can transfer more heat, resulting in improved electrical efficiency, thermal efficiency, and overall efficiency compared to traditional flat-plate PV/T systems;
- The heat pipe can efficiently transfer heat. While the vacuum tube can reduce heat loss between the system and the environment, thus improving the overall performance of the novel PV/T system from both aspects;
- Within a certain range, changes in ambient temperature and irradiance have a greater impact on the system's thermal efficiency. However, an increase in irradiance and a decrease in ambient temperature can significantly increase the total heat loss.

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