Surface Tension of Propane (R-290) + 1,1-Difluoroethane (R-152a) from (248 to 328) K

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The surface tension of binary mixture refrigerants propane (R-290) (1) + 1,1-difluoroethane (R-152a) (2) at three mass fractions of $w_1 = 0.2008$, 0.3497, and 0.4922 was measured at temperatures from (248 to 328) K with a differential capillary rise method. The uncertainties of measurements for the temperature and surface tension were estimated to be within ± 10 mK and ± 0.2 $\mathrm{mN \cdot m^{-1}}$, respectively. A correlation for the binary mixture refrigerant R-290 + R-152a was developed as a function of mass fraction.

Introduction

Under the burden of the ozone layer depletion and global warming, developing an environment friendly refrigerant has been a worldwide issue. Hydrocarbon (HC) refrigerants have been accepted as one of the promising alternative refrigerants or mixture composition because of their low global warming potential (GWP) and excellent refrigeration performance. Propane (R-290) and its mixtures with HC and hydrofluorocarbon (HFC) refrigerants have been widely investigated to substitute R-22.[1−4] Recently, a R-290 + R-152a mixture was used in residential air conditioners,[5] and the experimental results showed that R-290 + R-152a can be used as a drop-in substitute to R-22 with a high coefficient of performance and low refrigerant charge. Surface tension as a basic thermophysical property, influencing the heat transfer, flow, and phase-change characteristic of the working fluid, is useful for condenser and evaporator design in a refrigerator. Unfortunately, there are no surface tension data of a mixture of refrigerants R-290 + R-152a in the literature.

In this work, the surface tension of R-290 (1) + R-152a (2) was measured systematically at three mass fractions in the temperature range from (248 to 328) K. The experimental data of surface tension were correlated as a function of mass fraction.

Experiment

The surface tension was measured with a differential capillary rise method. The apparatus was described in detail in our previous work[6−8] and is briefly described here.

During the experiment, the capillary rise difference Δh_0 was measured, and the surface tension can be calculated using the following expression as

$$\sigma = \frac{(\Delta h_0 + r_1/3 - r_2/3)}{2(1/r_1 - 1/r_2)}(\rho_L - \rho_g)g = a^2(\rho_L - \rho_g)g \tag{1}$$

where σ is the surface tension, g is the local gravitational acceleration (in this work, $g = 9.7965\ \mathrm{m \cdot s^{-2}}$), and ρ_L and ρ_g are the densities of saturated liquid and vapor, respectively. Δh_0 is the height difference of the meniscus bottom of the two capillaries. r_1 and r_2 are the radii of the two different capillaries used in the experiments. a^2 is the capillary constant.

The bore radii of the two capillaries used in this work are $r_1 = (0.1490 \pm 0.0001)$ mm and $r_2 = (0.2340 \pm 0.0001)$ mm. Their radii were determined by partially filling the capillaries with plugs of mercury. The plugs were weighed, and their lengths were measured with a traveling microscope. The procedure was repeated at least six times for each capillary with different plugs of mercury.

The capillaries were placed in a small pressure cell with observation windows, and the pressure cell was placed in a thermostatic bath for which the temperature stability was within ± 10 mK in 2 h. Silicon oil was chosen as a thermostat fluid. The temperature measurement system consisted of an Agilent 3458A and two 25 Ω standard platinum resistance thermometers. One thermometer (no. 68033) is used in the temperature range (83.8058 to 273.16) K, and the other (no. 68115) is used in the temperature range (273.15 to 933.473) K. The thermometers were calibrated on the ITS-90 scale at the National Institute of Metrology of China. The total uncertainty of temperature for surface tension was less than ± 10 mK. The capillary rise difference was measured with a cathetometer with an uncertainty of ± 0.02 mm. In this work, all of the measurements were carried out under equilibrium conditions between the liquid and its saturated vapor, and the uncertainty of surface tension was estimated to be within ± 0.2 $\mathrm{mN \cdot m^{-1}}$.

Refrigerants R-290 and R-152a were provided by Jinlaier Company and Zibo Huaan Company. The purity was no less than 100 w (mass fraction) = 99.9. In this work, the refrigerants were first purified by freeze−pump−thaw cycles. The mixture was prepared by the following process. First, a known quality of R-152a with a lower saturation pressure was introduced into the cell by cooling the outside of the bulk with ice water. Second, R-290 with a higher saturation pressure was introduced into a cylinder and connected to the cell put in a thermostat. When the temperature of the thermostat was down to 253 K, R-290 was introduced to the cell by heating the cylinder with a hot-air generator for at least twenty minutes. The masses of refrigerants and cylinders were precisely measured by a balance (Shimadzu BW4200H) with a resolution of 0.01 g. Since the mass of the refrigerant was about 100 g, the uncertainty of the

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Table 1. Surface Tension of R-290

