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Experimental Research on Air-source Heat Pump Using Heat Pipes as Heat Radiator

Xu Shuxue, Shao Yueyue, Wang Yueyue, Ma Guoyuan*

Beijing University of Technology , Chaoyang district Pingleyuan No 100, Beijing, 100124, China

Abstract

In this study, a concept of air-source heat pump using heat pipes as heat radiator system (ASHPP) for room heating was proposed. The heat pipes radiator was developed to replace the heating terminal equipment used in traditional heat pump plants. All the heat radiators were connected in series. A tested room with artificial load was constructed and an experimental apparatus of ASHPP system was developed. Temperature distribution of each heat radiator has been experimentally investigated. The variations of system heating performance under the condition of different indoor air temperature and outdoor air temperature were researched. The purpose of this study is to provide technique reference for developing new heat pump room heating system.

Keywords: Heat pump;Heat pipe;Compressor;Heating;

1. Introduction

As an efficient technology for energy conservation, air source heat pumps have been widely used in industry and daily life, and are mainly applied for heating water or air. Particularly for household appliances, a heat pump can use water or refrigerant-cooled chillers for cooling in summer and heating in winter. It has the advantages of a high performance coefficient for water-cooled chillers in summer and the ability to function as a heat pump in winter (Willem H et al, 2017 [1] ; Østergaard et al, 2016 [2] ; Chai Qinhu et al,2002 [4]).

Winter heating is of significant concern in northern China, where the requirements for heating quality and thermal comfort have increased. A large amount of energy is consumed in the winter heating period in most of the northern regions of China, and inefficient heating will result in severe environmental pollution. In recent years, the “coal to electricity” program has been applied on a large scale. More than 2 million air source heat pumps were installed in more than 1 million family homes. In some rural areas that cannot be reached by district heating, air source heat pumps are the technology promoted by the government.

The main type of heat pump used in the China “Jing Jin Ji” area is the water loop air source heat pump, and a schematic diagram of the typical form of this common heat pump type is shown in Fig. 1. As shown in Fig. 1, the system consists of an outdoor unit, water pump, water expansion tank, water tank, and indoor radiator. however, they have some disadvantages, including a complex structure and high failure rate, as well as high electrical energy consumption, especially the leak-proof and anti-freeze of the waterway has always caused troubles to heat pump users. (Li Suhua et al, 2014 [5]). In a recent study (Xu et al, 2018 [3]), a new air source heat pump system was proposed. In that system, heat pipes were used as the heat radiator, and a compressor drove the heat pipes to release heat to the room. Based on this research, in order to meet the actual distribution of heating space, a “heat pump with multi-split heat pipe heat radiators” (ASHPP) was proposed for room heating. The heat pipe heat radiators were connected in series, and 9 groups of heat pipe heat radiators were used. At present, there are also many studies at home and abroad for systems that combine heat pipes and heat pumps. Chen Hongbing et al, 2016 [6] built a heat pipe solar PV/T heat pump system. The test results showed that the average daily power efficiency of the heat pipe mode was 25.7% higher than that of a single photovoltaic power generation system. QU Peipei et al, 2018 [7] established a new dual-evaporator heat pump and separate heat pipe coupling system to investigate the influence of factors such as outdoor temperature and solar radiation intensity on performance parameters under three operating modes.

In this paper, a prototype of the proposed ASHPP heating system was built and an experimental study was performed to analyze the temperature distribution of each radiator. The variation of the heating performance of the system with indoor air temperature and outdoor air temperature were studied. The goal of this research was further improving the energy efficiency level of traditional domestic heat pumps, and developing a new domestic heating technical means.

2. Circulation theory

The ASHPP system is shown in Fig. 1. It consists of a compressor, multiple condensers coupled with heat pipe heat radiators, consists of a compressor, multiple condensers coupled with heat pipe heat radiators, a throttling device, an evaporator, and connecting tubes. The heat pump system operates in servers with the vapour compression circulation. The liquid refrigerant is evaporated in the evaporator and the vapour is absorbed into the compressor. With power consumption in the compressor, the vaporised refrigerant is transformed into a supersaturated vapour at higher temperature/pressure. As shown in Fig. 1, the refrigerant flows out of the compressor through 9 groups of condensers and heat pipes, which combine to function as a heat exchanger. Each piece of equipment releases its embodied thermal energy into a single room, leading to an increase in the in-room air temperature.

