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Surface Tension of 1,1,1-Trifluoroethane (HFC-143a), 1,1,1,2,3,3,3-Heptafluoropropane (HFC-227ea), and Their Binary Mixture HFC-143a/227ea

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The surface tension of 1,1,1-trifluoroethane (HFC-143a), 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea), and their binary mixture HFC-143a/227ea at 3 nominal mass fractions of 27.91%/72.09%, 49.44%/50.56%, and 74.11%/25.89% were measured in the temperature range from 253 to 333 K using the differential capillary rise method (DCRM) under vapor-liquid equilibrium conditions. The temperature and surface tension uncertainties were estimated to be within $\pm 10\,\mathrm{mK}$ and $\pm 0.15\,\mathrm{mN \cdot m^{-1}}$, respectively. The present data were used to develop a van der Waals-type surface tension correlation for pure HFC-143a and HFC-227ea. Correlations for pure HFC-143a and HFC-227ea were used to develop a surface tension correlation for the experimental data of the HFC-143a/227ea mixtures as a function of the mass fraction.

KEY WORDS: differential capillary rise method (DCRM); HFC-143a; HFC-227ea; mixture; surface tension.

1. INTRODUCTION

Hydrofluorocarbons (HFCs) and their mixtures are expected to be considered as interim and long-term replacements for HCFC refrigerants (such as HCFC-22) and R502 because of their zero ozone depletion potentials and low global warming potentials. Surface tension is a basic thermophysical property, especially with respect to a vapor-liquid interface, and is required to analyze the heat transfer through a heat-exchanging surface with bubbles or fluid drops on it.

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In this work, the surface tension of 1,1,1-trifluoroethane (HFC-143a), 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea), and their binary mixtures HFC-143a/227ea were measured over the temperature range from 253 to 333 K. The experimental results for pure HFC-143a and HFC-227ea were represented with a van der Waals-type surface tension correlation. The experimental mixture data were then used to develop a surface tension correlation for HFC-143a/227ea mixtures as a function of the mass fraction using the correlations of pure HFC-143a and HFC-227ea.

2. MATERIALS, APPARATUS, AND PROCEDURES

2.1. Materials

The sample of HFC-143a was purchased from Zhejiang Fluoro-Chemical Technology Research Institute and used without further purification. The manufacturer stated that the purity was better than 99.95 mass%. The sample of HFC-227ea was obtained from Shanghai Huiyou Chemical Corp., and was used without further purification. The manufacturer stated that the water content was less than 20 ppm. As determined by gas chromatographic analysis, the purity of the sample was better than 99.9 mol%.

The mixtures were gravimetrically prepared using an accurate electronic balance with a resolution of ±0.001 g. Three HFC-143a/227ea binary mixtures were prepared at nominal mass fractions (the liquid and vapor average composition) of 27.91%/72.09%, 49.44%/50.56%, and 74.11%/25.89%.

2.2. Apparatus and Procedures

The surface tension was precisely measured using the direct optical measurement system shown in Fig. 1 based on the differential capillary rise method (DCRM). The apparatus was described in detail previously [1–5] and is only briefly described here. The measurement system includes a moveable coordinate frame, a telescope, and an accurate displacement sensor.

The sample cell contained three capillaries with inner radii of $r_1 = 0.390 \pm 0.001$ mm, $r_2 = 0.259 \pm 0.001$ mm, and $r_3 = 0.125 \pm 0.001$ mm. The three capillary radii were determined by partially filling the capillaries with mercury slugs of different masses.

The sample cell was installed in a thermostated bath. The bath temperature could be varied from 233 to 453 K. The overall temperature uncertainty including the bath instability and the temperature-measurement system was less than ±10 mK. The differences between the capillary rise

