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Vapor injected heat pump using non-azeotropic mixture R32/R1234ze(E) for low temperature ambient

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Abstract

The traditional refrigerants such as CFCs or HCFCs has been phased out for ODP and many HFCs is being phased down for their relatively high GWP. Among all the substitutions, the mixture has become much attractive because it can reach a balance between thermodynamic performance and environmental effects. R32/R1234ze(E) is one of them. At the same time, the technology of vapor injected technology is widely applied in heat pump under low temperature ambient for its great performance improvement. In this paper, the vapor injected heat pump model with R32/R1234ze(E) is established, the injection ratio, heating capacity and COP performance with variable concentrations is analyzed and compared with that of single-stage compression system.

Keywords: R32/R1234ze(E) non-azeotropic refrigerants vapor injected heat pump

1. Introduction

Influenced by ozone depletion and global warming crisis, CFCs and HCFCs refrigerants with great thermodynamic performance are being phased out and many HFCs refrigerants are accelerated to be phased down owing to their high GWP. Considering the contradiction of environmental effects and thermodynamic performance of current pure refrigerant, the use of mixed refrigerants are promoted to provide much flexibility in searching new environment-friendly alternatives. Among recent studies [1,2], R32/R1234ze(E) refrigerant mixtures have attracted great attention for their splendid properties of this two pure refrigerant. In fact, R32 has gained increasing attraction for its large latent heat and zero ODP and middle GWP, especially in the field of air source heat pump. At the same time, R1234ze(E) is regarded as excellent environmental refrigerant for air conditioning and heat pump system in new generation.

On the other hand, with the outdoor ambient temperature decreasing, air source heat pump (ASHP) suffers from low seasonal energy efficiency ratio and encounters heavily heating capacity degradation. Refrigerant injection systems provide a promising option for its applicability in large pressure ratio (low ambient temperature) operating conditions [3~5].

Rare literatures concentrate on vapor injected heat pump system with non-zeotropic refrigerants [6~8], the system performance of vapor injected heat pump with non-azeotropic mixture R32R1234ze(E) for low temperature ambient is researched in this study.

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2. Methodology

2.1. System description

The object of this study is the vapor injected heat pump system (Fig.1). Process 1-9 is the basic vapor injected compression cycle, the dotted line represents the heat transfer process of refrigerant and air at the evaporator and the condenser. the air flows from point 10 to point 11 at evaporator and flows from point 12 to point 13 at condenser.

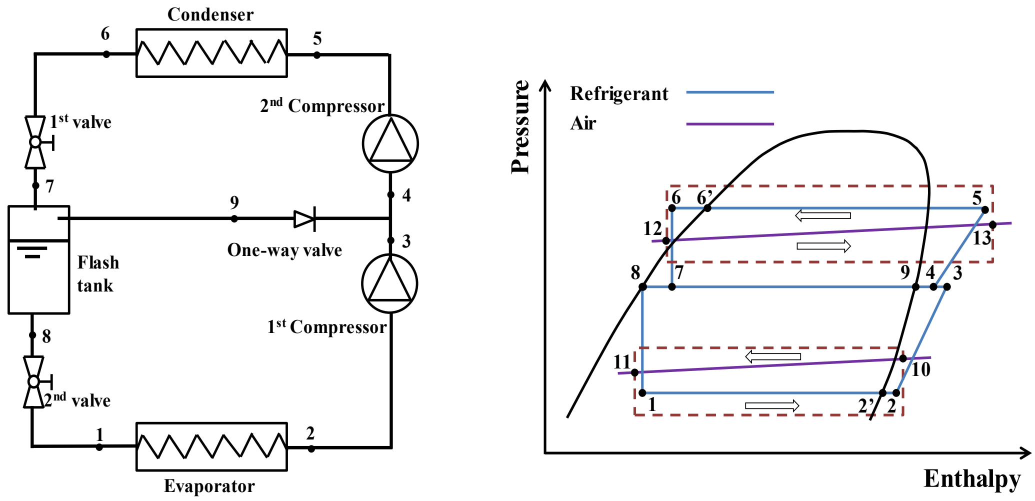

Fig. 1. Schematic of the vapor injected cycle and p-h diagram

2.2. Modeling

A detailed air source vapor injected system simulation is presented in this section. This model focus mainly on the effect to system performance of refrigerants, for which the configuration of heat exchangers and inlet air temperature on heat exchangers are fixed for different refrigerants simulation of various concentration. In order to simplify the simulation properly, the following assumptions are made:

- The superheated degree at the outlet of the evaporator is 5°C and the subcooled degree at the outlet of the condenser is 3°C;
- The pressure drop in evaporator, condenser and connecting tube are ignorable;
- The heat losses are ignorable;
- The difference of charged composition and circulation composition is neglected;
- The heat transfer area of intermediate heat exchanger is large enough.

