ENERGY AND EXERGY ANALYSIS OF HEAT PUMP USING R744/R32 REFRIGERANT MIXTURE

by

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An energy and exergy analysis of heat pump with blends of refrigerant mixture R744/R32 was carried out. The coefficient of performance and exergy efficiency of the system were studied with different mass fraction of R744 in the blends and different heat source temperatures. The volumetric heat capacity, condensing pressure, discharge temperature, and compression ratio were also investigated. The results indicate that at a certain concentration (15/85 by mass), the blends achieve better performance, and are superior to those of R22, the results also show that the new refrigerant mixture is an attractive option for promising alternative refrigerant.

Key words: *heat pump, R744/R32, coefficient of performance, modelling, exergy efficiency*

Introduction

In recent years, interests in alternative refrigerants have been growing because of the ozone depletion and global warming [1, 2]. A number of researchers have investigated heat pump performance with binary refrigerants containing R744, a natural solution for decreasing the impact of refrigeration and air conditioning applications on the global warming of anthropic origin. In one of recent study, Sarkar and Bhattacharyya [3] theoretically evaluated the blends R744/R600 and R744/R600a, and their results indicated that the blends can be employed very effectively in heat pumps for variable temperature or simultaneous cooling and heating applications at conventional high side pressure. Nicola *et al.* [4] numerically calculated the performance of a cascade refrigeration cycle operated with blends of R744/R170, R744/R290, R744/R1150, R744/ R1270, and R744/RE170 as the low-temperature working fluid, and they found that adding R744 to HC and dimethyl ether reduces the cycle performance, even if acceptable values are always achieved for the coefficient of performance (*COP*). In another study [5], they presented an analysis on a cascade refrigeration cycle using R744/HFC blends as the low-temperature working fluid, including R744/R32.

From the literature, the researchers found advantages of the refrigerant mixtures from different aspects. However, the second refrigerants are almost HC, such as R600, R290, R170, which have higher flammability. More recently, R32 draws more and more attention by its excellent thermodynamic property, and it is confirmed that R744 refrigerant is used as additives with R32 refrigerant to deal with the higher global warming potential and also to suppress the flammability of the new mixture. However, the studies on the R744/R32 mixture as alternative refrigerant are very rare in the open literature.

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Herein, this communication intends to contribute to the theoretical analysis on the process of the new refrigerant mixture R744/R32 used in heat pumps. Accordingly, a theoretical models based on pinch point was proposed. In the present study, an energy and exergy analysis on heat pump with blends of refrigerant mixture R744/R32 was carried out. The *COP* and exergy efficiency of the system were studied with different mass fraction of R744 in the blends and different heat source temperatures. The volumetric heat capacity, condensing pressure, discharge temperature, and compression ratio were also investigated, and the performance of the refrigerant mixture was compared with that of R22 under the same conditions.

Modelling and simulation

The heat pump cycle with the new refrigerant mixture R744/R32 is shown in fig. 1, and consists of a compressor, a condenser, an expansion valve, and an evaporator. Correspondingly, the temperature-entropy (*T-s*) diagram is illustrated in fig. 2. The energy and exergy analyses of the heat pump system with R744/R32 are evaluated based on thermodynamic cycle analysis methods, steady flow energy equation, and mass balance equation. The following assumptions have been made during the analysis [6].

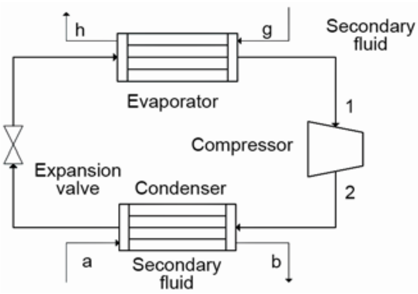

Figure 1. Schematic diagram of heat pump system

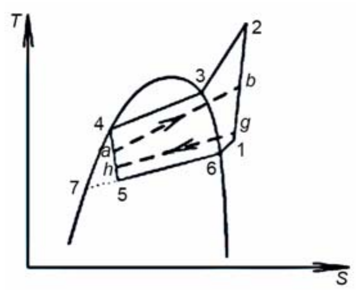

Figure 2. *T-s* diagram of heat pump system

- The refrigerant at the exit of the condenser is saturated liquid or saturated vapor, and that for evaporator is superheated vapor.
- The expansion process is isenthalpic.
- Heat transfer with the environment is negligible.
- A minimum approach temperature between the refrigerant and the secondary fluid for both evaporator and condenser are fixed to be 6 °C.
- The compression process is adiabatic with a constant isentropic efficiency of 0.75.

Based on the above assumptions, a modeling and simulation for subcritical R744/R32 heat pump systems using EES and REFPROP 9.0 was proposed [7, 8].

