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Experimental study on evaporator performance in mobile air conditioning system using HFO-1234yf as working fluid

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HIGHLIGHTS

► The experimental results of HFO-1234yf in variable evaporators is compared with R134a.
► Cooling capacity of laminated plate evaporator is reduced for HFO-1234yf up to 8.0%.
► In microchannel PF evaporator, cooling capacity is comparable and/or larger than that of R134a up to 6.5%.
► The refrigerant side pressure drop in both evaporators of HFO-1234yf is higher than that in R134a evaporators.
► Air side pressure for both evaporators and refrigerants are mostly the same.

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ABSTRACT

The widely used evaporators with two different type were experimentally studied in psychrometric calorimeter room using HFO-1234yf as working fluids. The evaporators types are laminated plate and microchannel parallel flow (PF) type. The experimental results compared with R134a system show that cooling capacity has different features in laminated plate evaporator and microchannel PF evaporator under different refrigerant pressure at expansion valve inlet. In general, cooling capacity of laminated plate evaporator of HFO-1234yf is reduced up to 8.0%. But in microchannel PF evaporator, cooling capacity is comparable and/or larger than that of R134a up to 6.5%. The HFO-1234yf evaporator air off temperature deviation is larger than that of R134a evaporator. The air side pressure drop is very close for both evaporators and refrigerants. HFO-1234yf refrigerant side pressure drop is larger than that of R134a for both evaporators.

1. Introduction

To find R134a alternative refrigerant is a crucial issue for mobile industry. Currently, HFO-1234yf is becoming more acceptable by the industry and the international society. Tanaka and Higashi [1] published the thermodynamic properties data of HFO-1234yf at saturated conditions and the results indicated that almost the thermodynamic properties of HFO-1234yf are lower than that of R134a but they are very close. Fig. 1 and Table 1 show the saturated vapor pressure comparison and saturated thermophysical and transportation properties of R134a and HFO-1234yf at 5 °C [2], respectively. The theoretical Life Cycle Climate Performance (LCCP) analysis of HFO-1234yf refrigeration system showed that this refrigerant can reduce CO_2 emission significantly compared to R134a system [3]. Park et al. [4] experimentally studied the condensation heat transfer features in plain, low fin and Turbo-C tubes. The test data showed that the condensation heat transfer coefficients of HFO-1234yf are very similar to those of R134a for all the different surface tubes. The boiling heat transfer and flow friction characteristics of HFO-1234yf in smooth small diameter tubes were experimental studied by Saitoh et al. [5]. The heat transfer coefficients of HFO-1234yf were almost the same with that of R134a and some empirical correlations on heat transfer and pressure drop can be used for HFO-1234yf. The authors also pointed out that heat flux and mass flux play different roles during boiling heat transfer process. In horizontal minichannel tubes, HFO-1234yf presents a higher heat transfer coefficients than R134a when refrigerant mass flux is lower than 100 kg/m^2-s [6]. The previous correlations were not adapted and a new correlation was proposed based on these data. These results will help the engineers

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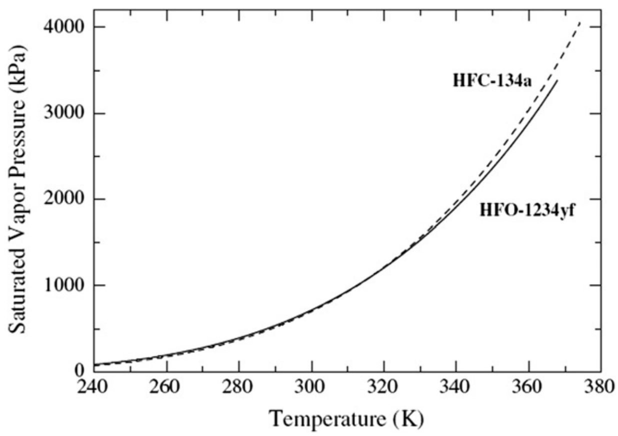

Fig. 1. R134a and HFO-1234yf saturated vapor pressure [1].

to design an available condenser and evaporator according to HFO-1234yf thermophysical properties.

