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Toshimitsu Kamada

Daikin Industries, LTD., Japan, toshimitsu.kamada@daikin.co.jp

Tomoyuki Haikawa

Daikin Industries, LTD., Japan, tomoyuki.haikawa@daikin.co.jp

Shigeharu Taira

Daikin Industries, LTD., Japan, shigeharu.taira@daikin.co.jp

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Research on Optimization of Heat exchanger in Heat pump using R32 and HFO-mixed Refrigerant

Toshimitsu KAMADA^{1*}, Tomoyuki HAIKAWA², Shigeharu TAIRA³

¹Daikin Industries, LTD., Technology and Innovation Center,
Settsu, Osaka, Japan
(+81-6-6195-7132, +81-6-6195-6639, toshimitsu.kamada@daikin.co.jp)

²Daikin Industries, LTD., Technology and Innovation Center,
Settsu, Osaka, Japan
(+81-6-6195-7132, +81-6-6195-6639, tomoyuki.haikawa@daikin.co.jp)

³ Daikin Industries, LTD., CSR and Global Environment Center
(Also)Planning Dep. Air Conditioning Manufacturing Div.
Osaka, Osaka, Japan
(+81-6-6374-9304, +81-6-6374-9321, shigeharu.taira@daikin.co.jp)

²Daikin Industries, LTD., Technology and Innovation Center,

* Corresponding Author

ABSTRACT

R32 is applied as refrigerant for split air conditioners in Japan and many countries from the view point of its safety, energy efficiency, and economy. On the other hand, some of zeotropic blends are proposed as next generation refrigerant for air-conditioners. In assumption to use them for cooling-only air conditioner in order to maximize their advantage of temperature glide characteristics, we conducted heat exchanger simulation to optimize the evaporator for R32 and zeotropic refrigerants, and evaluated their heat transfer characteristics.

Keywords: Air-conditioner, Heat exchanger, Refrigerant, Low-GWP

1. INTRODUCTION

The effects on global environment of the refrigerants for air-conditioners have been discussed for decades. After Montreal Protocol agreement in 1987, CFCs were replaced to HCFC, whose ozone depletion potential (ODP) is much smaller, or HFC, whose ODP is zero. After 1997, when Kyoto Protocol was adopted, discussions on the impact of refrigerants to global warming have been held continually. As the points to choose the refrigerant for air-conditioners, zero ODP, higher energy efficiency, safety, cost and better Life Cycle Climate Performance (LCCP) are very important. R32 is considered as the best refrigerant for air-conditioners with balance of those points of view. It is applied for residential and light commercial split air-conditioners, and spreading many parts of the world.

Since R32 is single component refrigerant, it does not have temperature glide. Therefore, even in case of counter flow configuration for condenser to achieve higher performance, performance with parallel flow in evaporator operation in reverse cycle is not disadvantageous so much than counter flow configuration. Due to this property, R32 achieves higher Annual Performance Factor (APF), which takes both cooling and heating performance in reversible heat pump / air-conditioners into account. They have major share of residential and commercial split air-conditioners in Japan and many other countries. On the other hand, zeotropic refrigerants which consist of R32 and HFO that may contain other HFC such as R125 in order to reduce Global Warming Potential (GWP) have been evaluated for car air-conditioner and water chiller, because their cooling-only usage are suitable to operate close to Lorentz cycle. In hot region such as southern China, South-eastern Asia, India and so on, since the almost all air-

conditioners are for cooling only, it may be advantageous to apply such zeotropic blends for residential and light-commercial split air-conditioners with optimized heat exchangers for such blends. In this report, the results of evaluation of such potential of zeotropic blends based on the simulations calibrated by drop-in tests with air-conditioner optimized for R32 are explained. The difference of performance of heat exchanger between single component refrigerant R32 and zeotropic blends is mainly evaluated. The heat exchanger simulation method to mimic the experimental results is established and calibrated. In addition, the guidelines to design heat exchangers for cooling-only air-conditioners with zeotropic blends are proposed.