From the first law point of view, the measure of performance the heat pump cycle is the *COP*, which is expressed as:

$$COP = \frac{q_{\text{con}}}{w_{\text{c}}} = \frac{h_2 - h_4}{h_2 - h_1} \tag{1}$$

where q_{con} [kJkg^{-1}] is the unit mass heating capacity, w_{c} [W] – the compressor electric power, and h [kJkg^{-1}] – the specific enthalpy.

The unit volumetric heat capacity [kJ m^{-3}] is given by:

$$q_{\text{h}\upsilon} = \frac{q_{\text{con}}}{\upsilon_1} = \frac{h_2 - h_4}{\upsilon_1} \tag{2}$$

where υ_1 [m^{3}kg^{-1}] is the specific volume at state point 1. Percentage of irreversibility due to expansion can be written with eq. (3):

$$I_{\text{ex}} = \frac{T_0(s_5 - s_4)}{w_c}, \text{ where } w_c = h_2 - h_1 \tag{3}$$

Similarly, irreversibility in compressor is given by eq. (4):

$$I_{\text{comp}} = \frac{T_0(s_2 - s_1)}{w_c} \tag{4}$$

Evaporator and condenser irreversibilities can be given by eq. (5) and (6), respectively:

$$I_{\text{e}} = \frac{T_0\left[(s_1 - s_5) - \dfrac{q_{\text{e}}}{T_{\text{ew}}}\right]}{w_c} \tag{5}$$

$$I_{\text{c}} = \frac{T_0\left[\dfrac{q_{\text{c}}}{T_{\text{cw}}} - (s_2 - s_4)\right]}{w_c} \tag{6}$$

The total irreversibility of the cycle can be written as:

$$I_{\text{total}} = I_{\text{ex}} + I_{\text{comp}} + I_{\text{e}} + I_{\text{c}} \tag{7}$$

Therefore, the second law efficiency, *i. e.* the exergy efficiency of the system is defined as:

$$\eta = 1 - \sum I \tag{8}$$

Results and discussions

Once all components of the cycles had been selected, the simulations were run by varying the inlet and outlet temperature of heat sources, which were set to 20 °C and 15 °C, 15 °C and 10 °C, and 10 °C and 5 °C, respectively, meanwhile, the inlet and outlet temperatures of heat sink were set to 17 °C and 65 °C according to the Chinese National Standards [9] (tab. 1).

Table 1. The working parameters of the heating pump

Conditions	Inlet temperature of heat sink [°C]	Outlet temperature of heat sink [°C]	Inlet temperature of heat source [°C]	Outlet temperature of heat source [°C]
1	17	65	20	15
2	17	65	15	10
3	17	65	10	5

Table 2. The performance of the heat pump using R22

Conditions	*COP* [–]	η [%]	q_c [m^{3}kg^{-1}]	t_{dis} [°C]	P_c [MPa]	r [–]
1	3.738	0.2667	4927	96.47	2.47	3.75
2	3.438	0.2876	4345	100	2.438	4.321
3	3.194	0.3054	3818	103.6	2.396	4.988

The cycle performance of the heat pump using R744/R32 mixtures such as coefficient of performance, exergy efficiency, discharge temperature, compression ratio, condensing pressure, volumetric heating capacity, was calculated, and the results were compared with that of R22 under the same conditions (tab. 2). All the results are shown in figs. 3-8.

Figure 3 shows the simulated *COP* of the three different heat source temperature as the function of the variation of the mass fraction of R744 in the blends. It can be seen that the *COP* increases and achieves the peak value when the mass fraction of R744 is about 15% and then decreases with increasing R744 concentration. The *COP* value is higher with the same R744 concentration in condition 1 than for the other two conditions (condition 2 and 3). Compared with that of R22, the optimal *COP* value is always higher among the three conditions.

Figure 4 represents the exergy efficiency as the function of the variation of the mass fraction of R744 in the blends. It is obviously seen that almost the same trend with the *COP*. However, the exergy efficiency value that are obtained in condition 3 is higher than that obtained in conditions 1 and 2. Compared with that of R22, the optimal exergy efficiency value is always higher among the three conditions.

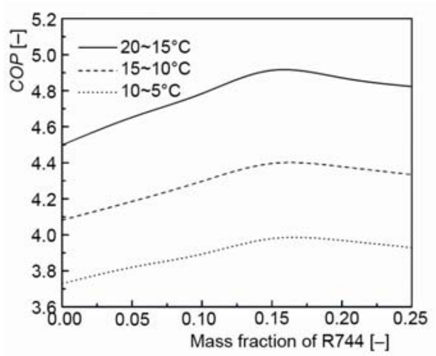

Figure 3. Variation of *COP* with mass fraction of R744

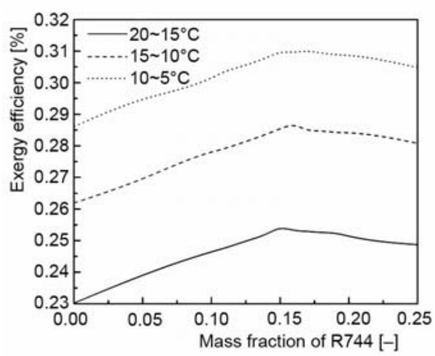

Figure 4. Variation of exergy efficiency with mass fraction of R744

Figure 5 illustrates that the more R744 exists in the mixtures, the greater capacity the mixtures has. The volumetric heating capacity value is higher with the same R744 concentration in condition 1 than the other conditions (conditions 2 and 3). It is well known, when heating capacity is certain, the greater volumetric heating capacity the mixtures have, the less compressor exhaust volume the system need, in other words, the compacter the compressor is. Compared with that of R22, the volumetric heating capacity is always higher in the three conditions.

