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Vapor–liquid equilibria of fluoroethane (HFC-161) + 2,3,3,3-tetrafluoroprop-1-ene (HFO-1234yf)

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ABSTRACT

In this study, isothermal vapor–liquid equilibrium (VLE) data were measured for the binary system of fluoroethane (HFC-161) + 2,3,3,3-tetrafluoroprop-1-ene (HFO-1234yf) over the whole composition range in the temperature range from 283.15 to 323.15 K at 10 K intervals. The experimental VLE data were correlated with the Peng–Robinson equation of state. The van der Waals (vdW) one-fluid mixing rule and the Wong–Sandler (WS) mixing rule with the non-random two-liquid (NRTL) activity coefficient model were both used. The correlation results show good agreement with the experimental data.

1. Introduction

Hydrofluorocarbons (HFCs) have been widely used as alternative refrigerants because of their zero ODP (ozone depletion potential). However, the most of HFCs including HFC-134a, HFC-143a, HFC-125 still have GWP (global warming potential) higher than 150 and will be banned according to the European Union's

F-Gas Regulations [1,2]. HFO-1234yf, jointly developed by Honeywell and DuPont, has a very low GWP of about 4, zero ODP, and a very short atmospheric lifetime of 0.03 years [3]. Some important thermophysical properties of HFO-1234yf have been experimentally measured [4–10], and its equations of state also have been developed [11,12]. Because of its vapor pressure and other properties similar to those of HFC-134a, HFO-1234yf has been proposed as the most promising replacement for HFC-134a in refrigeration and air conditioning applications. However, the latent heat of HFO-1234yf is small, that causes a large mass flow rate and a large pressure drop, and leads to a decrease in COP. To overcome this drawback, several binary systems containing HFO-1234yf have been proposed and their properties were experimentally measured [13–21]. HFC-161 has a lager latent heat, a very low GWP of 12, zero ODP, and a short atmospheric lifetime of 0.18 years [22]. It has been adopted as a component in some mixtures for refrigeration applications [23]. Thus, the mixture refrigerant HFC-161 + HFO-1234yf can be a promising alternative refrigerant with environmentally friendly properties. In this study, the vapor–liquid equilibrium data for the binary system of HFC-161 (1) + HFO-1234yf (2) were measured over the whole composition range in the temperature range from 283.15 to 323.15 K at 10 K intervals, and correlated with the Peng–Robinson (PR) equation of state.

2. Experimental

2.1. Chemicals

The purities and suppliers of HFC-161 and HFO-1234yf are summarized in Table 1. All samples were used without any further purification.

2.2. Apparatus

The VLE data of HFC-161 (1) + HFO-1234yf (2) were measured by a recirculation apparatus, which has been introduced in previous work [18–21]. As shown in Fig. 1, the apparatus consists of an equilibrium cell, a thermostatic liquid bath, a thermostatic air bath, a sampling system, and measurement instruments. To improve the stability of VLE measurement, the sampling loops outside the liquid bath were guarded by the thermostatic air bath, which is operated at the same temperature of the liquid bath. The pressure was measured by means of a TS109 pressure transducer (Kunshan Danrui Sensor Measurement & Control Technology Co.,

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Table 1
Suppliers and purities of the chemicals.

Component	Supplier	Purity/mass (%)
HFC-161	Miragas, China	99.9
HFO-1234yf	Honeywell, USA	99.9

Table 2
Critical properties and acentric factors of pure components [25].

Component	T_C (K)	P_C (kPa)	ω
HFC-161	375.3	5091	0.217
HFO-1234yf	367.85	3382.2	0.276

Ltd.) with an uncertainty of 0.5 kPa (0.025% of full scale 2 MPa, calibrated by the manufacture). The temperature was measured by a 25 Ω platinum resistance thermometer (Model WZPB-1, Kunming Temperature Instruments Ltd., China). The total temperature measurement uncertainty was estimated to be within 5 mK. A gas chromatograph (GC112A, Shanghai Precision and Scientific Instrument Ltd., China) was used for measurements of the mole fraction. It was equipped with a flame ionization detector (FID) and a SM-6 packed column (Shinwa Chem., 60/70 mesh, 6 m long, 3 mm inner diameter). The gas chromatograph was calibrated with mixtures of known mole fractions that were prepared gravimetrically using an electronic balance (JA5003, 1 mg/500 g, Shanghai Hengping, China). The total uncertainty of the mole fraction measurements was estimated to be within 0.003 for the HFC-161 (1) + HFO-1234yf (2) mixture.

