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Research Paper

Numerical study of gas injected heat pump using zeotropic R32/R1234ze(E) mixture: Comparison of two type economizers

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HIGHLIGHTS

- Both FT and IHX injection can largely enhance the performance of heat pump using R32/R1234ze(E) mixture.
- IHX injection more effectively promotes the heat pump with zeotropic mixture than FT injection.
- The lower the inlet HTF temperature, the larger improvement the injection system.
- The mass flowrate of HTF in evaporator has weak impact on the performance improvement.

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ABSTRACT

Rare pure refrigerants can meet the environmental, thermodynamic, and safety requirements to new-generation refrigerants completely. R32/R1234ze(E) zeotropic mixture is a potential replacement in the field of air conditioning and heat pumps. At the same time, gas injection technology is considered as a good solution to increase the seasonal energy performance of heat pump system. Accordingly, a comprehensive model of gas-injected water-water heat pump with R32/R1234ze(E) is built in this paper. Based on it, the performance of the gas injected heat pump with flash tank economizer and intermediate heat exchanger economizer are researched. Finally, the effect of type of the economizer type on the performance is identified. Three potential key parameters affecting the performance of the gas injection system, including molar fraction of refrigerant, inlet temperature of heat transfer fluid in evaporator, mass flowrate of heat transfer fluid in evaporator, are investigated. As a result, both flash tank gas injection and intermediate heat exchanger injection can largely enhance the heating capacity and COP of water-water heat pump using R32/R1234ze(E) mixture. Intermediate heat exchanger injection promotes the heat pump with zeotropic mixture more effectively than flash tank injection.

1. Introduction

Due to deplete the ozonosphere, chlorofluorocarbons (CFCs) have been phased out and hydrochlorofluorocarbons (HCFCs) are being alternated. At the same time, some hydrofluorocarbons (HFCs) also will be phased down due to their high global warming potential (GWP). While rare pure refrigerants can meet the environmental, thermodynamic, and safety requirements for new-generation refrigerants completely [1–3], the mixed refrigerants provide more flexibility in searching for new alternatives.

Among recent studies [4–7], HFC/HFO mixtures have attracted great attention due to their excellent properties, such as R32/R1234ze (E) in the field of air conditioning and heat pumps. Onaka et al. [8] analyzed the COP of domestic water heat pump with R32/R1234ze(E) mixtures during producing 45, 60, and 90 °C water from the same 20 °C inlet water. They concluded that the maximum COP could be obtained at 70 wt% R1234ze(E). Kojima et al. [9] tested a water heat pump with R410A and R32/R1234ze(E) mixtures. They found that when the heat sink water is heated by 10 K, the COP of the mixtures was significantly lower than R410A, but when the heat sink water temperature is increased by 25 K, the COP of the mixtures was generally comparable to that of R410A. Taira et al. [10] evaluated the performance of an air source heat pump with R32/R1234ze(E) (70/30) mixtures, R410A and R32. It was concluded that the COP of R32 was the highest among three refrigerants for the same capacity. Cheng et al. [11] investigated an air source heat pump with R32/R1234ze(E) mixtures. It is concluded that the heating capacity decreased by 67.2% while the COP continuously increased by 70.3% when the mass fraction of R1234ze(E) changes

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Nomenclature

A	surface area [m^2]
C	total number of components
c	specific heat [kJ mol^{-1} K^{-1} or kJ kg^{-1} K^{-1}]
d	diameter [m]
E	total energy [kJ]
h	specific enthalpy [kJ mol^{-1} or kJ kg^{-1}]
k_w	thermal conductivity [kW m^{-1} K^{-1}]
L	length [m]
M	molar mass [kg mol^{-1}]
m	refrigerant mass flowrate [kg s^{-1}]
n	number of inner tube
N	the number of moles [mol]
p	pressure [kPa]
q	capacity [kW]
Qc	heating capacity [kW]
S	entropy [kJ K^{-1}]
T	temperature [K] or [°C]
U	internal energy [kJ] or overall heat transfer coefficient [kW m^{-2} K^{-1}]
V	volume [m^3]
v	speed [m s^{-1}]
w	molar fraction
W	power consumption [kW]

Greek symbols

α	heat transfer coefficient [kW m^{-2} K^{-1}]
μ	chemical potential [kJ mol^{-1}]
ε	residual
θ	orbiting angle
Δ	difference