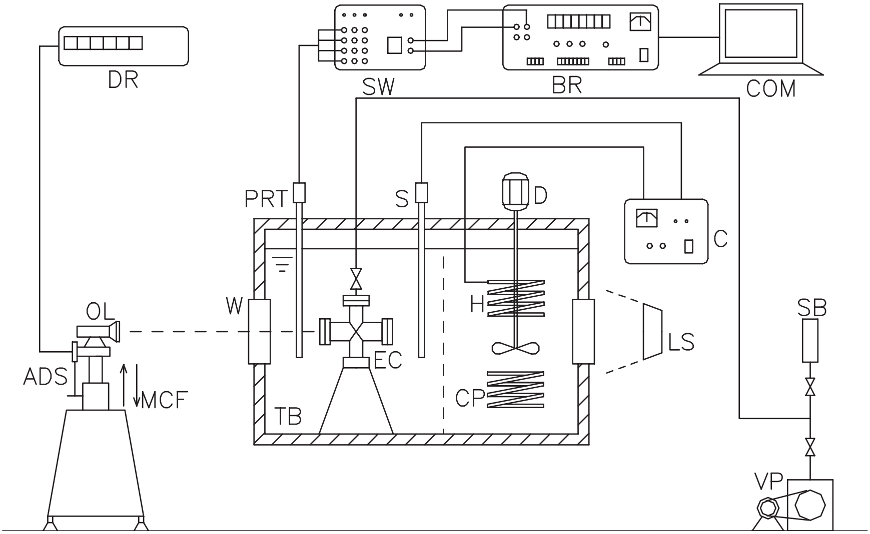

Fig. 1. Surface-tension apparatus. MCF: movable coordinate frame; OL: optical level instrument; ADS: accurate displacement sensor; DR: digital readout; EC: experimental cell; TB: thermostated bath; H: heater; CP: cooling pipe; D: dynamic-electric stirrer; S: thermally-sensitive resistance sensor; C: controller; PRT: platinum resistance thermometer; SW: selector switch; BR: automatic thermometer bridge; COM: computer; W: window; LS: light source; VP: vacuum pump; SB: sample bottle.

heights were determined with an uncertainty of $\pm 10\ \mu\mathrm{m}$ by measuring the meniscus locations in each capillary through a transparent window of the sample cell using a traveling telescope. The differential capillary rise between two capillaries was sensed by a height transducer on the telescope using a digital readout. The contact angle θ was assumed to be zero since the inner walls of the capillaries were carefully washed before the measurements.

All of the measurements were carried out under equilibrium conditions between the liquid and its saturated vapor. A total error analysis gave the estimated surface tension and temperature measurement uncertainties to be within $\pm 0.15\ \mathrm{mN \cdot m^{-1}}$ and ± 10 mK, respectively.

The binary mixture of HFC-143a/227ea in the sample cell was prepared by placing the proper amount of HFC-143a and HFC-227ea in separate gas cylinders. The two cylinders were precisely weighed on an accurate electronic balance with a resolution of ± 0.001 g (Mettler Toledo PR1203). The sample cell and connections were then evacuated by a vacuum pump (KYKY FD110) to remove impurities. The system vacuum was $< 10^{-4}$ Pa and was maintained for at least 5 hours. A targeted amount of HFC-227ea was introduced into the sample cell from the gas cylinder, and then the valve to the sample cell was closed and the cylinder was cooled by liquid nitrogen to force the vapor in the pipeline to flow back to the gas cylinder. After the sample cell was cooled by the liquid nitrogen, the proper mount of HFC-143a was supplied to the sample cell from the other gas cylinder using the same procedure as for HFC-227ea. The mass differences between the gas cylinders before and after the charging process were taken as the mass of each refrigerant in the sample cell used to calculate the nominal mass fractions in the sample cell. Since the sample mass to fill the sample cell was about 100 g, the mixture nominal mass fraction uncertainty was estimated to be better than ±0.01 mass%.

The sample cell was a cylinder having a volume of 0.353 l at room temperature, as determined by carefully filling with distilled water. The HFC-143a/227ea mixtures at the 3 nominal mass fractions of 27.91%/72.09%, 49.44%/50.56%, and 74.11%/25.89% are zeotropic, so the coexisting liquid and vapor compositions differed. The compositions were determined by measuring the liquid phase volume in the sample cell, based on the liquid height in the cell. The saturated liquid and vapor densities were calculated using NIST REFPROP 6.01 [6]. The actual liquid-phase composition was then calculated from the volumes and densities of the liquid and vapor phases in the sample cell. To verify the results, the gas phase composition was checked using gas chromatography (Lunan SP-6800A) with a thermal conductivity detector (TCD) after the surface tension measurements. The detector response was carefully calibrated using gravimetrically prepared mixtures. The differences between the measured and calculated compositions are within ±0.2%.

3. RESULTS AND DISCUSSION

The capillary constant is

$$a^2 = 2\sigma/(\rho_\mathrm{l} - \rho_\mathrm{v})\, g \tag{1}$$

where σ is the surface tension, g is the local acceleration of gravity at Beijing, China ($g = 9.8015\ \mathrm{m \cdot s^{-2}}$), and ρ_l and ρ_v are the densities of the saturated liquid and vapor, respectively. ρ_l and ρ_v were calculated using NIST REFPROP 6.01 [6] for the refrigerant mixture HFC-143a/227ea and from available literature data for HFC-143a [7] and HFC-227ea [8–10].

