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IMPACT STUDY OF HEIGHT DIFFERENCE ON SOLAR THERMAL PERFORMANCE OF A NOVEL SOLAR MICRO-CHANNEL LOOP HEAT PIPE-PV/T HEATING SYSTEM

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ABSTRACT

This paper aims to study the solar thermal performance of a novel solar micro-channel loop heat pipe-PV/T system on experimental stage based on the height difference between the PV/evaporator and condenser, including the impact of the height difference on the temperature distribution of PV panel, solar thermal efficiency. It is found that (1) when the system become steady, the PV module surface temperature is almost decreases with the rise of the height difference; (2) The aluminium (Al) plate in the mid-layer achieved a little higher temperature compared to the PV surface and micro-channel wall which were above and below the Al plate respectively; (3) the solar thermal efficiency of the novel PV/T-MCLHP system varied with the height difference between the heat exchanger and the evaporator; (4)During the specific operational process, solar thermal efficiency of the system increased from 48.85% to 57.13% while the height difference increased from 0.7 m to 1.3m. And 1.1m is finally taken as the optimal value of height difference. The results of this experiment can help to optimize the system construction and thus help to develop a high thermal performance and low cost solar PV/T system for the space heating.

Keywords: micro-channel, loop heat pipe, PV/T, height difference, efficiency

NONMENCLATURE

Parameters	
A	Area, m^2
c	Specific heat, kJ/(kg*K)
m	Mass, kg
G	Solar radiation, W/m^2
q	Heat output, W
Greek letters	
η	efficiency
Subscripts	
in	inlet
out	outlet
t	thermal
PVT	Photovoltaic/thermal
w	water

1. INTRODUCTION

The application of Loop Heat Pipe (LHP)/Heat Pipe (HP) for PV/T systems obtained wide attention recent decades owing to its high heat transfer capability. For example, Zhang et al. [1] investigated the dynamic performance of a novel PV/LHP heat pump system for potential use in space heating or hot water generation, using theoretical computer simulation, experimental verification to make comparison. He et al. [2] proposed a novel heat pump assisted solar façade loop-heat-pipe water heating system and studied the operational performance by applying both theoretical and experimental methods, finding that the average thermal efficiency of the LHP module is around 71% with the heat pump assistance.

However, almost existing loop heat pipe systems integrated into a PV/T system were designed with round tubes and plate fins (RTPF), which has problem in touching on the PV model. Therefore, micro channel Loop heat pipe (MCLHP) was recently applied to cool PV cells and make use of the solar thermal energy [3,4]. This kind of micro-channel loop heat pipe can greatly enhance the heat transfer ability with a small cross-section area and through a longer distance without consuming power for refrigerant compressors and has more compact structure compared to heat pipe with RTPF [5]. Furthermore, owing to its flat-plate surface, the micro-channel array has an advantage of easy binding approach with the PV model. Within the limited studies, the authors has previously [3,4,6] developed a novel solar micro-channel loop heat pipe PV/T (MCLHP-PV/T) system, which has been investigated through computer modelling and theoretical analysis from different perspectives. As both the PV/evaporator and condenser of this MCLHP-PV/T system are laid vertically, the refrigerant gravity inside the loop to be the driven force to the downward fluid flow. Thus a higher height difference can obtain a higher driven force to help on improving evaporating heat transfer ability. But too large height difference could consequently enlarge the size of the system thus make it not compact to install and apply. Therefore, the height difference between the PV/-evaporator and condenser plays an important role in the solar thermal performance of this system.

In terms of this key point, this paper is proposed to experimentally investigate on the impact of the height difference between the evaporator and the condenser on the solar thermal performance of this novel MCLHP-PV/T system, aiming at finding an optimal value of the height difference to optimize the system construction and thus helping to develop a high thermal performance and low cost solar PV/T system for the space heating.

2. DESCRIPTION OF THIS NOVEL MCLHP-PV/T SYSTEM

According to the results derived from the analytical investigation and computer modelling studies presented in the authors' previous papers [3,4], this testing solar PV/T-MCLHP sample system was designed and constructed as shown in Figure 1. This system comprises: (1) a PV/evaporator integrated with multiple micro-channel array; (2) co-axial triple-pipe heat exchanger with PCM to be the condenser; (3) separate vapour and liquid transportation lines; (4) PV module covered with glass without air gap, which is pressed on the aluminium (Al) plate, which can reduce the thermal resistance between the PV cells and the Al plate compared with the conventional PV panel with thermal grease.

