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Drop-in Experiments on Heat Pump Cycle Using HFO-1234ze(E) and Its Mixtures with HFC-32

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ABSTRACT

In the present study we have carried out the drop-in experiments of R410A, HFO-1234ze(E) and the mixture of 50mass%HFO-1234ze(E)/50mass%HFC-32 at heating mode, using a vapor compression heat pump system developed for R410A. It has found that in the case of mixture of 50mass%HFO-1234ze(E)/50mass%HFC-32 the COP value is little affected by the degree of subcooling at the condenser outlet and it is only about 7.5% lower than that of R410A at the same heating load of 2.8 kW. This reveals that mixtures of HFO-1234ze(E)/HFC-32 are considered to be applicable as low-GWP alternatives for R410A by adjusting the composition of the mixture and by reconsidering the design parameters of components of room air-conditioning system.

1. INTRODUCTION

In 1990's, HFCs were developed as alternative refrigerants for CFCs and HCFCs in order to protect the ozone layer in the stratosphere. However, at the 3rd Conference of Parties (COP 3), it was determined that HFCs must be reduced due to their global warming potential. From this viewpoint, it is required to introduce environmentally acceptable refrigerants and improve further the performance of refrigeration and air-conditioning systems.

Recently, natural refrigerants such as C_3H_8, i-C_4H_{10}, water, CO_2, NH_3, have been attracting considerable attention all over the world because of their zero-ODP (ODP: Ozone Depletion Potential) and low GWP (GWP: Global Warming Potential). However, appropriate alternatives for domestic air-conditioning systems still can not be found from natural refrigerants, though heat pump refrigeration systems using some kinds of natural refrigerants have been put to practical use. In this situation, we have noticed from early on HFO-1234ze(E), which was developed as cover gas for casting process of Magnesium alloy, because of its zero-ODP and low GWP.

In the present study, in order to investigate the possibility to introduce HFO-1234ze(E) and its mixture with HFC-32 as low-GWP alternatives for vapor compression heat pump/refrigeration systems, we have carried out the drop-in experiments of R410A, HFO-1234ze(E) and the mixture of 50mass% HFO-1234ze(E)/50mass%HFC-32 at heating mode, using a vapor compression heat pump system developed for R410A.

2. EXPERIMENTAL APPARATUS AND METHOD

Figure 1 shows the schematic view of an experimental apparatus, which was used for the drop-in experiments on the cycle performance of a domestic heat pump system. The experimental apparatus consists of a refrigerant loop and a heat sink water loop and a heat source water loop. The refrigerant loop is mainly composed of an inverter controlled hermetic type compressor (1) which was developed for commercial R410A systems, an oil separator (2), a double-tube type condenser (3), an electric expansion valve (4) and a double-tube type evaporator (5). Using constant-temperature baths (6) and (7), the heat sink water and the heat source water are supplied to the condenser and the evaporator, respectively. Mixing chambers to measure refrigerant pressure and temperature are installed between components in the refrigerant loop. Mixing chambers are also installed in heat sink and heat source water loops to measure water temperatures at the inlet and outlet of the condenser and the evaporator. The specifications of the condenser and the evaporator are listed in Table 1. In the condenser and the evaporator, the refrigerant flows inside the inner tube, while heat sink/heat source water flows in the annulus surrounding the inner tube.

In the experiment, the heat pump system is operated to achieve specified experimental condition by adjusting the compressor frequency and the pulse of the electric expansion valve. Physical quantities measured directly are as follows:

(1) Electric power inputs to the inverter and the compressor,
(2) Refrigerant temperature and pressure in every mixing chambers and refrigerant temperature at the discharge port of the compressor,
(3) Mass flow rate of refrigerant and volumetric flow rates of heat sink water and heat source water,
(4) Temperatures of heat sink water and heat source water at the inlet and outlet of condenser and evaporator.