The height h_0 of the bottom of the meniscus in each capillary was measured, and the actual rise height h was calculated using Rayleigh's correlation [11]. The capillary constant can be related to the rise heights as

$$a^2 = \frac{h_1 - h_2}{(1/r_1) - (1/r_2)} \tag{2}$$

Therefore, the surface tension can be calculated from

$$\sigma = \frac{(\rho_l - \rho_v)\, g}{2} \frac{(h_1 - h_2)}{[(1/r_1) - (1/r_2)]} \tag{3}$$

using the differential capillary rise method (DCRM) based on the height difference between two different capillaries; two sets of surface tension results were obtained using the height difference between capillaries 3 ($r_3 = 0.125 \pm 0.001$ mm) and 2 ($r_2 = 0.259 \pm 0.001$ mm) and between capillaries 3 and 1 ($r_1 = 0.390 \pm 0.001$ mm). The results are reported in Table I for HFC-143a, Table II for HFC-227ea, and in Tables III to V for

Table I. Experimental Surface Tension Data and Capillary Constants for HFC-143a

			a^2 (mm^2)		σ (mN·m^{-1})	
T (K)	ρ_l (kg·m^{-3})	ρ_v (kg·m^{-3})	(3, 2)	(3, 1)	(3, 2)	(3, 1)
253.66	1087.0	14.3	1.971	1.973	10.36	10.37
256.95	1076.9	16.1	1.908	1.911	9.92	9.93
259.57	1068.8	17.6	1.853	1.854	9.55	9.55
261.40	1063.0	18.7	1.809	1.810	9.26	9.26
262.78	1058.6	19.6	1.782	1.784	9.07	9.08
264.37	1053.5	20.6	1.742	1.742	8.82	8.82
266.72	1045.9	22.3	1.706	1.706	8.56	8.56
272.97	1025.2	27.2	1.582	1.586	7.74	7.76
277.40	1009.9	31.2	1.494	1.499	7.17	7.19
281.38	995.8	35.3	1.416	1.416	6.67	6.67
285.38	981.1	39.8	1.337	1.337	6.17	6.17
291.22	958.8	47.3	1.204	1.203	5.38	5.37
295.74	940.6	53.9	1.119	1.118	4.86	4.86
299.53	924.7	60.2	1.042	1.040	4.41	4.41
303.86	905.5	68.2	0.946	0.941	3.88	3.86
307.85	886.9	76.5	0.876	0.873	3.48	3.47
312.22	865.2	86.9	0.771	0.771	2.94	2.94
316.10	844.5	97.4	0.698	0.698	2.56	2.56
320.16	821.1	110.0	0.596	0.596	2.08	2.08
323.66	799.3	122.5	0.515	0.513	1.71	1.70
327.80	770.8	139.9	0.440	0.440	1.36	1.36

Table II. Experimental Surface Tension Data and Capillary Constants for HFC-227ea

			a^2 (mm^2)		σ (mN$\cdot$m^{-1})	
T (K)	ρ_l (kg$\cdot$m^{-3})	ρ_v (kg$\cdot$m^{-3})	(3, 2)	(3, 1)	(3, 2)	(3, 1)
254.67	1552.3	7.8	1.623	1.626	12.29	12.31
257.97	1540.9	8.9	1.576	1.576	11.83	11.83
261.00	1530.1	10.0	1.562	1.552	11.64	11.56
264.35	1518.3	11.4	1.502	1.502	11.09	11.09
266.81	1509.4	12.6	1.469	1.468	10.78	10.77
269.74	1498.7	14.0	1.426	1.426	10.38	10.38
273.15	1486.1	15.9	1.382	1.388	9.96	10.00
275.84	1476.2	17.4	1.346	1.346	9.62	9.62
279.31	1463.0	19.7	1.298	1.300	9.18	9.20
282.55	1450.5	22.0	1.259	1.259	8.81	8.81
284.67	1442.2	23.6	1.243	1.241	8.64	8.63
288.09	1428.8	26.4	1.185	1.190	8.14	8.18
291.24	1416.0	29.2	1.153	1.160	7.84	7.88
292.58	1410.6	30.5	1.136	1.132	7.68	7.66
294.92	1401.0	32.8	1.105	1.112	7.41	7.46
295.63	1398.0	33.5	1.086	1.087	7.26	7.27
298.81	1385.0	37.0	1.043	1.042	6.89	6.88
301.30	1373.6	39.9	1.010	1.010	6.60	6.60
304.26	1361.0	43.6	0.969	0.969	6.26	6.26
307.55	1346.5	48.0	0.930	0.929	5.92	5.91
310.51	1333.0	52.3	0.886	0.889	5.56	5.58
313.32	1319.2	56.8	0.850	0.851	5.26	5.27
316.99	1303.6	62.9	0.813	0.811	4.94	4.93
319.71	1287.6	68.2	0.772	0.774	4.61	4.63
322.33	1276.0	73.2	0.740	0.745	4.36	4.39
325.80	1257.4	80.7	0.697	0.697	4.02	4.02
328.70	1241.8	87.5	0.654	0.659	3.70	3.73
331.53	1226.1	94.7	0.629	0.631	3.49	3.50

