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Experimental study of a novel double temperature chiller based on R32/R236fa

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A B S T R A C T

A novel double-temperature chiller with zeotropic mixture R32/R236fa is proposed in this paper, and chilled water with two different temperatures is produced, such as low temperature water ($T_{L,out}$ = 7 °C) and high temperature water ($T_{H,out}$ = 16 °C). An experimental setup is established to test the performance of the chiller. Effects of mass fraction of R32 in mixture R32/R236fa (*M* (R32)), $T_{L,out}$, $T_{H,out}$ and the heat transfer media flow rate on the performance of the chiller are studied. When $T_{H,out}$ is 18 °C, $T_{L,out}$ is 8 °C and *M* (R32) is 0.6, *COP* and refrigerating capacity are 4.11 and 4.42 kW, respectively. *COP* and refrigerating capacity increase as *M* (R32) increases. Exhausting pressure of the chiller increases with the increase of *M* (R32). As *M* (R32) is 0.6, exhausting pressure is about 1.95 MPa. Compression ratio decreases with the increase of *M* (R32). When *M* (R32) increases from 0.3 to 0.6, the compression ratio decreases from 3.0 to 2.9.

1. Introduction

With the development of China's economy and society, building energy consumption is increasing rapidly. The building energy consumption accounts for about 25% of the total energy consumption and air conditioning system is one of the major energy-consuming equipment [1]. Therefore, the energy conservation of the air conditioning system is important for improving energy intensity in China. The temperature and humidity independent control air conditioning system (THICS) gets wide attention because of the advantages of energy saving and air quality [2]. At present, the realization of THICS is mainly through the liquid dehumidification and solid adsorption desiccant dehumidification to remove the latent heat of the air conditioning system, and the sensible heat is always removed by chilled water which is produced by chilled water unit [3–5]. THICS has a good effect on energy-saving. Zhang [6] proposed an operation strategy for THICS and analyzed the performance of the key equipment. The results showed that THICS can save 20–30% energy compared with the conventional air condition system. Zhao [7] tested the performance of THICS and analyzed the whole year energy consumption of the THICS. The research results showed that THICS had a large energy saving potential. However, liquid dehumidification systems have some problems, such as corrosion of pipeline and low dehumidification efficiency [8]. There are many problems for solid adsorption desiccant too, such as the large amount of adsorbent filling which increases the costs. In addition, solid desiccant regeneration calls for high temperature and needs high-grade heat energy [9]. Liang et al. [10] and Li [11] proposed heat and humidity segmental treatment air conditioning system which was based on THICS. The results showed that, compared to the present method, the *COP* can be enhanced by more than 9.14% when the cooler temperature difference is 7 °C and outlet air temperature is 16 °C.

In addition, researchers have done a lot of theoretical and experimental studies on the refrigerating system where refrigerant is a zeotropic mixture. Mehmet [12] presented the performance analysis of an air-to-water vapor compression heat pump system using pure refrigerants and zeotropic refrigerant mixture. The results showed that the *COP* and second law efficiency for the pure refrigerants could be improved by using an appropriate mixture of the refrigerant. Chen [13] proposed a novel domestic air conditioning system based on R32/R134a. The results of the theoretical analysis showed that, compared with traditional refrigerant R22, *COP* could be improved by 9%. Zerwekh et al. [14] and Yoon et al. [15] indicated that the energy consumption of the optimized L-M cycle using R290/R600 (40:60%) was 11.2% lower than that of a bypass two-circuit cycle using R600a in the same RF platform based on the experimental data. Yang et al. [16] proposed a novel combined power and ejector-refrigeration cycle using R23/R134a as the refrigerant. Results showed that the coefficient of performance and exergy efficiency of the new cycle can be improved by 8.42–18.02%, compared with the basic cycle at the same operation conditions. Sivakumar et al. [17] studied a three stage auto

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Nomenclature

COP	coefficient of performance
C_p	specific heat capacity of water, (kJ kg^{-1} K^{-1})
G	mass flow rate (kg s^{-1})
GTD	gliding temperature difference (°C)
GWP	global warming potential
M (R32)	mass fraction of R32 in mixture R32/R236fa
NBP	normal boiling point (°C)
ODP	ozone depression potential
P	pressure (Pa)
P_c	critical pressure (Pa)
Q_e	refrigerating capacity (kW)
T	temperature (°C)
T_c	critical temperature (°C)
W	power consumption (kW)