T K	ρ_l $kg\cdot m^{-3}$	ρ_g $kg\cdot m^{-3}$	σ $mN\cdot m^{-1}$	σ_{r1}[a] $mN\cdot m^{-1}$	σ_{r2}[b] $mN\cdot m^{-1}$	σ_{r3}[c] $mN\cdot m^{-1}$
283.16	514.7	13.79	8.8	8.8	8.9	8.9
288.17	507.5	15.82	8.1	8.2	8.3	8.2
293.13	500.1	18.07	7.6	7.6	7.6	7.6
298.10	492.4	20.59	6.9	7.0	7.0	7.0
303.12	484.4	23.43	6.3	6.4	6.4	6.4

[a] Surface tension values from refs 9, 10, and 11. [b] Surface tension values from refs 9, 10, and 11. [c] Surface tension values from refs 9, 10, and 11.

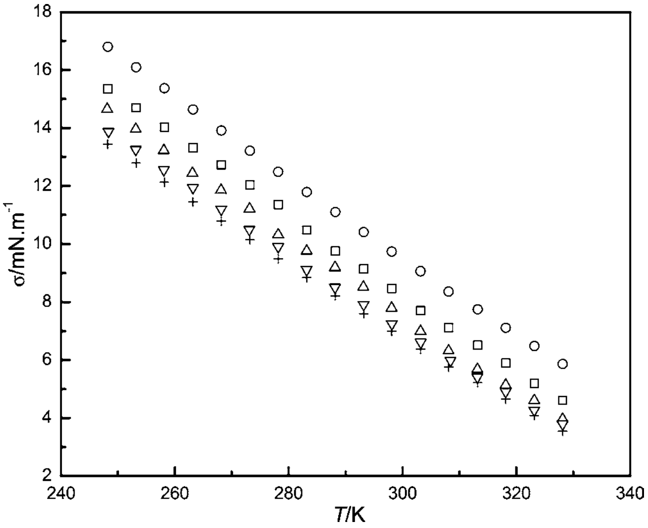

Figure 1. Experimental data of mixture refrigerant R-290 (1) + R-152a (2): ○, R-152a; +, R-290; □, $w_1 = 0.2008$; △, $w_1 = 0.3497$; ▽, $w_1 = 0.4922$.

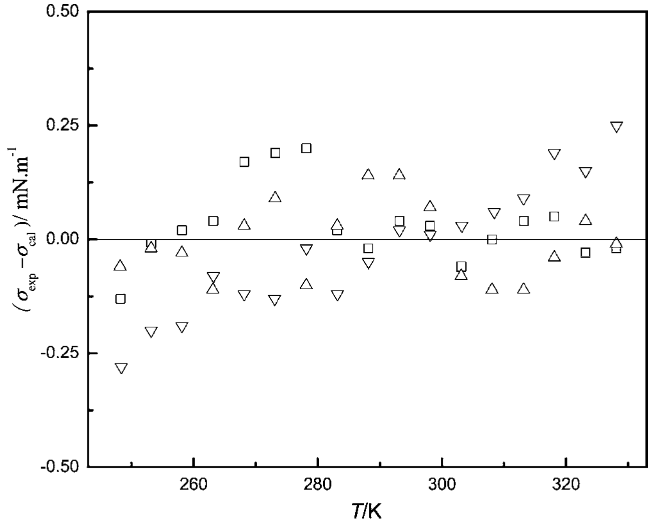

Figure 2. Absolute deviations of experimental surface tension data of R-290 (1) + R-152a (2) from eq 3: □, $w_1 = 0.2008$; △, $w_1 = 0.3497$; ▽, $w_1 = 0.4922$.

Table 2. Surface Tension of R-290 (1) + R-152a (2)