2.2.1 Heat exchanger model

The similar configuration is adopted on both evaporator and condenser, Fig.2 presents the configuration of heat exchangers, Table.1 shows the specific configuration and size parameters of evaporator and condenser, among which P_t is the distance between tubes perpendicular to the air flow direction, P_l is the distance between tubes parallel to the air flow direction, F_p is the distance between fins, D_i is the internal diameter of tube and D_o is the external diameter of tube.

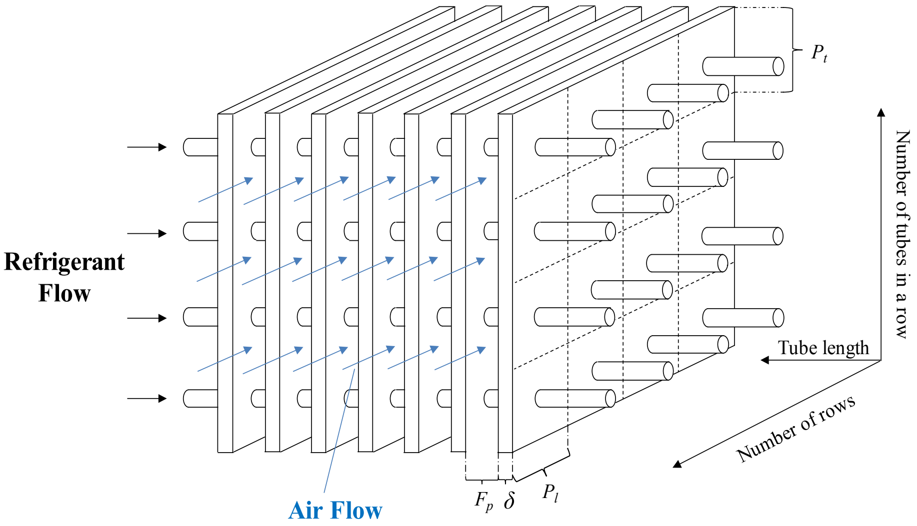

Fig. 2. Configuration of heat exchangers

Table 1. Heat exchanger designed parameters

	Number of flow paths (-)	Number of rows (-)	Number of tubes in a row (-)	Tube length (mm)
Evaporator	2	2	12	450
Condenser	2	3	8	450

	d_i (mm)	d_o (mm)	P_t (mm)	P_l (mm)	F_p (mm)	δ(mm)
Evaporator	6.35	7	16.3	20	1.8	0.115
Condenser	6.35	7	16.3	20	1.8	0.115

2.2.2 Compressor model

An isentropic efficiency model gained from a curve fitting of a practical compressor tested data is used in this study, the isentropic efficiency varies with the pressure ratio (Fig.3). The trend is that the isentropic efficiency increases in a high rate of speed between the pressure ration of two and three, the isentropic efficiency reaches the highest point in about pressure ratio of three and then decreases with the pressure ratio increasing, meanwhile the rate of rise slow down with the pressure ratio continuously increasing. The isentropic efficiency is defined as follows:

$$\eta = w_{isentropic} / w_{actual} \tag{1}$$

Where $w_{isntropic}$ is the power consumption when the compression process is isentropic, w_{actual} is the actual power consumption.