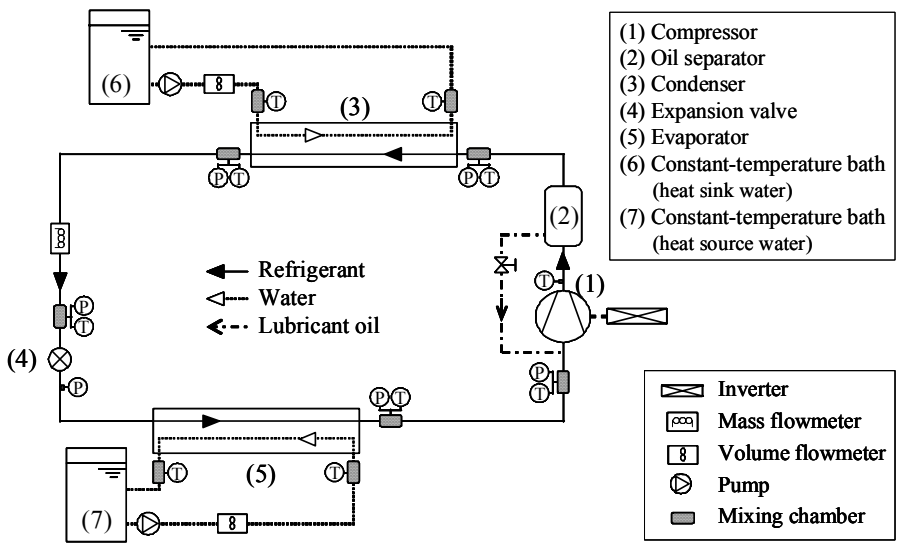


Figure 1: Schematic view of experimental rig for drop-in test

Table 1: Specifications of double-tube type heat exchangers

		OD (mm)	ID (mm)	Length (mm)	Type of tube
Evaporator	Outer tube	12.7	11.1	5000	smooth tube
	Inner tube	9.52	7.92	5000	smooth tube
Condenser	Outer tube	12.7	11.1	5000	smooth tube
	Inner tube	9.52	7.92	5000	smooth tube

Table 2: Experimental conditions at heating mode

Refrigerants		R410A	HFO-1234ze(E)/HFC-32	
			100 mass% HFO	50 mass% HFO
Capacity [kW]		2.8	from 1.0 to 2.2	from 1.9to 2.8
Superheat at evaporator outlet [K]		3		
Heat sink water for condenser	Inlet temp. [℃]	20		
	Outlet temp. [℃]	45		
Heat source water for evaporator	Inlet temp. [℃]	15		
	Outlet temp. [℃]	9		

Heat transfer rates of the condenser and the evaporator are calculated from the water-side energy balance equations using the measured volumetric flow rate and temperatures of heat sink water and heat source water. Then, the coefficient of performance (COP) at heating mode is obtained from the electric power input to the inverter and the heat transfer rate of the condenser.

Table 2 shows the experimental conditions at heating mode. Refrigerants tested in the present drop-in experiments are R410A, pure HFO-1234ze(E) and a mixture of 50mass% HFO-1234ze(E)/50mass%HFC-32. The conditions of superheat at evaporator outlet, heat sink water and heat source water are fixed for all experiments. The heating capacity is fixed at 2.8 kW in the experiment of R410A, while it changes in a relatively narrower range for the experiments of pure HFO-1234ze(E) and the HFO-1234ze(E)/HFC-32 mixture.