Subscripts

con	condenser
cv	control volume
ft	flash tank
in	inlet or inner tube
inj	injection
i,j	serial number of components, j = 1, 2, 3…C
liq	liquid
out	outlet outer tube
r	refrigerant
sec	section
sc	subcooling
suc	suction
tot	total

Abbreviations

COP	coefficient of performance
CFCs	chlorofluorocarbons
FT	flash tank
GWP	global warming potential
HTF	heating transfer fluids
HCFCs	hydrochlorofluorocarbons
HFCs	hydrofluorocarbons
IHX	intermediate heat exchanger

from 0% to 100%. To sum up, R32/R1234ze(E) mixture has good environmental properties and thermodynamic potential due to better temperature matching in heat transfer.

At the same time, enhancing the performance of the heat pumps in large compression ratio has become the key point to increase its seasonal energy performance. Gas injected technology is considered as a good solution to this problem. Xu et al. [12] comprehensively reviewed the refrigerant injection technology for heat pumping/air conditioning systems and confirmed the gas injection increased both the capacity and the efficiency obviously. Ma et al. [13] tested the performance of gas injected air source heat pump and found COP and heating capacity are increase effectively. Wang et al. [14] carried out an experimental investigation on heat pump with gas-injected scroll compressor. A 30% heating capacity improvement and 20% COP increase were found at the ambient temperature of −17.8 °C. Heo et al. [15] studied the effects of flash tank injection on the heating performance of a heat pump. The COP and heating capacity of the injection cycle were enhanced by 10% and 25%, respectively, at the −15 °C ambient. Wang et al. [16] found that gas injection is an effective method to improve the performance of scroll compressor and its system under high compression ratio, and comprehensively investigated the injection factors on the power consumption, volumetric efficiency, indicated efficiency and so on. Bertsch and Groll [17] constructed and tested a heat pump with gas injection, their results showed that the COP could reach 2.1 at −30 °C ambient temperature.

Although the gas injection technology has been widely researched, few of spotlight is focused on zeotropic refrigerant mixtures. Högberg and Berntsson [18] investigated the difference between zeotropic mixtures and pure fluids in two-stage cycles by simulation. R22/R152a, R22/R142b, R22/R114 were selected as the zeotropic mixtures. The main results showed that the COP and capacity of zeotropic mixtures were more largely increased than those of pure fluids by adopting the two-stage cycle with intermediate heat exchanger. Swinney et al. [19] conducted a computer simulation on zeotropic mixtures refrigeration cycle with pool boiling evaporator. A flash tank economizer was applied and the composition shift during flashing was considered. It was concluded that using mixtures always resulted in a loss of efficiency. Jung et al. [20] simulated the multi-stage heat pumps with a heat exchanger economizer. R22/R142b/R134a, R32/R134a, R125/R134a mixtures were studied. The results indicated that the three-stage heat pump is up to 27.3% more energy efficient than the conventional single-stage with pure refrigerant. Cao et al. [21] conducted an experimental study of heat pump water heater with mixture of R22/R600a. The result showed that the heating capacity and energy efficiency of the unit is increased, the discharge temperature of compressor decreased when using gas injection. D'Angelo et al. [22] presented a performance evaluation of a gas injected refrigeration system using R290/R600a. The results showed that the maximum COP was obtained for a mixture containing 40 wt% R290 and the COP was enhanced 16–32% by gas injection.

Actually, according to the difference of the economizer, the gas injection system can be classified into two types (Fig. 1): flash tank (FT) injection and intermediate heat exchanger (IHX) injection. It is commonly recognized that, for pure refrigerant, the FT system has a little higher performance than the IHX system [23–25]. However, gas injected system with zeotropic refrigerant is different from that with pure refrigerant, especially for FT system, in which the suction fraction varies from the injection fraction. The temperature-fraction diagram of FT injection system is shown in Fig. 2. It can be observed that all of suction fraction, injected fraction and discharged fraction are all different. While in IHX system, the refrigerant fraction at different locations keeps same all the time. That makes the performance of the injected system using zeotropic refrigerant with different economizer could be largely different.

To sum up, investigations on the gas injection system with zeotropic refrigerant are rare, especially for the new potential zeotropic mixture