2. DROP-IN TEST

2.1 Test System

In order to evaluate the performance of air-conditioners with different kinds of refrigerants, a residential mini-split air-conditioner was used. Figure 1 shows the schematic diagram for the refrigerant circuit of it. The test conditions and the facilities conform the Air-enthalpy method in ISO 5121-2010. The heat exchanger assembled in the indoor-unit was investigated as the object of this work, has 3 rows, 20 steps (8 steps for only 1st row), 825mm length, 1.2 mm fin pitch, 6.35mm tube outer diameter before expansion, 36mm width, 288mm height and 5 passes.

2.2 Tested refrigerants

Three refrigerants, R32, R32/R1234ze (70/30) and R32/R125/R1234yf (67/7/26) are evaluated. R32/R1234ze (70/30) and R32/R125/R1234yf (67/7/26) are zeotropic refrigerants. Figure 2 shows p-h diagram of ideal refrigerant cycle for the 3 types of refrigerant without consideration of pressure drop in heat exchangers and heat loss in compressor. Condensation temperature (T_c) is set 318K, evaporation temperature (T_e) is set 293K, sub-cooling at the outlet of condenser is set 5K, and superheating at the outlet of evaporator is 5K on Figure 2. NIST's REFPROP 9.1 is used as refrigerant property library and the properties of mixed refrigerants are calculated by means of .MIX file made by ourselves. The order of amplitude of enthalpy difference between the inlet and outlet of evaporator is R32, R32/R1234ze, R32/R125/R1234yf. The order of mass flow rate of refrigerant for the same heat capacity is the same as it, it is suggested to reduce the power of compressor in this order. On the other hand, as shown in Table 1, for temperature glides at dew point 293K, R32/R1234ze is larger and R32/R125/R1234yf is smaller.

2.3 Test condition

Table 2 shows the working conditions of evaporator in drop-in tests for R32, R32/R1234ze (70/30) and R32/R125/R1234yf (67/7/26). Cooling operation was held and evaporator means heat exchanger installed in the indoor-unit. T_e for each refrigerant could not be set equal since these are the test results to make the COP of system the best for each refrigerant, but they were chose to be as near as possible from multiple data with different refrigerant amount.

2.4 Test results

Figure 3 shows the results of drop-in tests with the conditions in Table 2.

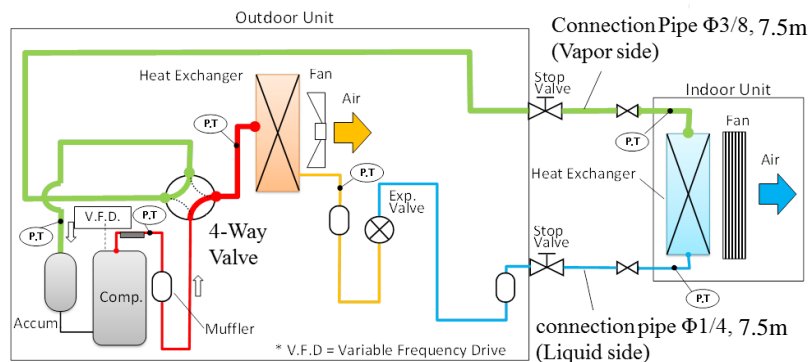


Figure 1: Schematic diagram of tested residential mini-split air-conditioner

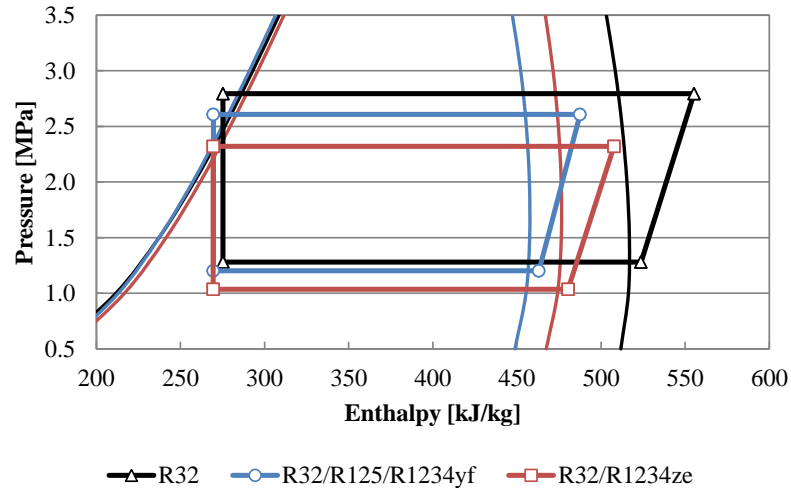


Figure 2: p-h diagram of theoretical refrigeration cycle for each tested refrigerant