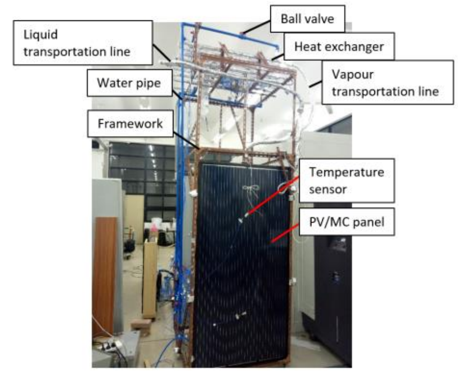

Fig 1 Construction of the MCLHP-PV/T heating system

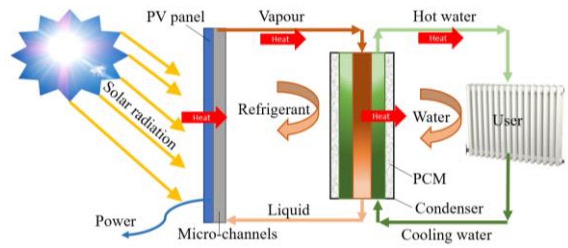

Fig 2 Cycle loop of the novel solar MCLHP-PV/T heating system

When the PV/evaporator receives the solar radiation striking on its upper surface, most of the solar radiation is absorbed by the PV/T panel, part of which is converted into electricity by PV cells to supply power and the rest is finally transformed into thermal energy. The thermal energy is absorbed by the Al plate and then transferred to the micro-channels, thus evaporating the working fluid (Refrigerant R134a) inside the channels. The evaporated fluid floating from the micro-channel array is collected in the upper vapour header and then transported into the condenser through the vapour transportation line. In the condenser, the latent heat from the vapour condensing in the central pipe is transferred to the water flowing inside the middle annulus tube, then the hot water will be circulated for space heating etc. At the same time, the heated water conducts the melting of the PCM inside the outer annulus tube to storage excess thermal energy and also to keep the water temperature within a certain temperature range. As a result, the condensed fluid from condenser, driven by gravity, flows directly into the upper liquid feeding header through the single liquid transportation line, and then penetrates the micro-channel wall to saturate the porous wick, which can thus offer timely replenishment of the evaporating fluid for absorbing heat from the solar energy. All these processes formulate a cycle loop as illustrated in Figure 2

3. EXPERIMENTAL SET UP AND PROCEDURE

3.1 Experimental set up

This integrated experimental MCLHP-PV heating system was built in an indoor space (lab. In GDUT) as presented in Figure 1, and equipped with pyranometer, rotameter, thermocouples/temperature probes, and pressure sensors, which were installed at appropriate positions to measure solar radiation, flow rate, temperature and pressure, respectively. In addition, the Solar Power Controller was used to as an electrical recorder and a converter.

3.2 Experimental procedure

In order to study the impact of height difference on the solar thermal performance of this novel system, four different height difference (i.e. 0.7m, 0.9m, 1.1m, 1.3m with an increment of 0.2m) were carried out under relatively steady conditions to determine the optimal value. The steady state defined in this experiment is that the thermal properties of the MCLHP stay the same against the operating time under dedicated testing mode, where the average solar radiation is maintained as 565±5W and the ambient temperature is around 30 ℃. The measurement data was recorded at 30s interval and logged into the computer to enable the follow-on analysis to be complete.

The analyses of the experimental data need to consider that the potential equipment uncertainties, such as that the tolerance of the solar radiation (±10W) and the temperature measurement discrepancy (±0.1 ℃). Additionally, there are some potential random errors, which may be caused by personal fluctuation, random electronic data logger fluctuation and influences of friction inside cooling pipes due to impure cooling water, etc.

4. RESULTS AND DISCUSSION

4.1 Theoretical equations

The following indicators are applied to evaluate the performance of this novel system.

Solar thermal efficiency (η_t)

$$\eta_t = \frac{q_t}{G \cdot A_{PVT}} \tag{1}$$

Where G is solar radiation, A_{PVT} is the PV/T area of base panel, q_t is heat output, which can be obtained:

$$q_t = c_w m_w (T_{wout} - T_{win}) \tag{2}$$

4.2 Determination of the optimal height difference

For this system, the height difference is defined as the distance from the refrigerant inlet of the PV/-evaporator to the middle position of the condenser. And the PV module surface temperature and solar thermal efficiency were applied to evaluate the solar thermal performance of this novel solar MCLHP-PV/T heating system under various height difference.