HFC-143a/227ea mixtures at 3 nominal mass fractions of 27.91%/72.09%, 49.44%/50.56%, and 74.11%/25.89%. The capillary constant a^2, which is not affected by the uncertainty of density values, the saturated liquid density ρ_l and the saturated vapor density ρ_v are also listed in Tables I to V. The liquid mass fraction of HFC-143a ($w_{\text{HFC-143a}}$) in the mixtures at each temperature is also listed in Tables III to V.

The surface tension is normally correlated as a function of temperature for pure refrigerants by a van der Waals-type correlation:

$$\sigma = \sigma_0 \left(1 - \frac{T}{T_c}\right)^n \tag{4}$$

Table III. Experimental Surface Tension Data and Capillary Constants for HFC-143a/227ea at a Nominal Mass Fraction of 27.91%/72.09%

				a^2 (mm^2)		σ (mN$\cdot$m^{-1})	
T (K)	ρ_l (kg$\cdot$m^{-3})	ρ_v (kg$\cdot$m^{-3})	$w_{HFC\text{-}143a}$	(3, 2)	(3, 1)	(3, 2)	(3, 1)
253.08	1387	13.2	0.2695	1.716	1.721	11.55	11.59
254.48	1382	13.8	0.2691	1.691	1.691	11.34	11.34
257.18	1373	15.2	0.2684	1.651	1.651	10.98	10.98
258.87	1368	16.1	0.2679	1.636	1.639	10.84	10.86
261.03	1361	17.4	0.2673	1.597	1.600	10.51	10.53
262.84	1354	18.4	0.2668	1.579	1.579	10.33	10.33
264.81	1348	19.7	0.2662	1.540	1.548	10.02	10.08
266.77	1341	21.0	0.2656	1.501	1.511	9.71	9.77
268.75	1334	22.4	0.2650	1.485	1.487	9.54	9.56
270.33	1329	23.5	0.2645	1.469	1.469	9.40	9.40
273.05	1319	25.6	0.2637	1.427	1.427	9.04	9.04
275.34	1311	27.5	0.2629	1.393	1.394	8.76	8.77
277.41	1304	29.3	0.2622	1.360	1.361	8.50	8.50
279.50	1296	31.2	0.2615	1.336	1.336	8.28	8.28
281.35	1289	32.9	0.2608	1.300	1.303	8.00	8.02
283.58	1281	35.2	0.2600	1.281	1.285	7.82	7.84
285.40	1274	37.1	0.2594	1.246	1.249	7.55	7.57
287.26	1267	39.1	0.2587	1.216	1.216	7.32	7.32
289.33	1259	41.5	0.2579	1.193	1.195	7.12	7.13
291.44	1251	44.1	0.2571	1.165	1.166	6.89	6.90
293.62	1242	46.9	0.2563	1.133	1.135	6.64	6.65
295.38	1235	49.2	0.2556	1.087	1.086	6.32	6.31
297.21	1228	51.8	0.2549	1.055	1.055	6.08	6.08
299.56	1218	55.3	0.2540	1.025	1.025	5.84	5.84
301.33	1210	58.0	0.2533	1.009	1.009	5.70	5.70
303.53	1201	61.6	0.2524	0.954	0.961	5.33	5.37
305.45	1192	64.8	0.2516	0.941	0.939	5.20	5.19
307.38	1184	68.3	0.2508	0.910	0.911	4.98	4.98
309.38	1175	72.0	0.2500	0.887	0.891	4.79	4.82
311.38	1165	75.9	0.2492	0.850	0.851	4.54	4.54
313.47	1155	80.3	0.2483	0.818	0.819	4.31	4.31
315.75	1144	85.2	0.2473	0.781	0.782	4.05	4.06
317.36	1136	88.9	0.2466	0.768	0.764	3.94	3.92
319.36	1126	93.8	0.2458	0.733	0.733	3.71	3.71
321.47	1115	99.1	0.2449	0.702	0.704	3.49	3.50
323.84	1102	105.5	0.2439	0.659	0.659	3.22	3.22
325.47	1093	110.2	0.2433	0.640	0.637	3.08	3.07
327.38	1082	115.9	0.2424	0.619	0.617	2.93	2.92
329.49	1070	122.6	0.2416	0.575	0.578	2.67	2.68
331.41	1058	129.0	0.2408	0.549	0.549	2.50	2.50
333.41	1046	136.2	0.2400	0.511	0.508	2.28	2.27