Table 1: Temperature glide for each tested refrigerant

Refrigerant	R32	R32/R1234ze	R32/R125/R1234yf
Temp. glide [K]	0	4.4	0.9

Table 2: Test condition on evaporator for drop-in test

Refrigerant	R32	R32/R1234ze	R32/R125/R1234yf
Inlet air temperature [K]	300	300	300
Inlet air humidity [kg/kg ³]	0.0105	0.0105	0.0105
Inlet air average velocity [m/s]	1.44	1.33	1.35
Inlet refrigerant enthalpy [kJ/kg]	292.3	262.6	264.0
Outlet refrigerant pressure [MPa]	1.3107	1.0213	1.1679
Te (dew point) [K]	289.0	287.7	287.2

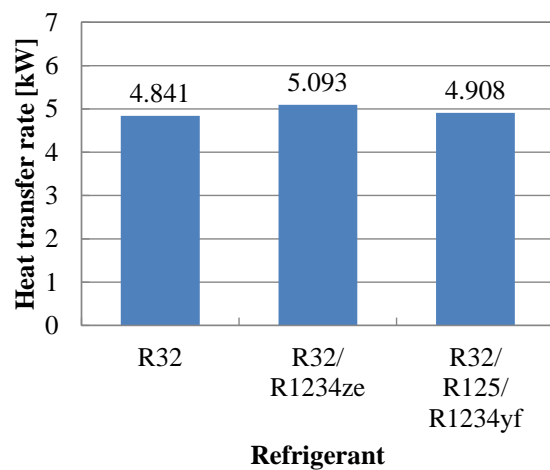


Figure 3: Performance of evaporator on drop-in test

3. VARIDATION FOR HEAT EXCHANGER SIMLATION

Fitting of correlations of heat transfer coefficient and pressure drop of fin and tube was held based on the drop-in test results described in chapter 2.

3.1 Heat exchanger model

Since the drop-in test was held by means of wall-hanged type indoor unit, the air velocity in the front of heat exchanger is considered to have non-uniform distribution. And the number of pass of the heat exchanger is 5, the distribution of the refrigerant is not always uniform either. The pass configuration and distributor of the heat exchanger is optimized to set the heat capacity for each pass with R32 refrigerant almost equal in the process of development for the product. So in the process of fitting the simulation to the test results, in order to simplify the task, single pass model in the total heat exchanger shown in Figure 4 was used and air velocity distribution is equal in average air frontal velocity. The tested product is heat pump air-conditioner and its heat exchanger of indoor-unit has pass configuration of counter flow for condenser because the performance of heating is taken into consideration. So the pass configuration for evaporator is parallel flow, in fitting process of heat exchanger simulation, input pass configuration is also parallel flow as shown in Figure 4.

3.2 Simulation method

Heat exchanger simulation was held with the method described in the paper (Jiang, et al., 2006). Hot water test with changing air flow rate was held separately with the heat exchanger assembled with the applied fin to derive air side heat transfer coefficient with Wilson plot method and the correlation between the air frontal velocity and air side heat transfer coefficient was produced. The correlation for refrigerant side heat transfer coefficient and pressure drop were produced by multiplied correction factor to existing correlations shown in Table 3. The same correction factors for the refrigerant side heat transfer coefficient and pressure drop were used for the 3 refrigerants evaluated in this paper.

3.3 Validation result

Figure 5 shows the ratio of the heat transfer rate given as results of heat exchanger simulation input the drop-in test conditions by using the same correlations between 3 refrigerants as described in chapter 3.2 to heat transfer rate of the drop-in test results. The difference between simulation results and experimental results confirmed to be within 1%. The simulation results with these correlation and correction factor will be discussed after chapter 4.