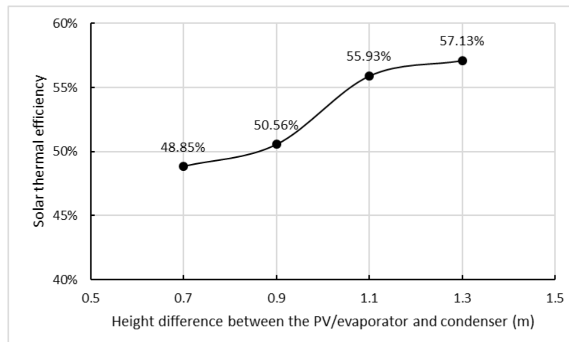

Fig 3 Solar thermal efficiency vs height difference

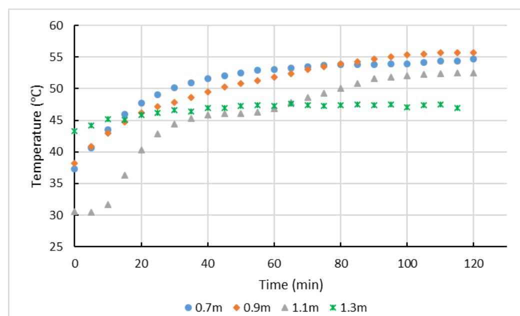

Fig 4 PV module surface temp against height difference

As presented in Figure 3, increased height difference led to the increased solar thermal efficiency of the MC-LHP-PV/T system. Because rising height difference led increasing the heat transfer capacity of the LHP owing to the increased driven force and the enhanced thermo-siphon effect caused by the density difference between the refrigerant vapour and liquid. This led to the increased heat transfer rate from the evaporator to condenser. As a result, under this specific operational condition, solar thermal efficiency of the system increased from 48.85% to 57.13% while the height difference increased from 0.7 m to 1.3m. In addition, it is obvious that there is not much difference between the average solar thermal efficiency when the height difference is 1.1m and 1.3m, so 1.1m is taken as an optimal value of height difference between heat exchanger and evaporator.

While the PV module surface temperature against the height difference at the same given testing condition is shown in Figure 4. It is found that at the first operation hour, PV module surface temperature shows a lowest value at the height difference of 1.1m, then PV module surface temperature shows a lowest value at the height difference of 1.3m and that of 1.1m become the second lowest value. When the system become steady, the PV module surface temperature is almost decreases with the rise of the height difference. This may because that higher height difference causes larger driven force which is superior to the heat transfer ability to efficiently cool the PV module thus leading lower PV module surface temperature.

4.3 Temperature distribution for optimal height difference under steady solar radiation

The temperature distribution of different layers of the PV/evaporator was experimentally investigated. It is found, as shown in Fig 5, that the Al plate in the mid-layer achieved a little higher temperature compared to the PV surface and micro-channel evaporator which were above and below the Al plate respectively. This indicates that the heat transfer across the panel was two-directional: one part of the heat is transferred from the Al plate to ambient and the other part is directed into the refrigerant within the LHP evaporator.

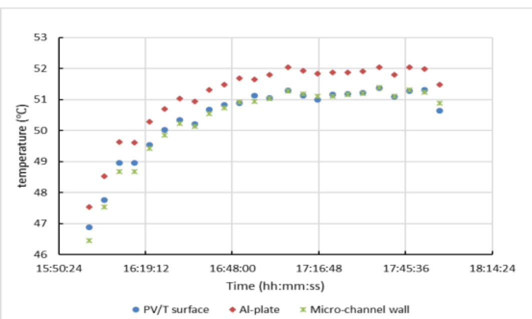

Fig 5 temperature of different layers of PV/T panel vs operating time

5. CONCLUSION

In this paper, the impact of the height difference between the evaporator and the condenser on the solar thermal performance of a novel MCLHP-PV/T system was experimentally investigated. Various tests were carried out to find the optimal value of the height difference between the PV/evaporator and the condenser to optimize the system construction and thus helping to develop a high thermal performance and low cost solar PV/T system for the space heating. The conclusions were summarized as following: (1) when the system become steady, the PV module surface temperature is almost decreases with the rising height difference; (2) the Al plate in the mid-layer achieved a little higher temperature compared to the PV surface and micro-channel wall; (3) under this specific operational condition, solar thermal efficiency of the system increased from 48.85% to 57.13% while the height difference increased from 0.7 m to 1.3m. Owing to the ignorable gap between the average solar thermal efficiency when the height difference is 1.1m and 1.3m, so 1.1m is taken as an optimal value of height difference between PV/evaporator and condenser.

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