Table IV. Experimental Surface Tension Data and Capillary Constants for HFC-143a/227ea at a Nominal Mass Fraction of 49.44%/50.56%

				a^2 ($\mathrm{mm^2}$)		σ ($\mathrm{mN \cdot m^{-1}}$)	
T (K)	ρ_l ($\mathrm{kg \cdot m^{-3}}$)	ρ_v ($\mathrm{kg \cdot m^{-3}}$)	$w_{\mathrm{HFC\text{-}143a}}$	(3, 2)	(3, 1)	(3, 2)	(3, 1)
252.56	1283	14.0	0.4839	1.778	1.778	11.06	11.06
254.50	1277	14.9	0.4834	1.744	1.749	10.79	10.82
257.11	1268	16.4	0.4825	1.714	1.714	10.51	10.51
258.88	1263	17.4	0.4819	1.672	1.672	10.21	10.21
261.14	1255	18.8	0.4812	1.646	1.646	9.97	9.97
262.97	1249	19.9	0.4805	1.624	1.624	9.78	9.78
264.31	1245	20.8	0.4800	1.598	1.598	9.59	9.59
266.63	1237	22.5	0.4792	1.571	1.578	9.35	9.39
268.67	1230	24.0	0.4784	1.537	1.538	9.08	9.09
270.41	1224	25.4	0.4777	1.496	1.504	8.79	8.83
273.21	1215	27.7	0.4766	1.471	1.479	8.56	8.61
275.43	1207	29.7	0.4756	1.434	1.435	8.27	8.28
277.26	1200	31.4	0.4748	1.390	1.394	7.96	7.98
279.33	1193	33.4	0.4739	1.365	1.365	7.76	7.76
281.35	1186	35.5	0.4730	1.347	1.343	7.59	7.57
283.33	1178	37.6	0.4721	1.296	1.296	7.24	7.24
285.63	1170	40.2	0.4710	1.261	1.265	6.98	7.00
287.84	1162	42.9	0.4699	1.237	1.238	6.78	6.79
289.61	1155	45.1	0.4690	1.206	1.206	6.56	6.56
291.63	1147	47.8	0.4680	1.149	1.149	6.19	6.19
293.50	1140	50.4	0.4670	1.114	1.115	5.95	5.95
295.61	1131	53.5	0.4659	1.093	1.092	5.77	5.77
297.80	1122	56.8	0.4647	1.055	1.055	5.51	5.51
299.49	1115	59.6	0.4637	1.030	1.029	5.33	5.32
301.55	1106	63.0	0.4626	0.996	0.995	5.09	5.09
303.60	1097	66.7	0.4614	0.957	0.955	4.83	4.82
305.61	1088	70.5	0.4602	0.921	0.922	4.59	4.60
307.47	1080	74.1	0.4591	0.889	0.891	4.38	4.39
309.56	1070	78.5	0.4578	0.854	0.851	4.15	4.14
311.43	1062	82.5	0.4567	0.831	0.829	3.99	3.98
313.99	1049	88.5	0.4551	0.776	0.773	3.65	3.64
315.37	1042	91.8	0.4542	0.759	0.754	3.53	3.51
317.24	1033	96.6	0.4531	0.748	0.742	3.43	3.40
319.37	1022	102.4	0.4517	0.709	0.709	3.20	3.20
321.29	1011	107.9	0.4505	0.672	0.672	2.97	2.97
323.37	999.4	114.2	0.4491	0.637	0.635	2.76	2.75
325.35	987.9	120.6	0.4478	0.595	0.594	2.53	2.52
327.71	973.6	128.8	0.4463	0.564	0.563	2.34	2.33
329.68	961.2	136.1	0.4450	0.527	0.527	2.13	2.13
331.42	949.8	143.0	0.4439	0.496	0.497	1.96	1.97
333.25	937.3	150.7	0.4427	0.467	0.464	1.80	1.79