3. RESULTS AND DISCUSSION

Figure 2 shows the experimental results of R410A at heating mode at 2.8 kW, where the ordinates in Figs. (a), (b), (c) and (d) express COP, degree of sub-cooling at condenser outlet, refrigerant flow rate and discharge-suction

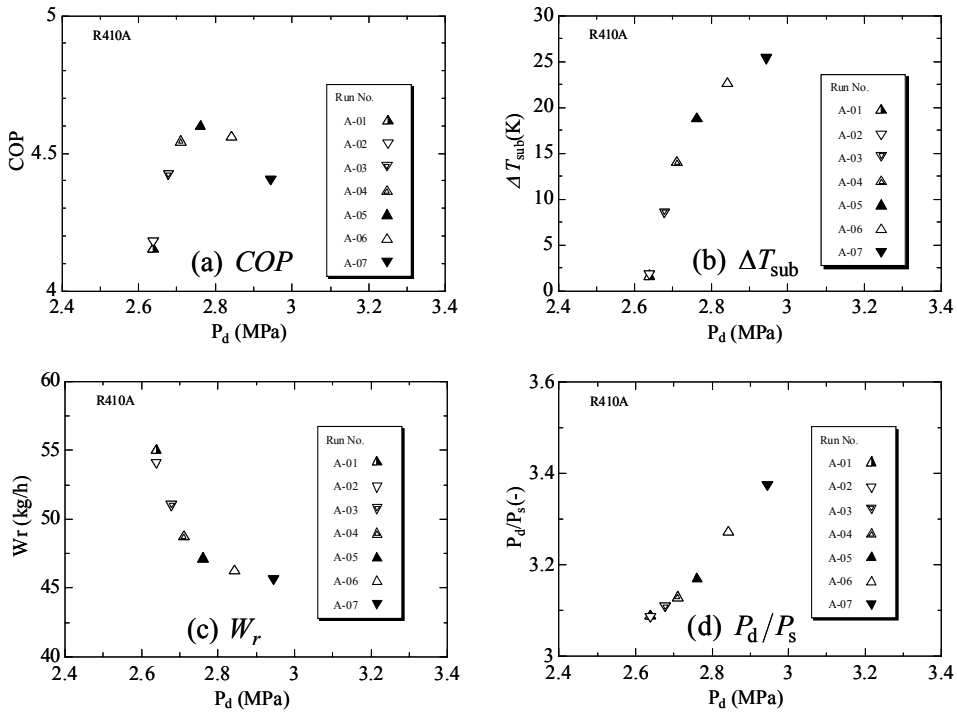


Figure 2: Experimental results of R410A at heating mode

pressure ratio, respectively, while the abscissa in all figures represents the discharge pressure, the difference of which corresponds to different refrigerant amount charged in the experimental rig; the difference of refrigerant charge amount is distinguished by experimental run number. The value of COP has a maximum at a certain discharge pressure and the degree of sub-cooling increases with increase of discharge pressure. The refrigerant flow rate decreases with the increase of discharge pressure due to the increase of refrigeration effect which is caused by the increase in degree of sub-cooling at condenser outlet. The discharge-suction pressure ratio increases because of the increase of refrigerant charge amount.

Figure 3 shows the experimental results of pure HFO-1234ze(E) at heating mode, where the ordinates in Figs. (a), (b), (c) and (d) are the same as in Fig. 2, while the abscissa in all figures represents the heat transfer rate of condenser (heating capacity). Number of experimental runs is also used to distinguish the refrigerant charge amount. In some experimental runs, the value of COP increases with increase of heat transfer rate and then decreases, while other experimental runs it decreases with increase of heat transfer rate. On the other hand, the degree of sub-cooling, the refrigerant flow rate and the discharge-suction pressure ratio increase with increase of heat transfer rate in all experimental runs. It is noted that the COP value has a maximum at a certain refrigerant charge amount. It was also found through the present drop-in experiments that the heating capacity of HFO-1234ze(E) was considerably lower than that of R410A.

Figure 4 shows the experimental results of the mixture of 50 mass% HFO-1234ze(E)/50 mass% HFC-32 at heating mode, where the ordinates and the abscissa in Figs. (a), (b), (c) and (d) are the same as in Figs. 3(a), (b), (c) and (d); number of experimental runs is also used to distinguish the refrigerant charge amount. The COP value of this mixture has a maximum in each experimental run, but it is insensitive to the heat transfer rate not like in case of pure HFO-1234ze(E). In each experimental run, the degree of sub-cooling increases moderately with the increase of heat transfer rate, while the refrigerant flow rate and the discharge-suction pressure ratio increase with the increase of heat transfer rate. It was found that the heat transfer rate of this mixture could be easily increased by increasing the revolution of compressor as in the case of R410A.