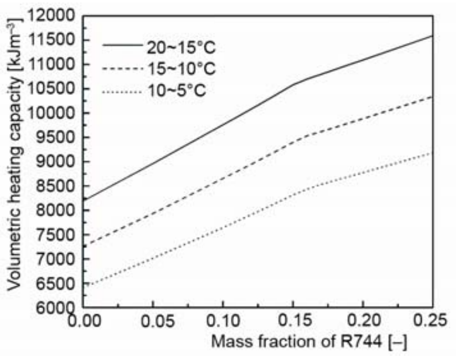

Figure 5. Variation of volumetric heating capacity with mass fraction of R744

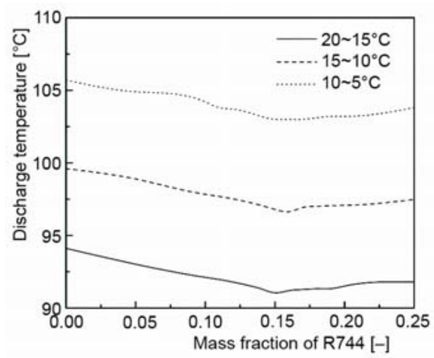

Figure 6. Variation of discharge temperature with mass fraction of R744

In fig. 6, the discharge temperature decreases with the mass fraction of R744 and reaches valley value at 15% R744 mass fraction, and then increases slightly when the R744 concentration increases. The discharge temperature value is higher with the same R744 concentration in 3 than the other conditions (condition 1 and condition 2). Generally, a system with a lower discharge temperature has a better operation. Compared with R22, the discharge temperature is always lower in the three conditions.

As can be seen, the condensing pressure increases linearly with R744 concentration in fig. 7. The value is higher with the same R744 concentration in condition 1 than the other conditions (conditions 2 and 3). Compared with that of R22, the condensing pressure is always higher in the three conditions.

Figure 8 depicts the compression ratio of the three different heat source temperatures as the function of the variation of the mass fraction of R744 in the blends. The results clearly show that the compression ratio decreases with R744 concentration first and then increases slightly when the R744 concentration exceeds 15%. As is known that the compressor efficiency is higher when the compression ratio is lower, and then the *COP*, exergy efficiency are higher, which is agreed well as shown in fig. 7. In addition, the compression ratio is higher with the same R744 concentration in condition 3 than the other two conditions. Compared with that of R22, the optimal compression ratio is always lower in the three conditions.

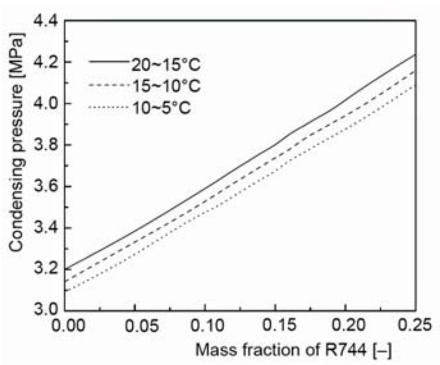

Figure 7. Variation of condensing pressure with mass fraction of R744

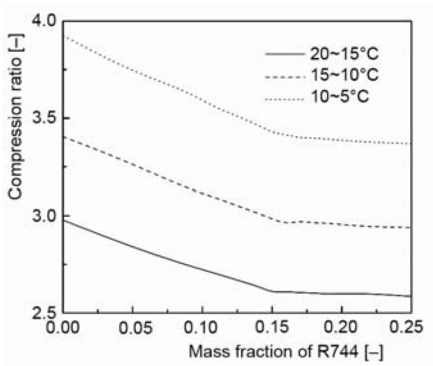

Figure 8. Variation of compression ratio with mass fraction of R744

Conclusions

In this work, an energy and exergy analysis on heat pump with blends of refrigerant mixture R744/R32 was carried out. The main conclusions can be summarized as:

- The concentration of the refrigerant mixture and the heat source temperature have great influence on the *COP*, exergy efficiency, volumetric heating capacity, discharge temperature, and other parameters.
- At certain concentration of the blends (15/85 by mass), the heat pump system shows better performance, and the *COP* and exergy efficiency reach a peak value.
- Compared with that of R22, the refrigerant mixture R744/R32 is more effective in the future considering alternative refrigerant.

Acknowledgments

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