Table V. Experimental Surface Tension Data and Capillary Constants for HFC-143a/227ea at a Nominal Mass Fraction of 74.11%/25.89%

				a^2 (mm^2)		σ (mN·m^{-1})	
T (K)	ρ_l (kg·m^{-3})	ρ_v (kg·m^{-3})	$w_{\text{HFC-143a}}$	(3, 2)	(3, 1)	(3, 2)	(3, 1)
253.12	1179	14.4	0.7343	1.865	1.863	10.64	10.63
254.82	1174	15.2	0.7340	1.826	1.830	10.37	10.39
257.12	1167	16.5	0.7335	1.793	1.797	10.11	10.13
258.85	1161	17.5	0.7331	1.766	1.767	9.90	9.90
260.83	1155	18.7	0.7326	1.721	1.721	9.58	9.58
262.73	1149	20.0	0.7322	1.697	1.693	9.39	9.37
264.78	1142	21.4	0.7317	1.659	1.659	9.11	9.11
266.95	1135	22.9	0.7311	1.629	1.626	8.88	8.86
268.48	1130	24.1	0.7307	1.592	1.592	8.63	8.63
270.56	1123	25.8	0.7301	1.544	1.544	8.30	8.30
273.35	1114	28.1	0.7293	1.513	1.513	8.05	8.05
275.56	1106	30.1	0.7286	1.466	1.466	7.73	7.73
277.51	1099	32.0	0.7280	1.430	1.430	7.48	7.48
279.65	1091	34.1	0.7273	1.382	1.382	7.16	7.16
281.30	1085	35.8	0.7268	1.358	1.358	6.98	6.98
285.65	1069	40.8	0.7253	1.293	1.293	6.51	6.51
287.80	1061	43.5	0.7245	1.254	1.255	6.25	6.26
289.29	1056	45.4	0.7239	1.222	1.222	6.05	6.05
293.53	1039	51.3	0.7222	1.131	1.128	5.47	5.46
295.51	1031	54.3	0.7214	1.091	1.098	5.22	5.26
298.21	1020	58.6	0.7203	1.049	1.049	4.94	4.94
299.35	1015	60.5	0.7198	1.028	1.028	4.81	4.81
301.41	1006	64.2	0.7189	0.992	0.994	4.58	4.59
303.42	997.2	67.9	0.7180	0.944	0.945	4.30	4.30
305.39	988.4	71.7	0.7170	0.910	0.910	4.09	4.09
307.37	979.3	75.8	0.7161	0.878	0.874	3.89	3.87
309.54	969.0	80.6	0.7150	0.830	0.835	3.61	3.64
311.52	959.4	85.2	0.7140	0.794	0.794	3.40	3.40
313.24	950.8	89.4	0.7131	0.763	0.762	3.22	3.22
315.39	939.7	95.0	0.7120	0.732	0.737	3.03	3.05
317.43	928.8	100.7	0.7109	0.695	0.697	2.82	2.83
319.41	917.9	106.5	0.7098	0.658	0.656	2.62	2.61
321.61	905.3	113.5	0.7086	0.609	0.612	2.36	2.37
323.41	894.6	119.6	0.7075	0.581	0.578	2.21	2.20
325.54	881.4	127.3	0.7063	0.525	0.525	1.94	1.94
327.50	868.7	135.0	0.7051	0.495	0.495	1.78	1.78
329.89	852.3	145.1	0.7037	0.453	0.456	1.57	1.58
331.55	840.3	152.8	0.7027	0.419	0.420	1.41	1.42
333.42	826.0	162.2	0.7016	0.399	0.391	1.30	1.27

Table VI. Numerical Constants in Eq. (3) for HFC-143a and HFC-227ea

Refrigerants	σ_0 ($mN \cdot m^{-1}$)	n	T_c (K)	$\overline{\delta_a}$ [a] ($mN \cdot m^{-1}$)
HFC-143a	53.7124	1.245	345.86 [7]	0.030
HFC-227ea	51.9885	1.273	375.95 [8]	0.024

