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Experimental study of a novel PV/T- air composite heat pump hot water system

Gang Wang[a], Zhenhua Quan[a, *], Yaohua Zhao[a], Peng Xu[a], Chenming Sun[a]

[a]*The Department of Building Environment and Facility Engineering, The College of Architecture and Civil Engineering, Beijing University of Technology, No.100 Pingleyuan, Chaoyang District, Beijing 100124, China*

Abstract

Solar energy utilization and heat pump are common technologies of renewable energy utilization for solving the problem of energy crisis and environmental pollution in present. This paper proposed a novel PV/T-air composite heat pump hot water system. The system was comprised of independently developed flat plate solar PV/T collector based on micro-channel heat pipe array and air source heat pump, which were combined by a new composite evaporator. The performance of the system were experimentally studied，COP of heat pump reduced from 5.61 to 1.69 and the average was 3.03. Comprehensive COP_{sys} of PV/T-air composite heat pump system ranged from 6.07 to 1.33, the average was 2.99. The result showed the system was worthy of promotion and application.

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Keywords: PV/T collector, air source heat pump, Composite evaporate , Coefficient of Performance (COP)

1. Introduction

The joint operation of solar energy and heat pump is a significance technology, which can address the problem of energy crisis and environmental pollution. In recent years, domestic and foreign scholars have done a lot of research on solar-assisted heat pump (SAHP) heating system to improve energy efficiency of the system. The system of SAHP can be sub classified as series, parallel and dual system according to the heat source to the evaporator. Though variety of different binding modes among solar collector and heat pump were possible and studied, the main

* Corresponding author. Tel.: +86 13601266535; fax: +86 010 67391608-801.
E-mail address: quanzh@126.com

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research focuses were on the combination of solar collector and air source heat pump or water source heat pump [1-3]. Hawlader at el. [4] designed and fabricated a SAHP system, the drying medium was air. The Coefficient of Performance and Solar Fraction used as the main evaluation indicators of system performance were 5.0 and 0.61 derived from experimental results, and were 7.0 and 0.65 from simulation results, respectively. Fu at el. [5] presented a technology of combing heat pump with heat-pipe photovoltaic/thermal (PV/T) collector, the performances of heat pipe mode, solar assisted heat pump and air-source heat pump mode were investigated in that paper, and concluded ultimately that the system could satisfy the demand of domestic hot water with or without solar energy. This paper designed a novel PV/T-air composite heat pump hot water system. It comprised of independently developed solar photovoltaic-thermal (PV/T) collector and composite heat source heat pump. This system can not only obtain electric power, but also effectively use the solar battery waste heat through the heat pump, which makes the system energy utilization efficiency is improved greatly. And the performance of the system can be guaranteed, supplemented by air source heat pump.

2. Experimental setup of PV/T-air composite heat pump hot water system

PV/T-air composite heat pump hot water system is comprised of the solar PV/T system, composite heat pump system and the system of heat utilization, as shown in Fig.1. The core component of solar system is PV/T collector based on flat plate micro heat pipe and composite evaporator, which combined air source and PV/T water source. Low temperature hot water is generated by PV/T collector, which effectively utilizes the waste heat of PV modules and decreases the temperature of the battery temperature to improve the power generation. The low temperature hot water flows through the composite evaporator and heat transfer to the refrigerant. After that cooled water flows back into the PV/T collectors to start the next cycle. Thus, the backboard of the PV/T collector can maintain a relatively low temperature, the efficiency of photovoltaic power generation is improved and the battery life is prolonged. Meanwhile, low temperature hot water into PV/T collector increases the evaporation temperature of composite heat evaporator, which can solve the problem of air source heat pump anti-frost in cold regions and improve the performance of heat pump system. This technology will expand the scope of application of air source heat pump.