T K	ρ_l $kg\cdot m^{-3}$	ρ_g $kg\cdot m^{-3}$	Δh mm	σ $mN\cdot m^{-1}$
		$w_1 = 0.2008$		
248.24	922.2	3.53	8.34	15.3
253.19	912.6	4.29	8.08	14.7
258.15	902.9	5.18	7.80	14.0
263.19	893.0	6.22	7.50	13.3
268.19	882.9	7.41	7.26	12.7
273.19	872.6	8.77	6.96	12.0
278.18	862.1	10.32	6.66	11.4
283.16	851.4	12.08	6.24	10.5
288.18	840.4	14.09	5.90	9.8
293.16	829.2	16.35	5.62	9.1
298.10	817.8	18.87	5.30	8.5
303.18	805.8	21.80	4.92	7.7
308.11	793.7	24.99	4.64	7.1
313.19	780.8	28.69	4.34	6.5
318.14	767.8	32.75	4.02	5.9
323.18	754.0	37.40	3.64	5.2
328.12	739.9	42.55	3.32	4.6
		$w_1 = 0.3497$		
248.15	854.9	3.73	8.59	14.6
253.14	846.0	4.51	8.28	14.0
258.10	836.9	5.41	7.94	13.2
263.10	827.7	6.46	7.56	12.4
268.13	818.2	7.67	7.30	11.8
273.15	808.6	9.06	7.00	11.2
278.16	798.7	10.62	6.54	10.3
283.16	788.7	12.40	6.28	9.8
288.15	778.5	14.40	6.01	9.2
293.13	768.0	16.66	5.67	8.5
298.10	757.2	19.19	5.28	7.8
303.15	746.0	22.09	4.83	7.0
308.11	734.5	25.29	4.46	6.3
313.18	722.4	28.96	4.10	5.7
318.14	710.2	33.00	3.80	5.1
323.16	697.2	37.62	3.50	4.6
328.12	683.8	42.76	3.10	4.0
		$w_1 = 0.4922$		
248.37	790.1	3.96	8.81	13.9
253.15	782.1	4.73	8.51	13.3
258.10	773.7	5.65	8.16	12.6
263.18	764.9	6.73	7.86	11.9
268.16	756.2	7.95	7.47	11.2
273.08	747.3	9.32	7.10	10.5
278.18	738.0	10.93	6.80	9.9
283.18	728.6	12.71	6.36	9.1
288.17	719.0	14.72	6.04	8.5
293.16	709.2	16.98	5.72	7.9
298.15	699.1	19.53	5.34	7.3
303.20	688.5	22.42	4.97	6.6
308.46	677.1	25.81	4.60	6.0
313.16	666.6	29.22	4.26	5.4
318.14	655.0	33.25	3.96	4.9
323.17	642.7	37.85	3.54	4.3
328.15	630.0	42.99	3.24	3.8

composition of this mixture was estimated to be better than 0.01 % in mass fraction. The R-290 (1) + R-152a (2) mixtures were prepared with mass fractions w_1 of 0.2008, 0.3497, and 0.4922.

Results and Discussion

The surface tension of pure R-290 was measured along the saturation line from (283 to 303) K first to test the reliability of the experimental apparatus. The experimental data are listed in Table 1 and compared with the calculated data using NIST Refprop 8.0[9] and experimental data from refs 10 and 11. The results indicated that the maximum absolute deviations of R-290 were (0.08, 0.06, and 0.02) $mN\cdot m^{-1}$, respectively, and the maximum relative deviations were (1.10, 0.68, and 0.35) %, respectively.

In this work, the surface tensions of R-290 (1) + R-152a (2) at three mass fractions w_1 of 0.2008, 0.3497, and 0.4922 were measured, and 51 points of experimental data were obtained and shown in Table 2 and Figure 1. The densities of saturated liquid and vapor were also obtained from NIST Refprop 8.0.[9] The uncertainties in density are 0.2 % in the liquid phase and vapor phase.

The surface tension of pure refrigerant is usually correlated as a van der Waals type correlation:

$$\sigma = \sigma_0(1 - T/T_c)^n \qquad (2)$$

where σ_0 and n are empirical parameters obtained from the experimental data. T_c is the critical temperature. In this work, the parameters σ_0 and n of R-290 and R-152a are from refs 12 and 13, respectively. For R-290, σ_0 and n are 56.66 $mN\cdot m^{-1}$

and 1.265, respectively. For R-152a, σ_0 and n are 59.06 $\text{mN}\cdot\text{m}^{-1}$ and 1.221, respectively. The critical temperature of R-290 is 370.4 K from ref 12, and that of R-152a is 386.41 K from ref 13.

On the basis of the pure refrigerant, the surface tension of the mixture refrigerant was developed as the following expression:

$$\sigma = w_1\sigma_1 + w_2\sigma_2 + Cw_1w_2 \tag{3}$$

where σ_1 and σ_2 are surface tensions of the pure refrigerant calculated from the eq 2. w_1 and w_2 are the mass fractions. C is an empirical constant obtained from the experimental data. When $C = 0$, the average deviation and the maximum deviation from eq 3 are (-0.819 and -1.392) $\text{mN}\cdot\text{m}^{-1}$, respectively.

Because there is only one constant C in eq 3, C can be determined by one composition point; the other two composition points can check the accuracy of the equation. Using the experimental data listed in Table 2, the parameter C is found to be 4.921. The deviations of the experimental data from eq 3 with different mass fractions were depicted in Figure 2. The average deviation and the maximum deviation from eq 3 are (0.12 and 0.28) $\text{mN}\cdot\text{m}^{-1}$, respectively.

Conclusion

The surface tension of the mixture refrigerant R-290 + R-152a was measured over a wide temperature range from (248 to 328) K using the differential capillary rise method. The uncertainty of the surface tension measurements is estimated to be within ± 0.2 $\text{mN}\cdot\text{m}^{-1}$. On the basis of the present results, the correlation for the binary mixture refrigerant R-290 + R-152a was developed as a function using correlations of the pure refrigerant R-290 and R-152a.

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