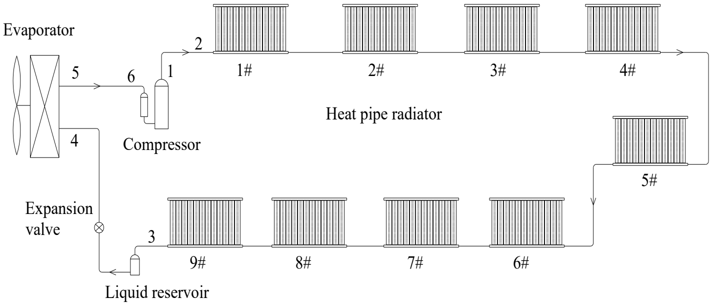

Figure 1: ASHPP system

3. Experimental Study

The heating performance of ASHPP system was mainly affected by indoor and outdoor temperatures. This article built a system and tested it in different indoor and outdoor temperatures. The experimental device mainly included a compressor, finned tube heat exchangers, axial flow fans, etc. The specific models and parameters of the compressor are shown in Table 1.

Table 1 Specific models and parameters of compressors

Model	Frequency	Voltage	LRA I-Block	I-Open max	Volume	Speed
ZW34KSE-PFS-582	50 Hz	220VAC	75.2A	19.75A	8.0 m^3/h	2900/min

The ASHPP system was placed in air enthalpy-type psychrometric rooms, as shown in Fig. 2. A total of 9 indoor units were connected to the outdoor unit in series, and pressure sensors were installed at the inlet and inside each indoor unit. The temperature of both the indoor and outdoor chambers can be controlled from -10 ℃ to 50 ℃.

In the experimental system, the air-side inlet and outlet temperature and humidity could be measured with a temperature transducer (Pt100) and humidity transducer. A hermetic-type compressor with a nominal capacity of 2100 W designed for R410A was installed. Refrigerant pressures in the heat pump and heat pipes were measured using pressure transducers with an uncertainty of ±0.5%. Temperatures were measured using Pt100 temperature transducers with an uncertainty of ±0.15 °C. A mass flow meter was installed to measure the mass flow rate of the refrigerant through the condenser. The power input to the compressor was measured using a power meter with an uncertainty of ±0.5%.

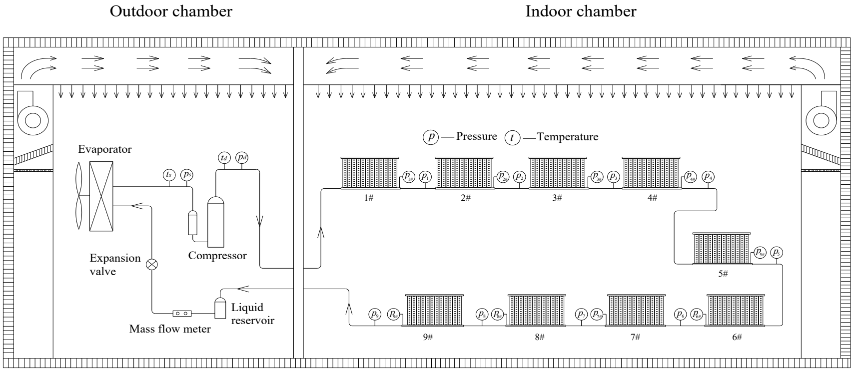

Figure 2: Schematic diagram of the prototype test system

4. Results and discussion

4.1. Radiator surface temperature distribution

Figure 3 shows that, with the exception of the first heat pipe, the surface temperatures of the heat pipes are approximately consistent with each other. For example, the surface temperature of heat pipe 2 is 50 ℃, while it is 49 ℃ at the final heat pipe (#9) when the outdoor temperature t_o=-10 ℃. The surface temperature of first heat pipe (#1), is approximately 18–25 ℃ higher than the other heat pipes. This was because the high-temperature compressor discharge vapor first entered in the first heat pipe (#1), exothermic heat of the first heat pipe contained some sensible heat, so the temperature was high. The surface temperature of heat pipe 2-9 was similar, the final heat pipe (#9) was slightly lower. This indicated that the number of end heat pipe radiators in series matched with the heat pump well, and the refrigerant was fully condensed. Figure 3 also shows that the difference in surface temperature between the first heat pipe and the other heat pipes varies. The lower the outdoor temperature, the larger this surface temperature difference will be. The reason for this is that when the outdoor temperature is lower, the compressor discharge temperature is higher, and the first heat pipe will receive the highest temperature refrigerant from the compressor discharge ports; thus, the surface temperature difference between the first heat pipe and the other heat pipes is increased.