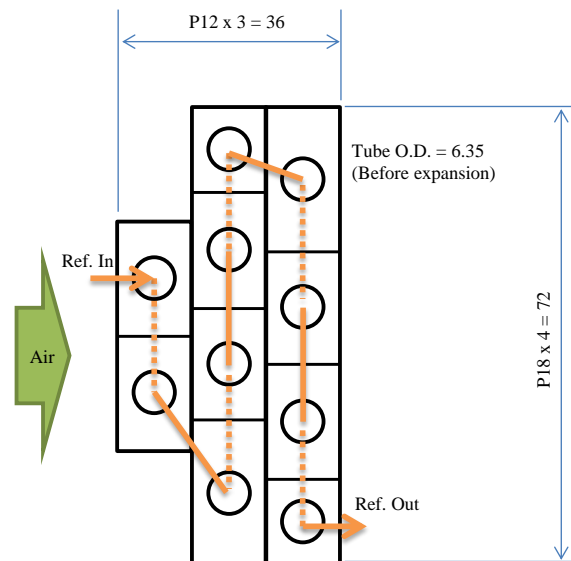
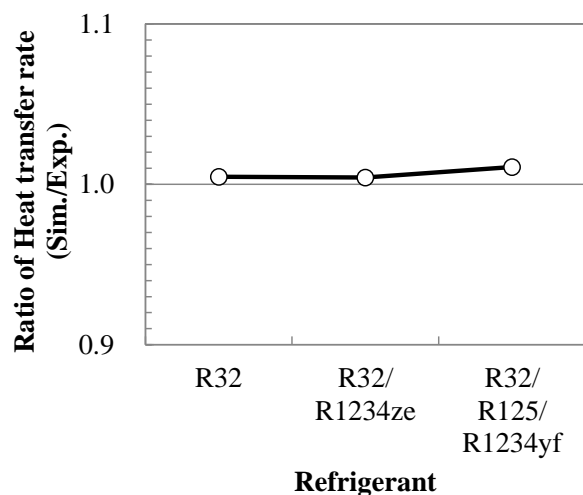


Figure 4: Pass configuration of evaporator for heat exchanger performance simulation

Table 3: Correlations used for fitting drop-in test

Properties	Name
Refrigerant side heat transfer coefficient (single phase)	Gnielinski
Refrigerant side heat transfer coefficient (two phase)	Kido (1994)
Refrigerant pressure drop (single phase)	Blasius
Refrigerant pressure drop (two phase)	homogeneous (Didi 2002)

**Figure 5:** Validation results on heat exchanger simulation

4. OPTIMIZATION OF HEAT EXCHANGER FOR COOLING

The machine for the drop-in test results described in chapter 2 and 3 is heat pump air-conditioner. In this paper, we focus on the cooling-only split type air-conditioners and discuss the heat exchanger performance with application of non-azeotropic refrigerants consist of R32 and HFO.

4.1 Pass configuration design

As described in chapter3.1, the air conditioner used for the drop-in test has the pass configuration with taking into account of the performance of heating and optimized for single R32 refrigerant. Then evaporator performance with counter flow for single R32 and non-azeotropic refrigerant are simulated and compared to that with parallel flow. The heat exchanger for the simulation has 6.35mm tube outer diameter before expansion and 1.2mm fin pitch as well as those for drop-in test. For simplification, row number is 2 and step number is 18. In order to evaluate the effect of pass number to the evaporator performance, simulation with 4types of pass number, 3, 6, 9, and 18 were held. Figure 6 shows the pass configuration in case of 9 passes for the simulated heat exchanger.

4.2 Simulation condition

Table 4 shows the air side and refrigerant side conditions input of the simulation. For non-azeotropic refrigerants, evaporation temperature, T_e is defined to the averaged temperature of dew point and boiling point corresponding to the outlet refrigerant pressure.