[a] $\overline{\delta_a} = \frac{1}{n}\sum_{i=1}^{n} |\sigma_{exp,i} - \sigma_{cal,i}|$.

where σ_0 and n are empirical constants obtained from a least-squares fit of the experimental data. The value of n normally falls between 1.2 and 1.3 for most fluids. The values of σ_0 and n for HFC-143a and HFC-227ea, listed in Table VI, were determined by fitting Eq. (4) to the experimental surface tension data listed in Tables I and II, respectively. Figure 2 shows the absolute deviations of present data and available literature results [12–15] from Eq. (4) for HFC-143a. From the deviation plot, it is clear that present results show scatter within $\pm 0.1 \, mN \cdot m^{-1}$, which is less than the estimated uncertainty. The measurements of Higashi et al. [12], Schmidt et al. [13], and Heide [14] show good agreement with our data and Eq. (4) within $\pm 0.15 \, mN \cdot m^{-1}$ for HFC-143a, but Fröba et al.'s results

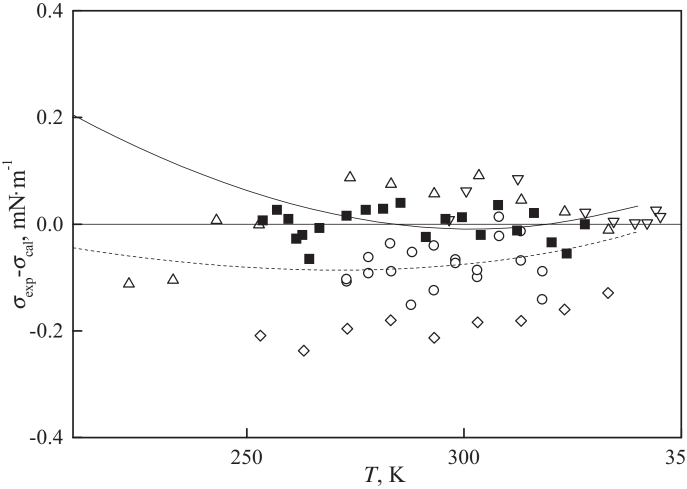

Fig. 2. Absolute deviations of experimental surface tension data of HFC-143a from Eq. (4). (■) this work; (○) Higashi et al. [12]; (▽) Schmidt et al. [13]; (△) Heide [14]; (◇) Fröba et al. [15]; (——) correlation of Heide [14], and (- - - -) correlation of Higashi et al. [12].

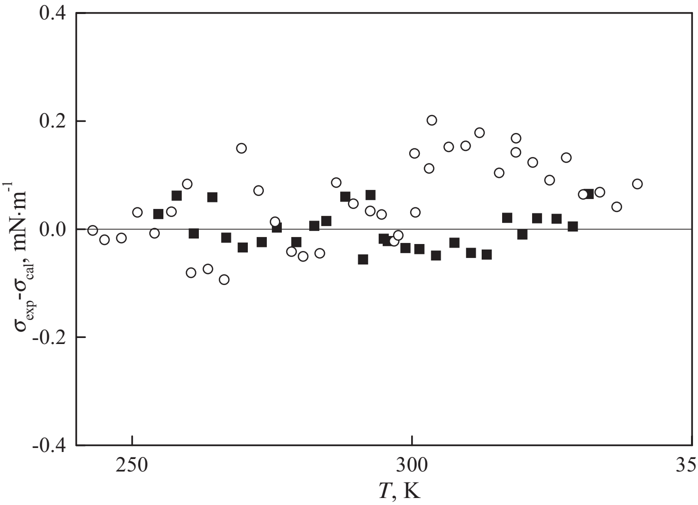

Fig. 3. Absolute deviations of experimental surface tension data of HFC-227ea from Eq. (4). (■) this work; (○) Duan et al. [5].

[15] are systematically 0.2 mN · m^{-1} lower than Eq. (4). Figure 3 shows the absolute deviations of present data and available literature results [5] from Eq. (4) for HFC-227ea. Our data are scattered within ±0.1 mN · m^{-1}. Although the results of Duan et al. [5] are 0.1 to 0.2 mN · m^{-1} higher than Eq. (4) in the temperature range of 300 to 330 K, they are consistent with Eq. (4) in the remaining temperature range.