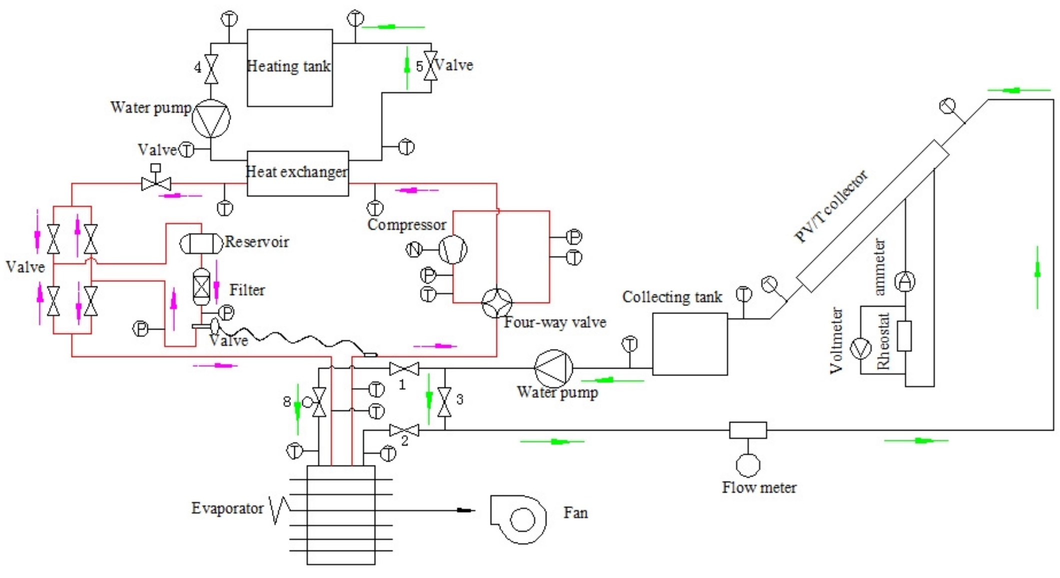

Fig. 1 Diagram of PV/T-air composite heat pump system

The drawing of PV/T collector is showed as Fig.2. The new type of PV/T collector is fabricated on the basis of photovoltaic cell, whose backboard is affixed to flat plate micro-channel heat pipe array.

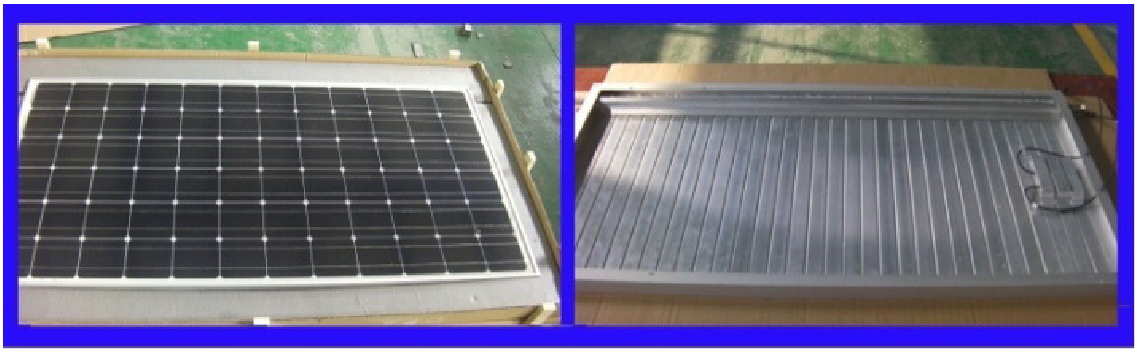

Fig. 2 The component drawing of PV/T base on micro heat pipe array

The composite evaporator is designed on the basis of finned - tube evaporator, as shown in Figure 3. The channel 1 and channel 2 are loop of solar photovoltaic water and loop of working refrigerant, respectively. A number of heat exchange fins are connected in order between the two channels. Air flows through the gap of the fins.

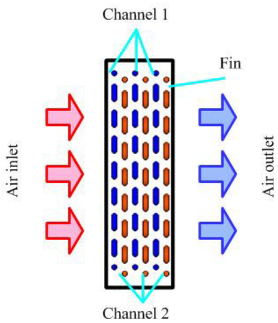

Fig. 3 Schematic diagram of evaporator

3. Experimental test

3.1 Experimental description

The experimental platform of PV/T-air composite heat pump system was established, as Fig.4. The experimental plan was designed to study the performance of the system for solar heat collecting operating mode firstly and then air source heat pump operating meanwhile. The PV/T system had two pieces of collectors, whose type is CSUN-195-72M and peak power is 195W. The circulating flow of collecting tank and heating tank are 678L/h and 952L/h, respectively. The power of collecting water pump and heating water pump are 114W and 138W, respectively. The volume of heating tank and collecting tank are 78L and 64L, respectively. Water in the heating tank was heated by 1HP heat pump, water temperature of initial and termination in the heating tank were 15.21℃ and 50.22℃, respectively. The PV/T system began to operate from 9:00 to 14:28, air source heat pump operated at 12:45 without opening the fan, when water temperature in the collecting tank decreased certain value, then opening the fan at 13:42. The main researched performances of the system included photovoltaic power and thermal power of PV/T collector, photovoltaic efficiency, and thermal efficiency. And, COP of composite heat pump and COP_{sys} of composite heat pump were also evaluated.