Greek symbols

Δ	differential
ε	relative error

Subscripts

b	bubble point temperature
ch	chilled water
co	cooling water
com	compressor
d	dew point
exh	exhausting
H	high temperature chilled water
in	inlet
L	low temperature chilled water
out	outlet
TG	temperature glide

refrigerating cascade (ARC) system which used R290/R23/R14 or R1270/ R170/R14 as the refrigerant. The results showed that when the mass fraction of zeotropic mixture of R290/R23/R14 was 0.218:0.346:0.436, the performance of the system was better, and *COP* can reach 0.253 when the evaporating temperature was 176 K.

This paper proposes a novel double temperature chiller based on a zeotropic mixture R32/R236fa with large temperature glides. This chiller can produce two kinds of chilled water with different temperatures and utilizes the characteristic of the phase change process to realize the Lorenz cycle which improves the *COP* of the chiller. Finally, effects of mass fraction of R32 in mixture R32/R236fa (*M* (R32)), heat transfer media flow rate and temperature of chilled water on the *COP*, exhausting pressure, exhausting temperature and compression ratio of the chiller are experimentally studied. The results of the experiment provide a database for the application and design of the double temperature chiller.

2. Description of the double temperature chiller

2.1. Introduction of experimental setup

The schematic diagram and experimental setup of the double temperature chiller are shown in Fig. 1. The chiller includes four loops: the refrigerant loop, the cooling water loop and two chilled water loops. The refrigerant loop consists of a compressor, a condenser, a reservoir, an expansion valve, a low temperature evaporator, and a high temperature evaporator. The cooling water loop and chilled water loop have the same components, which include a water pump, an electrical heater, a flow meter, a water tank, and a stop valve.

The refrigerant enters the compressor and is compressed to the point where the vapor can be condensed by cooling water. The compressor is a hermetically-sealed rotary compressor and the rated power is 1.1 kW. After compression, the refrigerant enters the condenser, and is condensed through rejecting the heat to the cooling water. The condenser is a double-pipe heat exchanger and the rated heat transfer capacity is 6 kW. Cooling water is circulated by a water pump and the rated pump capacity is 0.22 kg s^{-1}. An electrical heater controlled by a digital regulator is used to ensure the water entering the condenser at the designed temperature. The low temperature evaporator is a double-pipe heat exchanger and the rated heat transfer capacity is 3 kW. An electrical heater controlled by a digital regulator is used to ensure that the water entering the low-temperature evaporator at the designed temperature. After passing the low temperature evaporator, the refrigerant enters the high temperature evaporator. An electrical heater controlled by a digital regulator is also used to ensure that the water entering the high temperature evaporator at the designed temperature. Chilled water is circulated by a water pump and the rated pump capacity is 0.11 kg s^{-1}.

2.2. Test conditions and measurements

The temperature and pressure of the zeotropic mixture are measured at several locations of the system. T-type thermocouples are used to measure temperature of the chiller. The zeotropic mixture temperatures are measured at the inlet and outlet of the condenser, compressor and evaporators. The temperature of the cooling water and the chilled water are measured at the inlet and outlet of the condenser and two evaporators. Four manometers are installed at the inlet and outlet of the compressor, the outlet of the condenser and the inlet of the low temperature evaporator. The flow rates of the cooling water and chilled water are measured with three turbine flow-meters. Compressor input power is measured using a digital wattmeter.

After each experiment, the raw data is recorded. All the measurements of the parameters are collected via a personal computer acquisition system every 5 s. The data is saved to the database for deep investigation. A list of measurement accuracies is shown in Table 1.

2.3. Experimental refrigerant

In this paper, R32/R236fa is selected as the refrigerant for the chiller. Phase change characteristics of the refrigerant are calculated by REFPROP 8.0 software. Results are shown in Table 2. The minimum temperature glide of the mixtures at different mass component concentrations is 14.5 °C, which can satisfy the requirements of the double temperature chiller.

2.4. Performance index

For a chiller, the coefficient of performance (*COP*) is a very important index, and is calculated in the following.

$$COP = \frac{Q_e}{W_{com}} \tag{1}$$

Refrigerating capacity (Q_e) of the chiller is calculated using the Eq. (2).