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Saturated liquid density and pressure measurements for HFC134a + HC290 by a compact single-sinker densimeter

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ABSTRACT

Saturated liquid densities and bubble point pressures for binary mixtures of 1,1,1,2-tetrafluoroethane (HFC134a) + propane (HC290) were measured using a compact single-sinker densimeter. The temperature range was from 253 to 293 K and mole fractions of HFC134a were 0.105, 0.197, 0.331, 0.387, 0.536 and 0.557. The standard uncertainties were estimated to be less than 5 mK for temperature, 1 kPa for pressure, 0.003 for mole fraction, and 0.02% for density. The experimental results were reproduced by VNDS equation and our modified Rackett equation. The saturated pressures data were correlated by the PR-Soave-vdW equation. Good agreement between values of calculation and experiment were found.

Mesure de la densité et de la pression du liquide saturé pour les mélanges FC134a/HC290 à l’aide d’un densimètre compact à simple contrepoids

Mots clés : HFC134a + HC290 ; Densité de liquide saturé ; Pression de saturation ; Équation d’état

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Nomenclature

Abbreviations

AARD	average absolute relative deviation
ARB	automatic resistance bridge
CFCs	chlorofluorocarbons
HCs	hydrocarbons
HC290	propane
HCFCs	hydrochlorofluorocarbons
HFCs	hydrofluorocarbons
HFC134a	1,1,1,2-tetrafluoroethane
MARD	maximum absolute relative deviation
MFDT	Mole fraction fluctuation at different temperature
O.F	objective function
PR	Peng-Robinson
TFDM	Temperature fluctuation during measurement
vdW	van der Waals
VLE	vapor-liquid equilibrium

Symbols

N	total number of the experimental data of the binary mixtures
p	experimental pressure [MPa]
R	universal gas constant [8.3144598 $J\cdot mol^{-1}\cdot K^{-1}$]
T	experimental temperature [K]
$T_{c,i}$	critical temperature of component i [K]
v	molar volume [$cm^3\cdot mol^{-1}$]
x	liquid mole fraction

Greek letters

ρ	density [$kg\cdot m^{-3}$]
τ	inverse reduced temperature

Subscripts

c	critical characteristic
cal	calculated data
exp	experimental data
i	component index

1. Introduction

Traditional refrigerants, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), have already been or will be phased out because of the ozone depletion or the greenhouse effect. The mixtures of hydrofluorocarbons (HFCs) and hydrocarbons (HCs), especially those with azeotropic characteristics, are considered as promising alternatives. The flammability of HCs will be reduced or eliminated by adding HFCs, while the lubricants suitability of HFCs can be improved by adding HCs (Xu et al., 2004). The mixtures of HFC134a and HC290 are azeotropic and considered as promising alternatives for HCFC22 (Jung et al., 2000).

The reliable thermodynamic properties of HFC134a and HC290 are very important for evaluating its performance in the refrigeration cycle. The vapor-liquid equilibrium (VLE) and pressure-density-temperature-composition (p-ρ-T-x) are essential thermodynamic properties. Many papers about the VLE experimental data of HFC134a and HC290 mixtures have been published, such as Kleiber (1994), Stryjek et al. (1998), Lim et al. (2006) and Dong et al. (2011). The gaseous p-ρ-T-x experimental data have been published in literature (Naganuma et al., 2001; Qi et al., 2014; Zhang et al., 2015). However, the saturated liquid densities for HFC134a + HC290 binary mixture are still absent in the open literature.

In this work, the saturated liquid p-ρ-T-x experimental data for HFC134a + HC290 has been presented. The measurements were performed by a compact single-sinker densimeter. The temperature range was from 253 to 293 K, and mole fractions of HFC134a were 0.105, 0.197, 0.331, 0.387, 0.536 and 0.557. The experimental densities were correlated by VNDS equation (Frenkel et al., 2017) and our modified Rackett equation (Gong et al., 2016). The saturated pressure data were correlated by the PR-Soave-vdW equation.

2. Experimental

2.1. Chemicals

The HFC134a and HC290 samples used in this work were supplied by ZHEJIANG JUHUA Co., Ltd and Beijing AP BAIF Gases Industry Co., Ltd, respectively. The declared mass fraction purity for HFC134a is 0.9999 and mole fraction purity for HC290 is 0.999. The two samples were used without further purification. The detailed information is shown in Table 1.

2.2. Apparatus

The experiment of the thermophysical properties p-ρ-T-x was performed on a compact single-sinker densimeter. It is based on the well-known Archimedes' buoyancy principle. The apparatus, experimental procedures and calculation of uncertainties have been described in our previous work (Li et al., 2014; Zhang et al., 2016a). The densimeter covers a density range of 0 to 2000 $kg\cdot m^{-3}$, temperature range of 210 to 300 K and pressure range up to 6.0 MPa. The gaseous p-ρ-T-x measurements of HFC134a + HC290 (Zhang et al., 2015), HFO1234ze(E) + HC290 (Zhang et al., 2016b), HFO1234ze(E) + HFC134a (Zhang et al., 2016c), R1234yf + R290 (Zhong et al., 2017), and the saturated liquid p-ρ-T-x measurements of HFO1234ze(E) (Gong et al., 2016), HFO1234ze(E) + HC290 (Zhang et al., 2016a) were proceeded by this apparatus. The apparatus is only briefly described here.

The schematic drawing of the apparatus is shown in Fig. 1. It mainly consists of the following five parts: magnetic suspension balance, thermostat system, (temperature, pressure and composition) measuring systems, sample filling system, vacuum and auxiliary systems. The apparatus is based on the well-known Archimedes' buoyancy principle:

$$\rho_{fluid} = \frac{m_s - W}{V_s(T, p)} \quad (1)$$