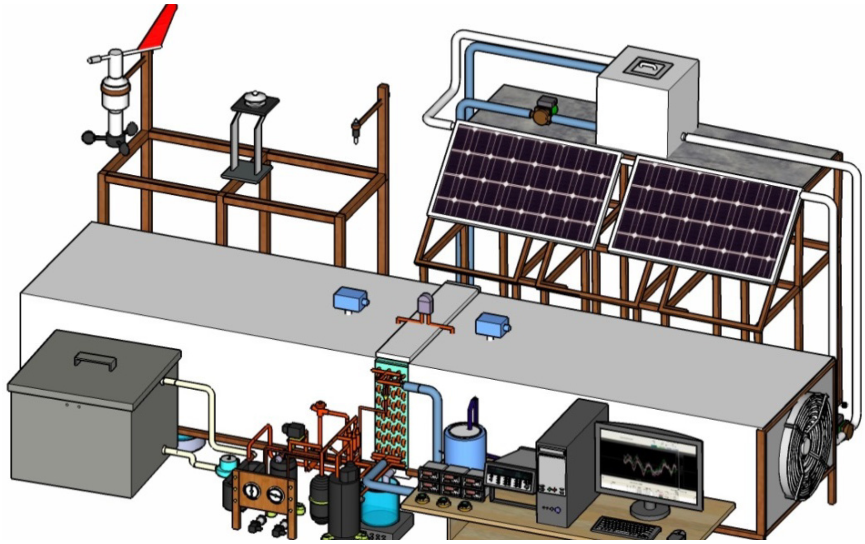

Fig. 4 Experimental platform of PV/T-air composite heat pump system

3.2 Instantaneous efficiency of system

Coefficient of performance is an important target of heat pump, which is defined as

$$COP_{hp} = \frac{c_w m_w (T_{w,t+\tau} - T_{w,t})}{\int_t^{t+\tau} W_{hp}(\tau) d\tau} \tag{1}$$

Where Whp(τ) is the power consumption of compressor, kW; Cw is the heat capacity of water, kJ /(kg·K); mw is the capacity of heating tank, kg; Tw,t+τ is the initial temperature of heating tank,℃; Tw, t + τ is the termination temperature of the heating tank, ℃.

COP_{sys} is a major evaluation indicator of the system performance, which is defined as

$$COP_{sys} = \frac{Q_t}{w_p - w_e} \tag{2}$$

Where COP_{sys} is the overall performance of system; Q_t is heat gain in the heating tank; W_p is the compressor power, W; W_e is the photovoltaic power generation, W.

4. Experimental results and analysis

Fig.5 shows that the ambient temperature and solar irradiance changes with time. The ambient temperature ranged from 0℃ to 3.1℃, the solar irradiance changed from 365 W/m^2 to 783W/m^2.

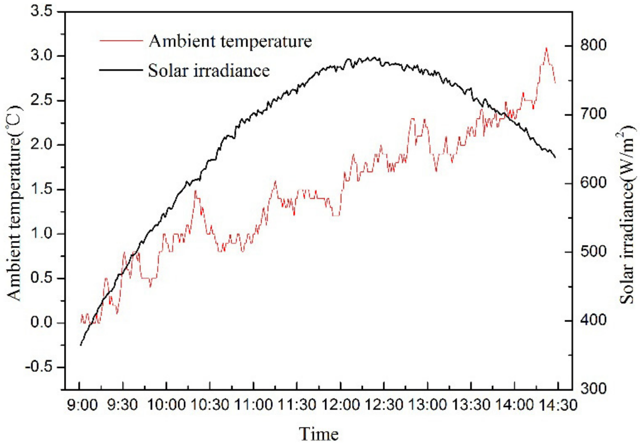

Fig. 5 Solar irradiance and ambient changing with time

Fig.6 shows photovoltaic power and photovoltaic efficiency changes with time. The maximum power was 295W when the system operated from 9:00 to 14:28, and the maximum photovoltaic efficiency was 18.13%, which had obvious advantages compared to separate solar PV collector. Shadow has a large impact for the photovoltaic efficiency, thus, the figure appeared the phenomenon of depressing because of the shade shelter.