In HFO-1234yf application researches, Mathur [7] experimentally investigated the mobile air conditioning (MAC) system performance with HFO-1234yf as the working fluid. The system cooling capacity and COP were measured and compared with R134a system. The test results implied that the HFO-1234yf system can reduce the optimum refrigerant charge to 90% of the R134a system. Although the HFO-1234yf operation pressure is a little higher, it can improve system efficiency. The author's experimental results showed that system cooling capacity and COP is higher than the base R134a system at 35 and 45 °C ambient air temperature. Jarall [8] theoretically and experimentally compared the cycle performance of HFO-1234yf with that of R134a using drop-in replacement. The theoretical study showed that superheating and subcooling temperature play more important roles than that of R134a system. The drop-in replacement experiments indicated that performance of HFO-1234yf system was less than that of R134a system in cooling capacity, COP and compressor efficient. Seybold et al. [9] proposed some internal heat exchanger (IHX) design criteria in HFO-1234yf system and the experimental data showed that tube length, efficiency and tube internal structure influence IHX performance. Mathur [10] did a thorough experiment on parallel flow condenser using HFO-1234yf and R134a. The test data demonstrated that the condenser operation pressure is a little lower than that of R134a as well as saturated temperature, but the refrigerant mass flow rate is much higher under same cooling capacity condition. The author also showed the ratio of desuperheating, two phase condensation and subcooling area according to tube side temperature measurements.

Table 1
Saturated thermophysical and transportant properties of R134a and HFO-1234yf at 5 °C.

Refrigerant	R134a	R1234yf
Saturated pressure (kPa)	349.66	372.92
Liquid density (kg/m^3)	1278.1	1160.4
Vapor density (kg/m^3)	17.131	20.744
Liquid enthalpy (kJ/kg)	206.75	206.5
Vapor enthalpy (kJ/kg)	401.49	366.52
Liquid Cp (kJ/kg-K)	1.3552	1.308
Vapor Cp (kJ/kg-K)	0.92059	0.94835
Liquid therm. cond. (W/m-K)	89.806×10^{-3}	73.422×10^{-3}
Vapor therm. cond. (W/m-K)	11.954×10^{-3}	12.044×10^{-3}
Liquid viscosity (Pa-s)	250.11×10^{-6}	197.1×10^{-6}
Vapor viscosity (Pa-s)	10.911×10^{-6}	11.363×10^{-6}

In this paper, two kinds of widely used MAC evaporators (laminated plate and microchannel parallel flow (PF) type) will be experimentally studied in psychrometric calorimeter room using HFO-1234yf as working fluid. The cooling capacity, air and refrigerant side pressure drop and evaporator air off temperature will be compared with that of R134a evaporator.

2. Experiments preparation

2.1. Evaporators

Fig. 2 shows the schematic diagram of laminated plate and microchannel PF evaporators. The laminated plate evaporator is composed of corrugated louver fins, U-type plates (as shown in Fig. 2(a)) and/or internal fins to enhance refrigerant side heat transfer. The refrigerant passes is formed by internal baffles. The microchannel PF evaporator is composed of corrugated louver fins and microchannel tubes (as shown in Fig. 2(b)). There are two rows of parallel flow microchannel tubes with inlet and outlet headers. The detailed dimensions are listed in Table 2. In the present study, two samples for each type are selected.

2.2. Test rig

The schematic diagram of psychrometric calorimeter test facility is shown in Fig. 3. In this test rig, MAC system operation conditions can be simulated. For example, the vehicle speed, ambient temperature, relative humidity can be adjusted according to test standards. The MAC system performance and component performance can be tested. The tested evaporator samples are installed in a special wind tunnel in which air temperature and humidity can be controlled. Air side pressure drop is measured by a differential pressure transducer and air volume flow rate is measured and calculated by nozzles. The refrigerant side pressure, temperature and mass flow rate can be controlled by a compressor which is driven by a variable speed electrical motor.

In order to figure out the internal refrigerant distribution for each type evaporator using HFO-1234yf and R134a, a thermocouple matrix is installed at exit of evaporator as shown in Fig. 4 to measure the evaporator air off temperature distribution. There are 30 thermocouples in this matrix and the assembly distance away from the evaporator air off direction is about 10 mm. The arrow in Fig. 4 shows the refrigerant inlet direction in evaporator.

During this experiment, the temperature of air and refrigerant and the pressure of refrigerant side are recorded in the data acquisition system by platinum resistance temperature sensor (YAMARI, Model: JPT100) and silicon piezoresistive type pressure transducers (OHKURA, Model: PT3011AZZZ1FZ) respectively. The refrigerant mass flow is measured by a mass flow meter (OVAL, Model: D025S-SS-200) assembled in liquid pipe. The precision and uncertainties of the measured parameters is shown in Table 3 based on Moffat's proposal [11]. During the test period, the total energy balance between air side and refrigerant side is about 3%. Table 4 shows the test conditions in this study including different inlet air temperature and relative humidity, volume flow rate and refrigerant side parameters. The evaporators were tested using R134a as working fluid firstly. Before HFO-1234yf is charged into test rig, R134a refrigerant in the previous tests should be recycled and then the tested samples, system components, connection tubes should be cleaned by special equipments (the connection tubes with compressor will be disconnected and pressurized nitrogen will piped into system to