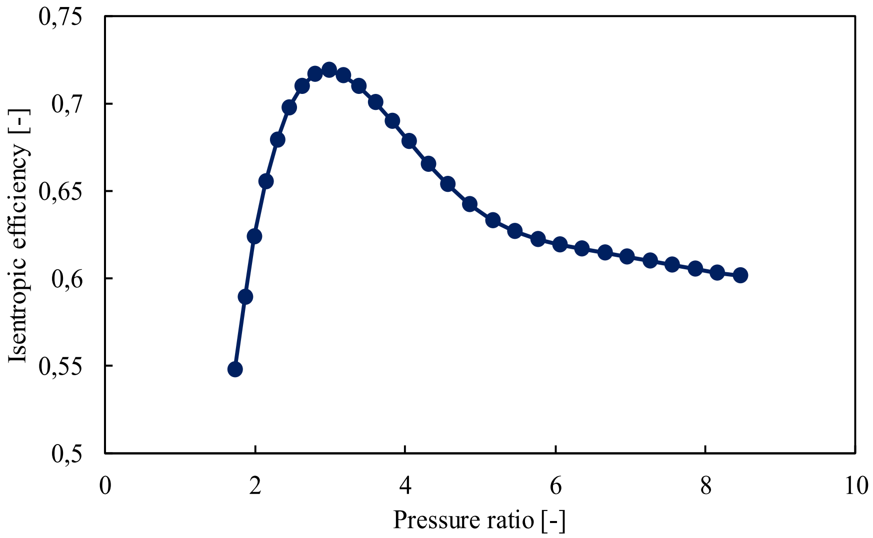

Fig. 3. Isentropic efficiency of compressor versus the pressure ratio

3. Solving procedure

Based on above-mentioned model of each component, a complete air source heat pump model with non-azeotropic refrigerants is presented. The method of inverse calculation is applied in evaporator and condenser because the iterations can be reduced when calculated from refrigerant outlet side and the assumption of the air outlet side temperature in every section is avoided.

The code is developed in the Matlab language. The REFPROP program subroutines [9] are linked to the present code to calculate the thermodynamic properties of the refrigerants and the air.

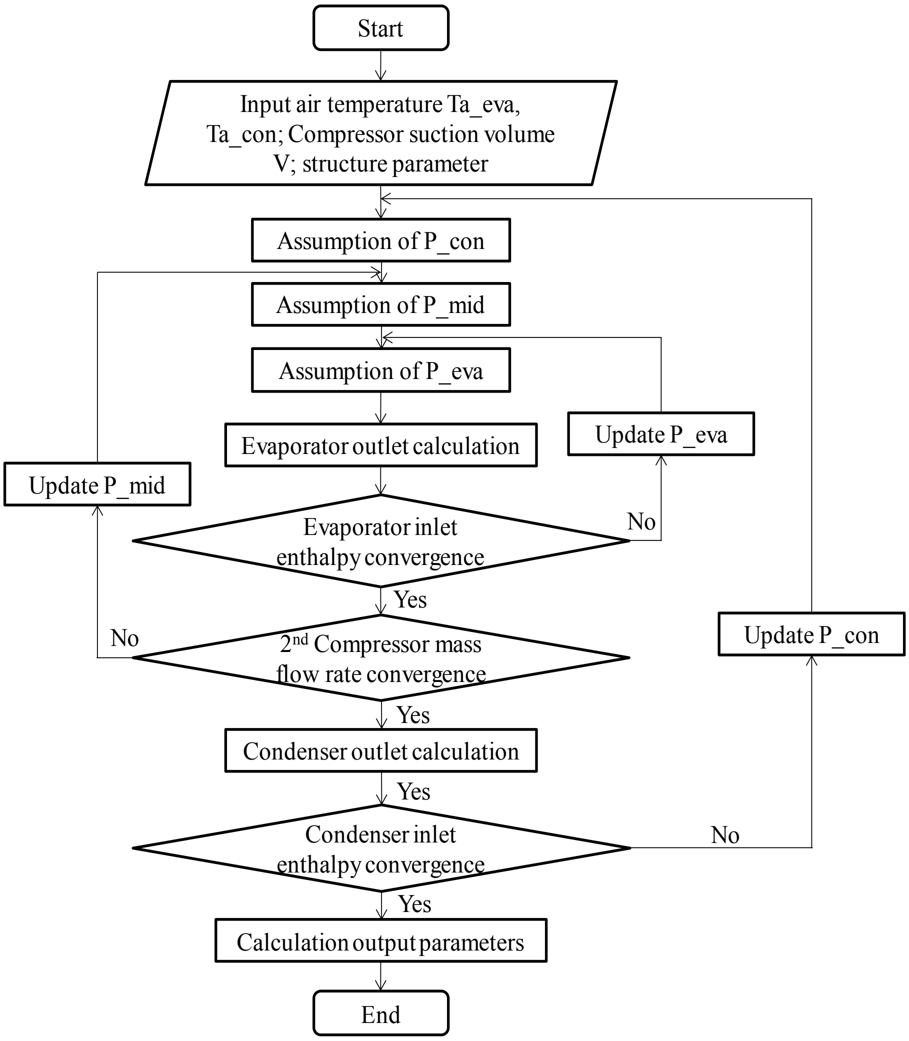

Fig. 3. Isentropic efficiency of compressor versus the pressure ratio

4. Results and discussions

Performance of vapor injected system with non-azeotropic refrigerant R32/R1234ze(E) mixtures is studied in this section. The influence of composition of refrigerant mixtures and ambient temperature to system performance are taken into account. Injection ratio, heating capacity and COP are both analyzed, where by, the normal vapor compression system (VCS) is presented and compared with the vapor injected system (VIS).