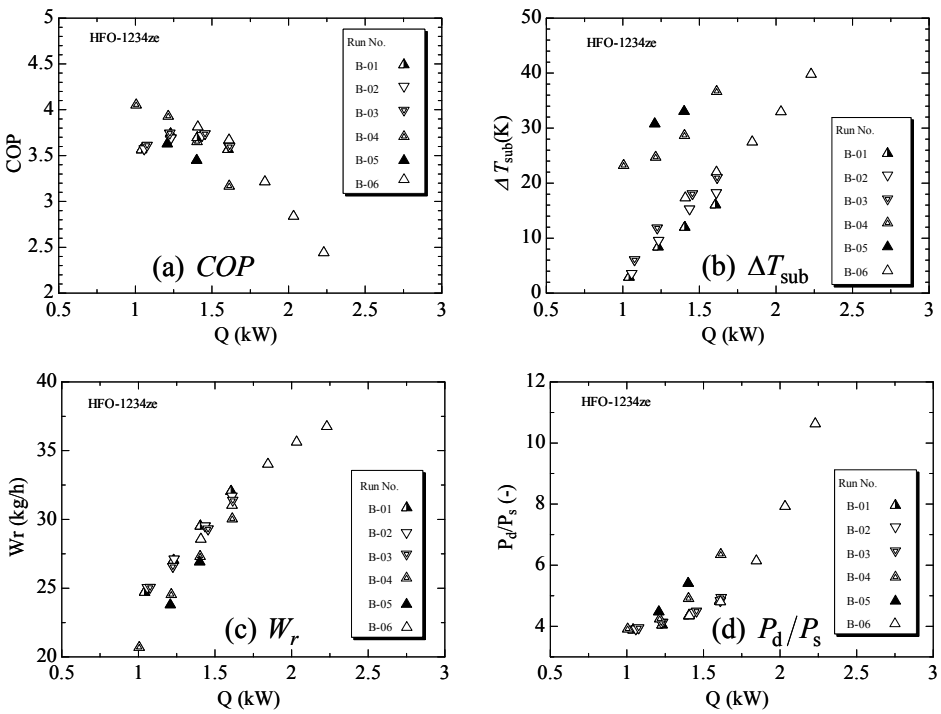


Figure 3: Experimental results of pure HFO-1234ze(E) at heating mode

Figure 5 shows the relation between COP and sub-cooling at condenser outlet, where symbols of closed circle, closed square and closed triangle represent the results of R410A at 2.8 kW, 50mass%HFO1234ze(E)/50mass% HFC-32 mixture at 2.8 kW and pure HFO-1234ze(E) at 1.6 kW, respectively. It has found that in case of the mixture of 50mass%HFO-1234ze(E) the COP value is slightly affected by the degree of sub-cooling at the condenser outlet and it is only about 7.5% lower than that of R410A at the same heating load of 2.8 kW. This reveals that mixtures of HFO-1234ze(E)/HFC-32 are considered to be applicable as the low-GWP alternatives for R410A by adjusting the composition of the mixture and by reconsidering the design parameters of components of room air-conditioning system. On the other hand, in case of pure HFO-1234ze(E) at 1.6 kW the COP value is 20% lower than that of R410A at 2.8 kW. This means that the heating effect of pure HFO-1234ze(E) is considerably lower than that of