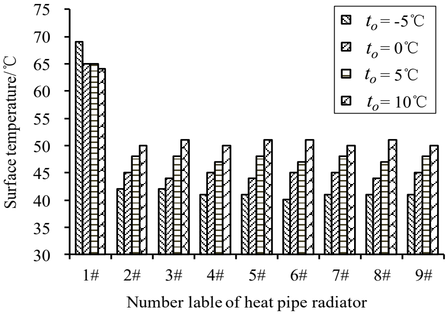

Figure 3: Surface temperature of ASHPP system

4.2. Heating performance of the ASHPP system

According to the experimental results, the heating performance of the system is analyzed. The unit heating capacity formulas are calculated as follows:

$$Q = m(h_1 - h_2) \tag{1}$$

In the formula:
Q——Heating capacity, kW;
m——Mass ratio of refrigerant to mixed liquid in mixed liquid of refrigerant and lubricating oil, kg/s;
h_1——Specific enthalpy of refrigerant at the inlet of heat exchanger, kJ/kg;
h_2——Specific enthalpy of refrigerant at the outlet of heat exchanger, kJ/kg;

The system power consumption was analyzed with the power data recorded by the power meter when the system reached at a stable operating state under a given working condition. The COP was calculated by the power meter and the heating value was calculated by the enthalpy difference during the system reaches at a stable operating state:

$$Q = m(h_2 - h_3) \tag{2}$$

According to calculation, the variation in heating performance with different refrigerants is shown in Fig. 4. Four different refrigerants (R134a, R410A, R32, and R718) were considered, with outdoor temperatures of -10 ℃, -5 ℃, and 0 ℃; the indoor temperature was 20 ℃. Figure 5 indicates that the selection of refrigerant g has an effect on the heating capacity and heating COP of the system. R32 and R410A yield the highest heating capacity and heating COP. Among the four types of refrigerants, the heating COP value with R32 is approximately 1.3%–2.2% higher than that with R134a. For example, the heating COP value of R32 can reach 2.8 for an outdoor temperature of -10 ℃ and indoor temperature of 20 ℃. R718 can also be used as a heat pipe working fluid for room heating, but its heating COP is relatively low, about 8% less than that of R410A.

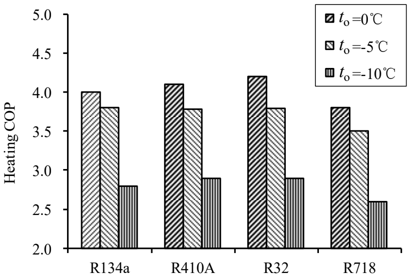

Figure 4: Heating COP for different refrigerant

5. Conclusion

An air-source heat pump with multi-split heat pipe heat radiators (ASHPP) system for room heating was proposed. Heat pipe radiators were connected in series and driven by a compressor and condenser. A test room with an artificial load was constructed, and an experimental ASHPP system was developed. The pressure and temperature distribution were investigated experimentally. Variations in the system heating performance with different numbers of heat pipes were investigated, and the most important conclusions of this study are as follows:

1) Except for the first heat pipe, the surfaces of the other heat pipes were approximately consistent with each other. The surface temperature of the first heat pipe was about 18–25 ℃ higher than that of the other heat pipes.

2) R32 and R410A yield the highest heating capacity and heating COP. Among the four types of refrigerants tested, the heating COP value of R32 was about 1.3%–2.2% higher than that of R134a. R718 can

also be used as the heat pipe working fluid for room heating, but its heating COP was relatively small, about 8% less than that of R410A.

3) When the ASHPP system was run with an outdoor temperature of -10 ℃ and indoor temperature of 20 ℃, the heating COP can reach 2.8.

6. Acknowledgements

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