4.1. Injection ratio analysis

The injection ratio is defined as follows:

$$\alpha = m_{inject} / m_{con} \tag{2}$$

Where m_{inject} is the injection mass flowrate and m_{con} is mass flowrate through the condenser.

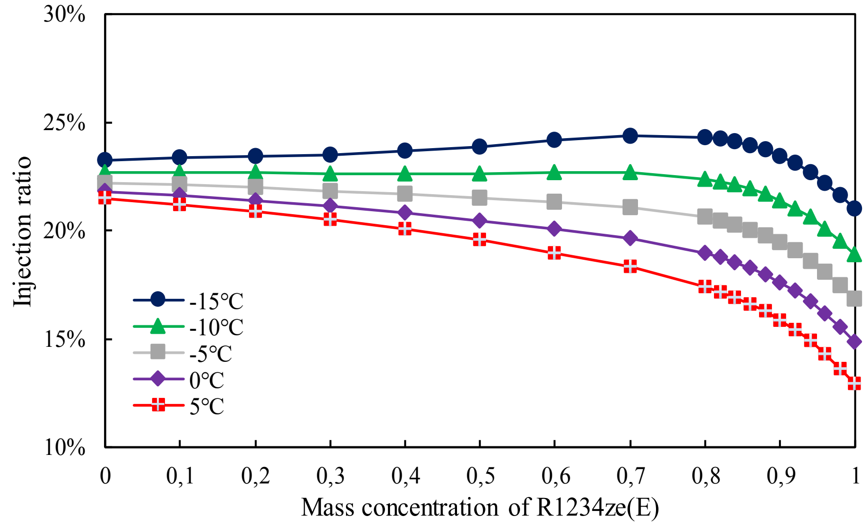

Fig. 4. Injection ratio under different outdoor ambient temperature versus composition

Fig.4 presents the injection ratio under different outdoor ambient temperature utilizing refrigerant mixtures with different compositions. It can be shown that the injection ratio increases with the outdoor ambient temperature decreasing, and it almost drops with the increase of the mass concentration of R1234ze(E) except for the case of -15°C outdoor ambient temperature. With the increase of the mass concentration of R1234ze(E), the condensing pressure will decrease obviously, which can result in the drop of injection ratio due to the decrease of the injection pressure.

4.2. Heating capacity analysis

The effects of outdoor ambient temperature on VCS and VIS are presented in Figure. 5. As a result, the changing trend of VIS and VCS versus the composition variation is similar, they both decrease with the mass concentration increasing, which is mainly caused by obvious decrease of the condensing latent heat and the dramatic decrease of the suction density with the increase of the mass concentration of R1234ze(E).

At the same time, it can be found that the gas injection can effectively enhance the heating capacity, especially for refrigerant mixture with less R1234ze(E).