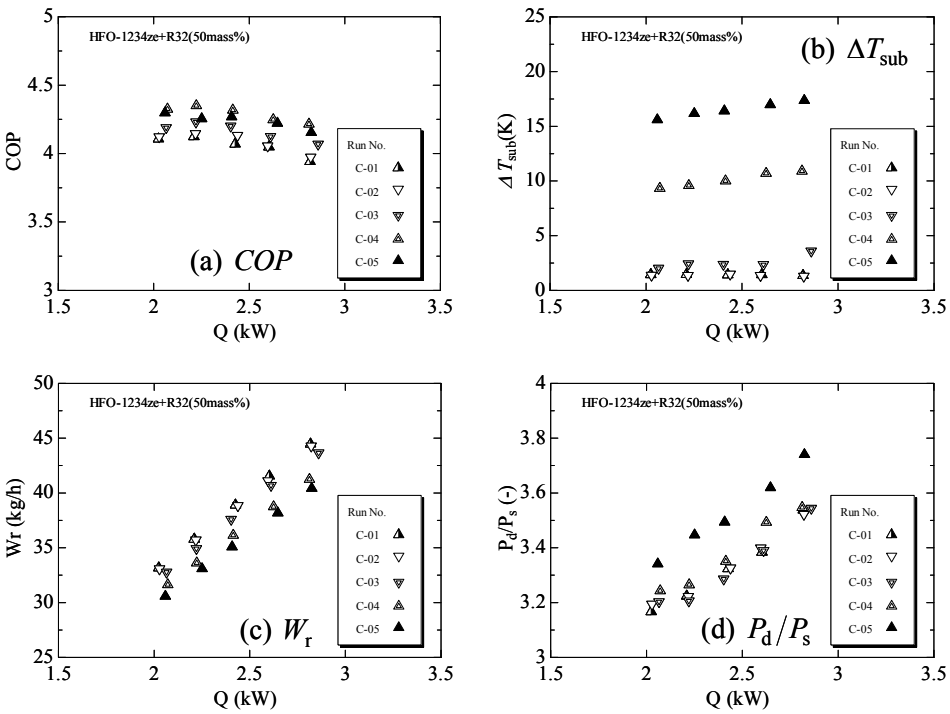


Figure 4: Experimental results of HFO-1234ze(E)/HFC-32 mixture at heating mode

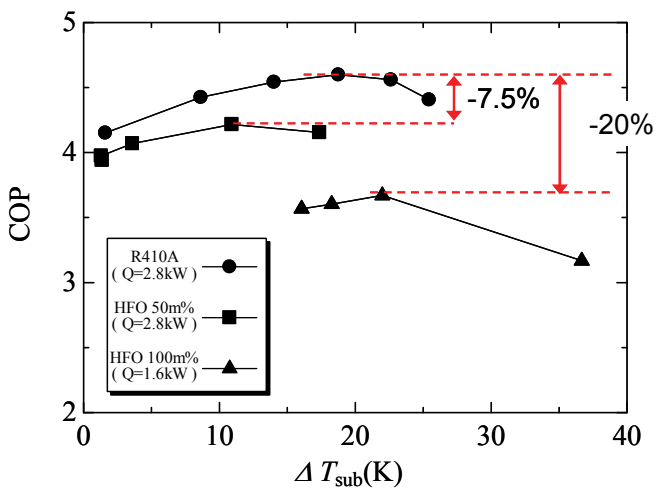
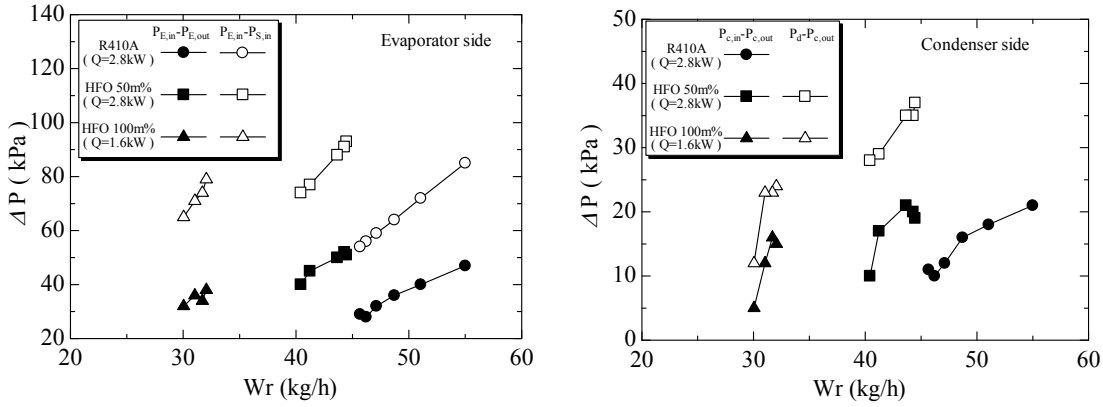