4.3 The effect of pass configuration of heat exchanger

Figure 7 shows the effect of the change of pass number on the evaporator performance for each refrigerant with different T_e and flow pattern.

At first, the influence of flow pattern is considered. There is little difference between the performance of evaporator on counter flow and that on parallel flow for single R32. Though for R32/R1234ze, there are significant difference between counter flow and parallel flow on their evaporator performance. These are because of the temperature glide, which affects to raise the refrigerant saturation temperature from evaporator inlet to outlet with the change of refrigerant quality, makes counter flow to have more merit to get the temperature difference between air and refrigerant at the back side of heat exchanger than parallel flow. To consider application to cooling air conditioners, counter flow is effective for evaporator, and the larger the temperature glide of refrigerant, the larger the difference of evaporator performance between counter flow and parallel flow.

Next, the influence of pass number is considered. At the condition T_e is low enough, $T_e=279\text{K}$, the temperature difference between air and refrigerant is so large that the mass flow rate of refrigerant is large, and the rate of degradation of heat transfer rate due to refrigerant pressure drop in the case the pass number is less. Since R32/R1234ze has the merit to get more temperature difference between air and refrigerant as above, pressure drop makes the saturation temperature at the inlet refrigerant with higher quality higher and the merit less. Due to this effect, the ratio of degradation of evaporator performance with the decrease of pass number of R32/R1234ze is larger than that of single R32. For 9 passes, there is difference of heat transfer rate between R32 and R32/R1234ze, but there is not such difference for 6 passes. It is known that the more pass number, the more the cost of distributor and pipes while the productions design and the more risk of mal-distribution of refrigerant. At the condition with higher T_e , $T_e=290\text{K}$, since the refrigerant mass flow rate is small and the influence of refrigerant pressure drop is also small, the influence of pass number is small either.

For R32 /R125/R1234yf, which has smaller temperature glide, shows less ratio of improvement of heat transfer rate by the optimization of pass configuration, there is no condition to show the better performance than R32.

4.4 The effect of outlet superheating

Some of split type air-conditioners, especially in the products connecting multiple indoor-units, controls the refrigerant state at the outlet of evaporator to set superheating gas from the view of protecting compressor. Zeotropic refrigerants tend to get the temperature difference between air and refrigerant smaller than single refrigerants because their saturation temperature gets higher from inlet to outlet in evaporator. Due to this effect, it is concerned that zeotropic refrigerants have characteristics to be hard to take outlet superheating. The heat exchanger simulations are held on this effect and gives considerations on it. Simulations in this chapter applies the same specification of heat exchanger and condition as those shown in chapters 4.1 and 4.2, except for the multiple outlet superheating with changing the refrigerant mass flow rate and the pass number fixed to 6 for R32 and 9 for R32/R1234ze and R32/R125/R1234yf from the conclusion of chapter 4.3.

Figure 8 shows the simulation results on the influence of outlet superheating on the performance of evaporator. Zeotropic R32/R1234ze shows more ratio of degradation of heat transfer rate with the increase of superheating than single R32 without temperature glide. For $T_e=279\text{K}$, R32/R1234ze shows 6% higher heat transfer rate than R32, though the difference gets smaller with the increase of superheating. In the region of superheating over 8K, R32 has better performance than the others. And for $T_e=290\text{K}$, the superheating where the performance of R32 and R32/R1234ze cross is 3.5K. The condition with low T_e and large superheating and with high T_e will be encountered in part load operation with low heat load. To take the long-term energy conservation in actual usage into consideration, it is known that the ratio of part load operation is major. It is suggested that the flat performance characteristics of single R32 has merit in this point of view.