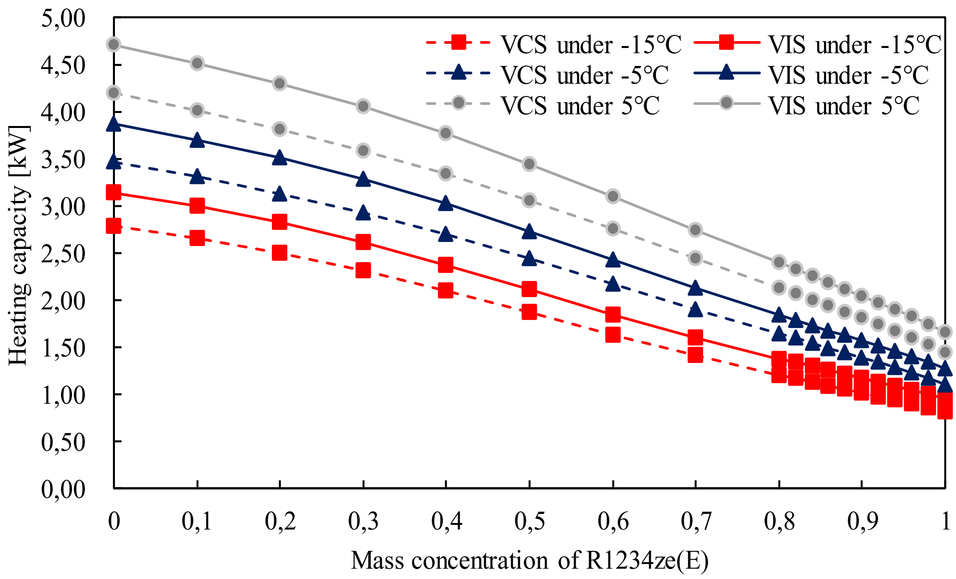

Fig. 5. Heating capacity under different outdoor ambient temperature

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4.3. COP analysis

The influence of the outdoor ambient temperature on the COP are presented in Figure.6. Firstly, it can be found that the COP of VIS increases with the increase of the mass concentration of R1234ze(E). It's coincident with previous study on VCS. This trend is closely linked with the isentropic line during compression and the temperature glide of refrigerant mixtures. The former one will become steeper with more R1234ze(E) which causes the decrease of the compression power and the increase of the COP. For the latter one, with matching better when the mass concentration of R1234ze(E) is more than 80%, the COP of both VCS and VIS increases rapidly.

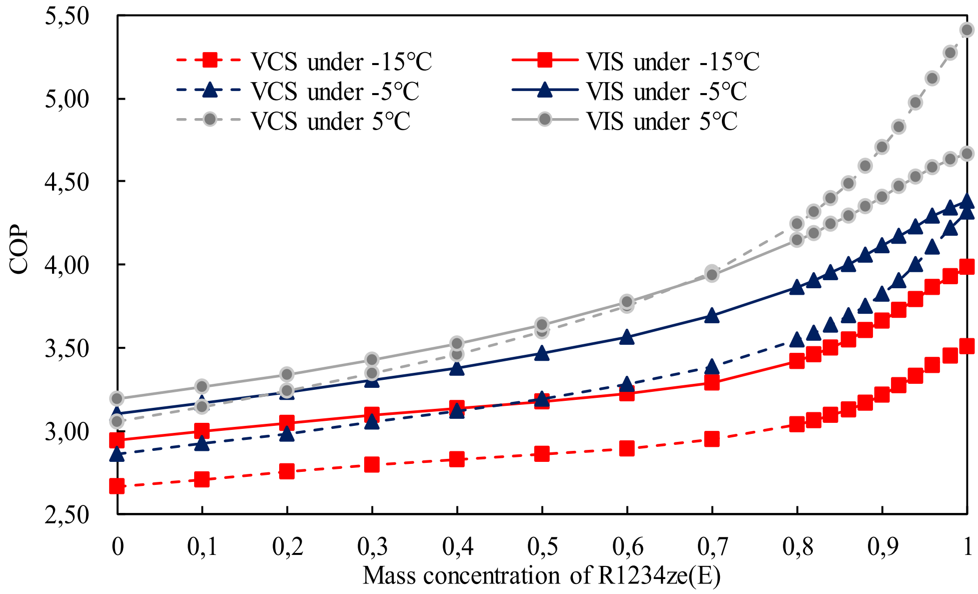

Fig. 6. COP under different outdoor ambient temperature

On the other hand, with the mass concentration of R1234ze(E) increasing, the COP difference between VIS and VCS becomes smaller and the COP of VIS even exceed that of VCS under higher outdoor ambient temperature. That is because the vapor injection is effective to system efficiency under large compression ratio, such as low ambient working conditions or refrigerant mixture with less R1234ze(E). For heat pump system with refrigerant mixtures rich in R1234ze(E) under high outdoor temperature, the system compression ratio is quite small, so the refrigerant injection will not enhance the COP but decrease it.

5. Conclusions

A detailed vapor injected heat pump model using non-azeotropic mixture R32/R1234ze(E) for low temperature ambient is developed for performance analysis. The main results are summarized as follows:

(1) With the mass concentration increasing of R1234ze(E), the injection ratio decreases except for higher outdoor ambient temperature;

(2) With the mass concentration increasing of R1234ze(E), the heating capacity of VIS decreases which is same as that of VCS. And gas injection can effectively enhance the heating capacity;

(3) The COP of VIS increases with the increase of the mass concentration of R1234ze(E). And with the mass concentration of R1234ze(E) increasing, the COP difference between VIS and VCS becomes smaller and the COP of VIS even exceed that of VCS under higher outdoor ambient temperature.

Acknowledgements

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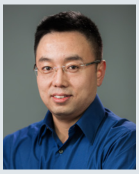

SHORT BIO

Dr. Baolong Wang is an associate professor serving the Department of Building Science of Tsinghua University in China, where he received his Ph.D degree in 2006. Dr Wang's research interest focuses on the area of efficient equipment in HVAC system, including scroll compressor, rotary compressor, low ambient temperature air source heat pump, high seasonal performance air conditioner, and low-GWP blend refrigerant.

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SHORT BIO

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