Figure 5: Relation between *COP* and degree of subcooling



(a) Evaporator side (b) Condenser side

Figure 6: Relation between pressure drop in heat exchangers and refrigerant flow rate

R410A. However, the present drop-in experiments proves that the heating effect and COP of HFO-1234ze(E) can be improved by adding HFC-32 as the second component into HFO-1234ze(E).

Figure 6 shows the relation between pressure drop in heat exchanger and refrigerant flow rate, where symbols of cycle, square and triangle represent the results of R410A at 2.8 kW, 50 mass%HFO1234ze(E)/50 mass% HFC-32 mixture at 2.8 kW and pure HFO-1234ze(E) at 1.6 kW, respectively. In Figure 6(a), open and closed symbols correspond to the pressure difference between evaporator and compressor inlets and the pressure difference in evaporator, respectively, while in Figure 6(b), open and closed symbols correspond to the pressure difference between compressor and condenser outlets and the pressure difference in condenser, respectively. In Figure 6(a), the pressure drops in evaporator side of HFO-1234ze(E) and its mixture with HFC-32 are almost at the same level as that of R410A though the refrigerant flow rate of HFO-1234ze(E) based refrigerants is lower than that of R410A. Similar characteristics of pressure drop are also observed in the condenser side. In Figure 6(b), the pressure drop in condenser side shows the same trend as in evaporator side. It is implied from the pressure drop characteristics that the diameter of heat transfer tubes and connecting tubes should be enlarged compared with the case of R410A in order to improve the performance.

4. CONCLUSIONS

In the present study, drop-in experiments were carried out in order to investigate the possibility to introduce HFO-1234ze(E) and its mixture with HFC-32 as low-GWP alternatives for vapor compression heat pump/refrigeration systems. The results obtained are as follows:

(1) In case of the mixture of 50mass%HFO-1234ze(E) the COP value is slightly affected by the degree of sub-cooling at the condenser outlet and it is only about 7.5% lower than that of R410A at the same heating load of 2.8 kW. On the other hand, in case of pure HFO-1234ze(E) at 1.6 kW the COP value is 20% lower than that of R410A at 2.8 kW. These results proves that the heating effect and COP of HFO-1234ze(E) can be improved by adding HFC-32 as the second component into HFO-1234ze(E).

(2) The pressure drops in both evaporator and condenser sides of HFO-1234ze(E) and its mixture with HFC-32 are almost at the same level as that of R410A though the refrigerant flow rates of HFO-1234ze(E) and its mixture with HFC-32 are lower than that of R410A. This result suggests that the diameter of heat transfer tubes and connecting tubes should be enlarged as compared with the case of R410A.

(3) At the present stage, it seems that mixtures of HFO-1234ze(E) and HFC-32 are strong candidates for replacing HFC-410A in domestic heat pump system.

NOMENCLATURE

COP	coefficient of performance	(-)	P_d	discharge pressure	(Pa)

P_s	suction pressure	(Pa)	Q	heat capacity (heat transfer rate)	(kW)
ΔT_{sub}	degree of sub-cooling at condenser outlet	(K)			

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