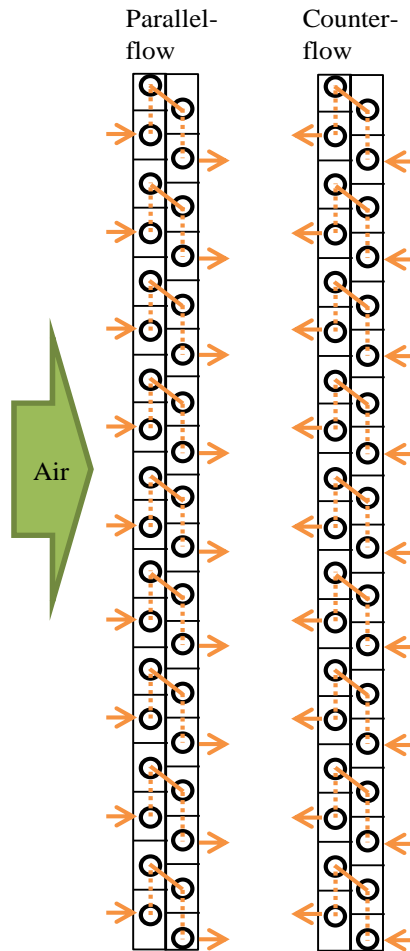


Figure 6: Pass configuration for simulation (in the case of 9 passes)

Table 4: Simulation condition

Refrigerant	R32	R32/R1234ze	R32/R125/R1234yf
Inlet air temperature [K]	300	300	300
Inlet air humidity [kg/kg ³]	0.0105	0.0105	0.0105
Inlet air average velocity [m/s]	1.00	1.00	1.00
Inlet refrigerant quality [-]	0.15	0.15	0.15
Te [K]	279.15, 290.15	279.15, 290.15	279.15, 290.15