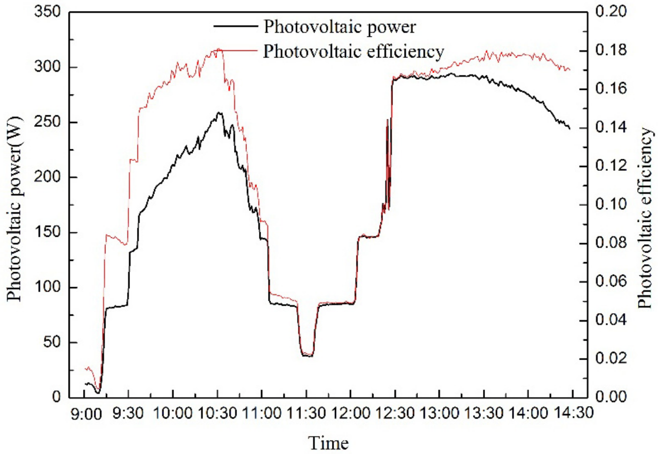

Fig. 6 Photovoltaic power and photovoltaic efficiency changing with time

Fig.7 shows thermal power and thermal efficiency changing with time. Thermal power was calculated by test the instantaneous inlet and outlet water temperature of solar PV/T collector. Thermal power and thermal efficiency presented the parabolic trend. The maximum thermal power was 664W and the minimum was 421W. The changing of thermal efficiency in the collecting tank was relatively stable and ranges in 28.2%-35.3%.

Fig.8 shows COP of heat pump and COP_{sys} of system changing with time. The compressor power was gradually increasing so that the COP of heat pump gradually decreased. The maximum COP was 5.61 and the minimum was 1.69, the average was 3.03. The COP_{sys} of system ranged from 6.07 to 1.33 and the average was 2.99, and the changing trend basically was consistent with heat pump COP. The curve of COP_{sys} sagged in the operation for the reason that the fan opened at this point.

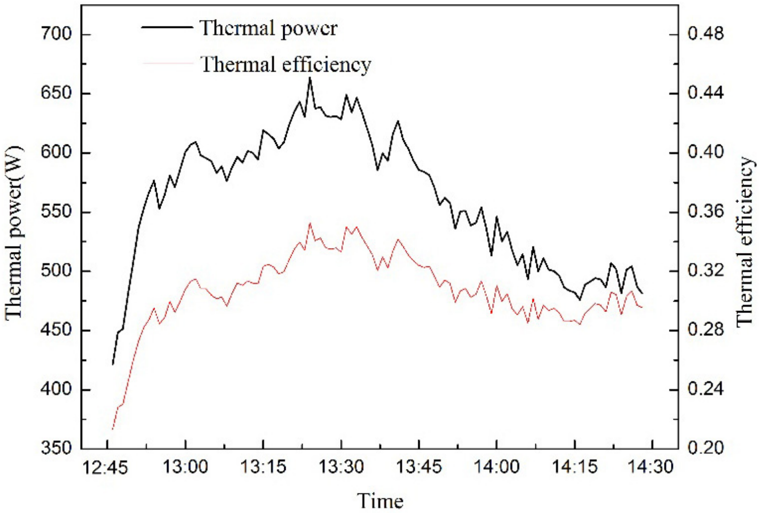

Fig. 7 Thermal power and thermal efficiency changing with time

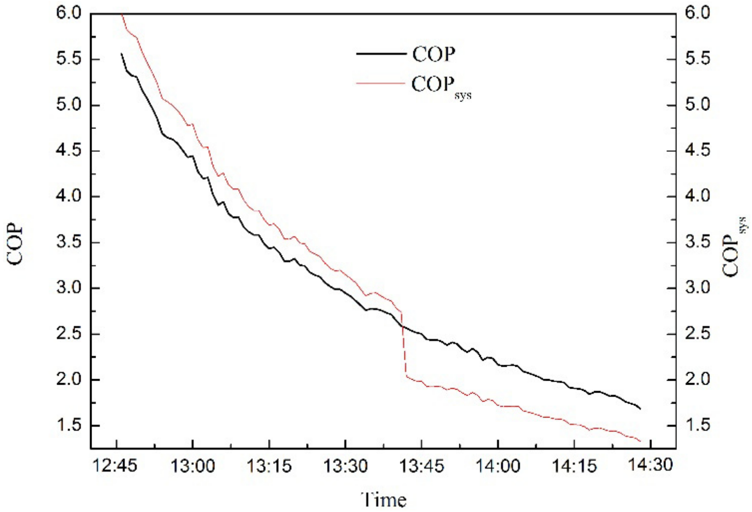

Fig. 8 COP and COP_{sys} changing with time

5. Conclusions

The novel PV/T-air composite heat pump hot water system was experimentally studied and the experimental results were discussed and analysed. The maximum photovoltaic power and the instantaneous efficiency were 295W and 18.13%, respectively. The changing range of thermal power and thermal efficiency were 421W-664W and 28.2%-35.3%. COP of heat pump reduced from 5.61 to 1.69 and the average was 3.03. Comprehensive COP_{sys} of PV/T-air composite heat pump system ranged from 6.07 to 1.33, the average was 2.99. And COP_{sys} is a major evaluation indicator of the heat pump system performance. we can see from the results analysis, compared with single air source heat pump, the PV/T-air composite heat pump hot water system has some advantages and is worthy of promotion and application.

Acknowledgement

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