Table 3
Vapor pressures for pure components.[a]

Component	T (K)	P_{exp} (kPa)	P_{ref} (kPa) [25]	ΔP (kPa)[b]	δP (%)[c]
HFC-161	283.15	601.2	600.6	0.6	0.10
	293.15	805.6	805.6	0.0	0.00
	303.15	1058.8	1058.6	0.2	0.02
	313.15	1365.8	1366.2	-0.4	-0.03
	323.15	1735.2	1735.7	-0.5	-0.03
HFO-1234yf	283.15	437.9	437.5	0.4	0.09
	293.15	591.5	591.7	-0.2	-0.03
	303.15	782.9	783.5	-0.6	-0.08
	313.15	1018.2	1018.4	-0.2	-0.02
	323.15	1302.4	1302.3	0.1	0.01

[a] $u(T) = 0.005$ K, $u(P) = 0.5$ kPa.
[b] $\Delta P = P_{exp} - P_{ref}$.
[c] $\delta P\% = 100 \times (\Delta P/P_{exp})$.

2.3. Measurement procedure

The equilibrium cell and pipes were evacuated by a vacuum pump, a small amount of pure HFO-1234yf was introduced into the cell and then evacuated. This procedure was repeated 3 times to remove residual gases. After that, an appropriate amount of HFO-1234yf was introduced into the cell, and then HFC-161 was filled in. A magnetic pump was used to circulate the vapor from the top of the cell through a four-way valve to the bottom of the cell. To ensure that equilibrium has been achieved, the temperature remained constant for more than an hour when it reached the desired value. Then the pressure was measured. The six-port valve 1 was switched to take the vapor sample into the loops, which connected to the gas chromatograph through the six-port valve 3. After that the six-port valve 3 was switched to inject the vapor sample into the gas chromatograph for the measurement of vapor mole fraction. To avoid the carrier gas polluting the refrigerants in the cell, the loops between six-port valve 1 and six-port valve 3 was evacuated to 3×10^{-4} Pa before the six-port valve 1 was rotated back. Then the four-port valve was switched over to change the vapor phase circulation into liquid phase circulation, and the liquid sample was taken into the gas chromatograph through six-port valve 2 and valve 3 for the measurement of liquid mole fraction. The mole fractions were measured at least four times, and the average values were considered as the results.

3. VLE correlations

The PR equation of state [24] was adopted in this work to correlate VLE data for HFC-161(1) + HFO-1234yf (2) system. The critical properties and the acentric factors of HFC-161 and HFO-1234yf are tabulated in Table 2 [25].

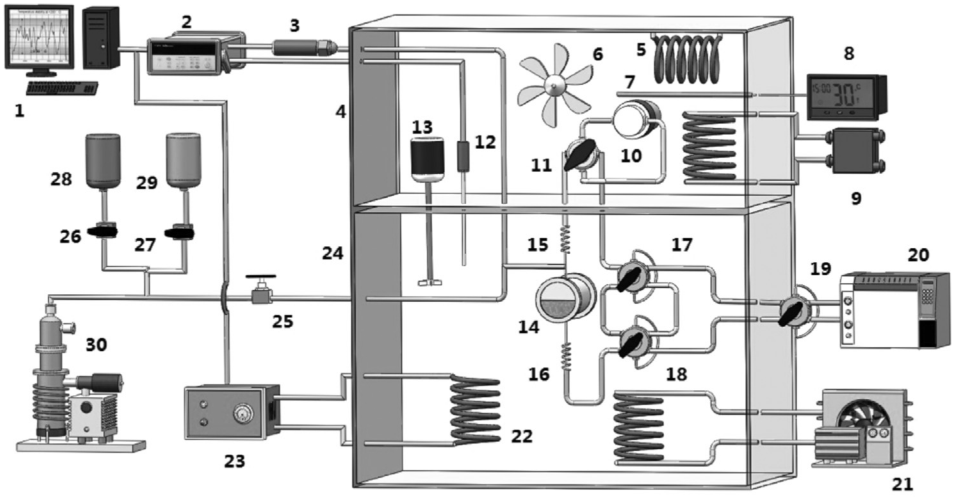

Fig. 1. Schematic diagram of the VLE experimental system. (1) Computer (2) data acquisition instrument (3) pressure transducer (4) air thermostatic bath (5) heater A (6) fan (7) temperature sensor (8) digital temperature controller (9) semiconductor chiller (10) magnetic pump (11) four-port valve (12) platinum resistance thermometer (13) stirrer (14) equilibrium cell (15) liquid-phase heat exchanger (16) vapor-phase heat exchanger (17) six-port valve 1 (18) six-port valve 2 (19) six-port valve 3 (20) gas chromatograph (21) refrigeration system (22) heater B (23) temperature controller (24) liquid thermostatic bath (25)–(27) valves (28) sample cylinder A (29) sample cylinder B (30) vacuum pump.