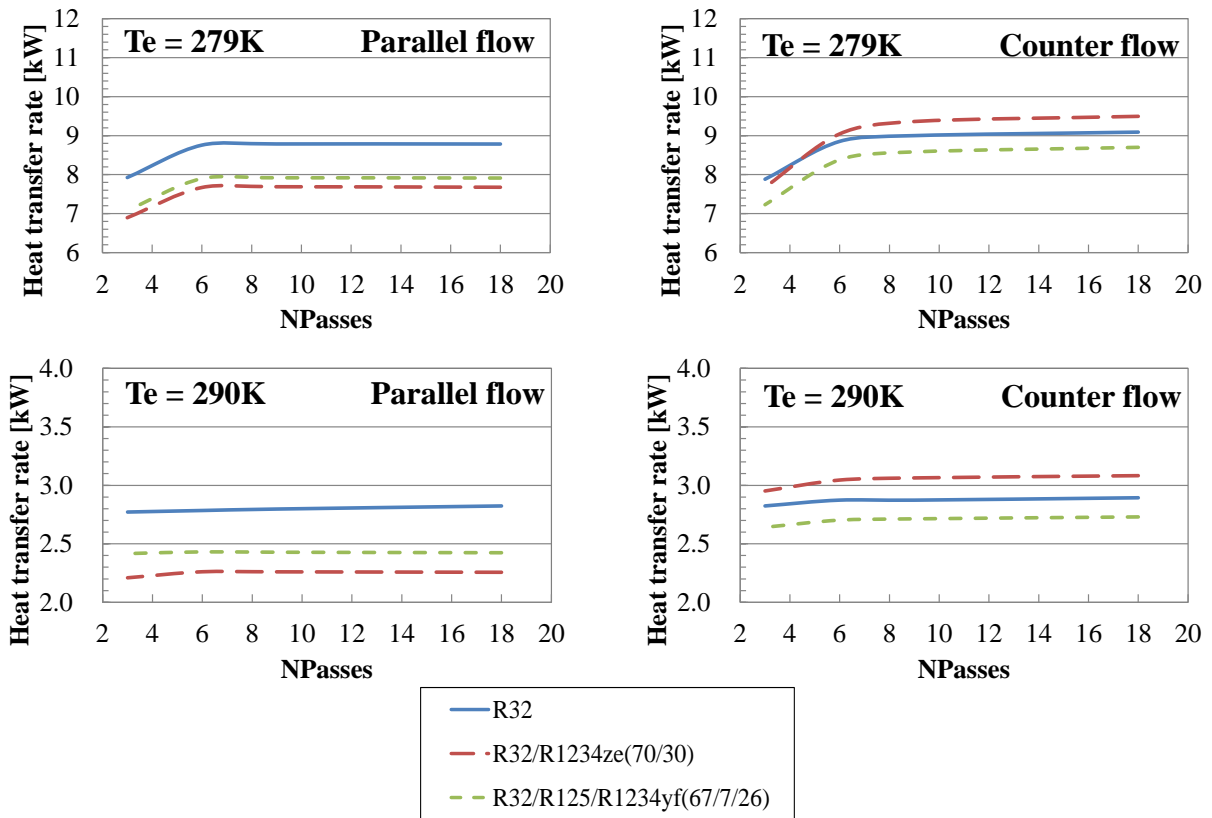


Figure 7: Effect of number of passes on evaporator performance for each refrigerant

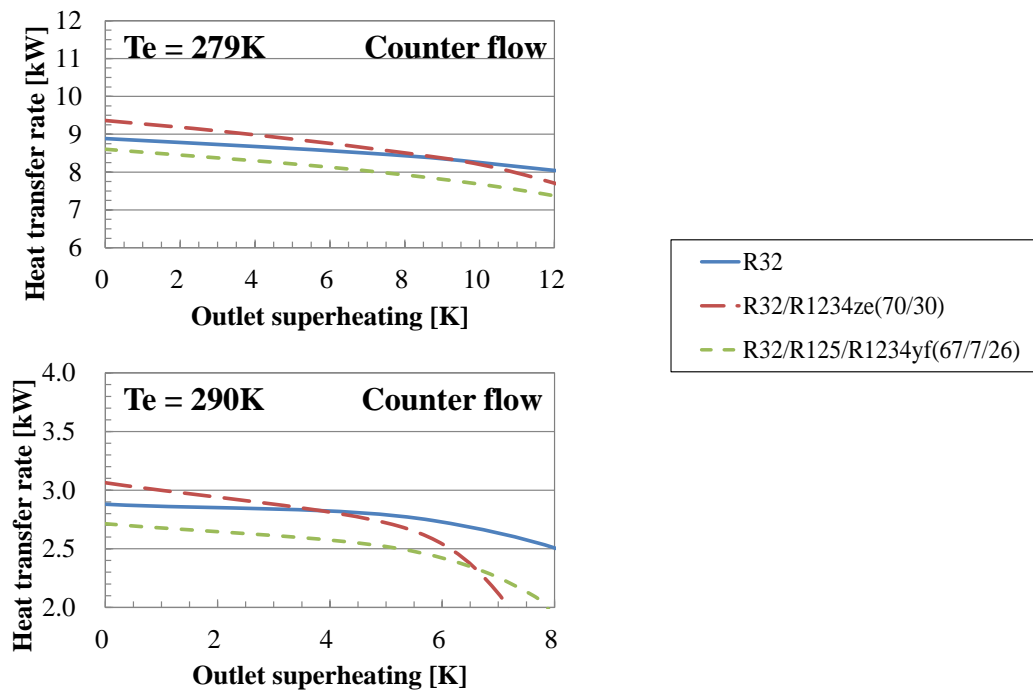


Figure 8: Effect of outlet superheating on evaporator performance for each refrigerant

5. CONCLUSIONS

By means of heat exchanger simulation with accuracy ensured by drop-in test, the heat transfer properties of 3 refrigerants, single component R32, R32/ R1234ze (70/30), R32/R125/R1234yf (67/7/26) in the heat exchanger installed in indoor-unit of split air-conditioner are evaluated and conclusions below are obtained.

- It was found that in some counter-flow design conditions of evaporator, R32/1234ze can achieve better overall heat transfer than R32
- On the low load conditions of heat exchangers where refrigerant temperature becomes close to air temperature, which occurs most periods in actual operation in variable speed air conditioners, disadvantage in performance of R32/R1234ze was observed because lower average evaporating temperature of the blend than R32 is required due to its temperature glide.
- Any condition for R32/R125/R1234yf to achieve better performance than R32 was found in this study even though the pass configuration was optimized for evaporator.
- Taking penetration of variable speed drive air conditioners into market and overall energy efficiency into account, single component refrigerant R32 has advantage because of its efficient performance in wide operating range without temperature glide.

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