The surface tension correlation used here for the HFC-143a/227ea mixtures [14] is

$$\sigma = w_1\sigma_1 + w_2\sigma_2 + w_1 w_2 C \tag{5}$$

where σ_1 and σ_2 are the surface tensions of the pure refrigerants calculated using Eq. (4) and w_1 and w_2 are the liquid mass fractions. The coefficient C was determined by fitting Eq. (5) to the present experimental data listed in

Table VII. Coefficient in Eq. (5) and Absolute and Relative Deviations of Experimental Data from Eq. (5)

Mixture	C	$\overline{\delta_a}$ (mN · m^{-1})	$\overline{\delta_r}^a$ (%)
HFC-143a/227ea	−1.6638	0.043	0.86

[a] $\overline{\delta_r} = \frac{1}{n}\sum_{i=1}^{n} \frac{|\sigma_{exp,i}-\sigma_{cal,i}|}{\sigma_{cal,i}}$.

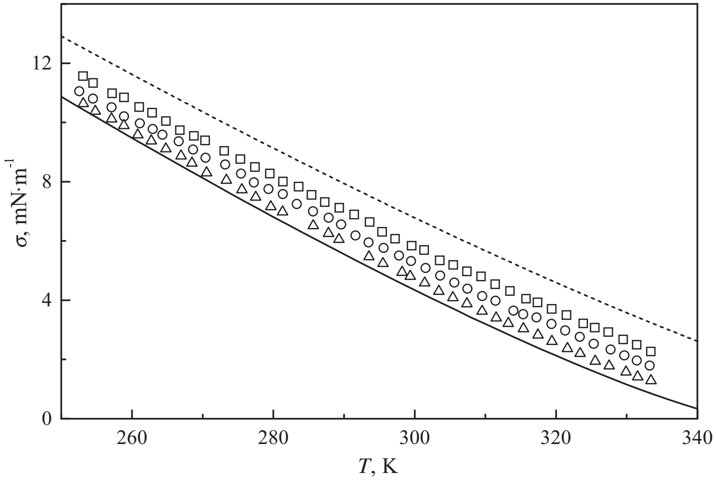

Fig. 4. Surface tension variation for HFC-143a/227ea. (□) mass fraction 27.91%/72.09%; (○) mass fraction 49.44%/50.56%; (△) mass fraction 74.11%/25.89%; (——) Eq. (4) for HFC-143a, and (- - - -) Eq. (4) for HFC-227ea.

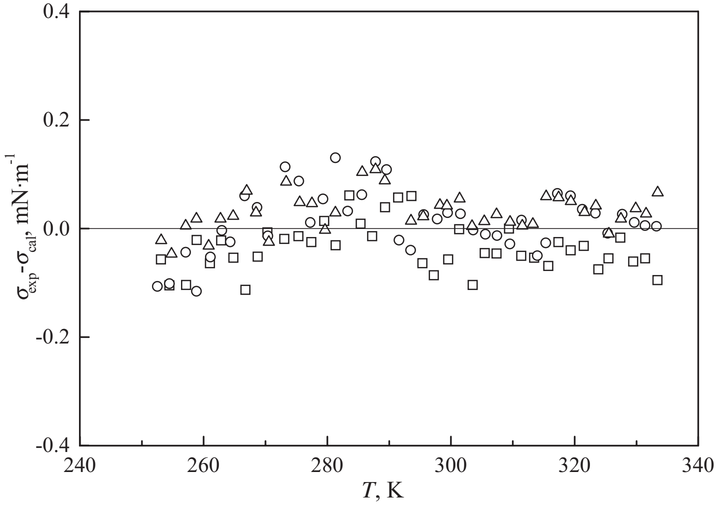

Fig. 5. Absolute deviations of experimental surface tension data of HFC-143a/227ea from Eq. (5). (□) mass fraction 27.91%/72.09%; (○) mass fraction 49.44%/50.56%; (△) mass fraction 74.11%/25.89%.

Tables III to V. Table VII lists the values of C, the average absolute deviation, and the average relative deviation of the present experimental data from Eq. (5). Figure 4 shows the surface tension variation for the HFC-143a/227ea mixtures, pure HFC-143a, and pure HFC-227ea as a function of temperature. Figure 5 shows the absolute deviations of the present data from Eq. (5) for HFC-143a/227ea mixtures with various mass fractions. No other experimental data are available for HFC-143a/227ea. The results in Fig. 5 show that the absolute deviations of the present data from Eq. (5) are less than $\pm 0.15\ \mathrm{mN \cdot m^{-1}}$.

4. CONCLUSIONS

The surface tension of the binary mixture HFC-143a/227ea, pure HFC-143a, and HFC-227ea were measured over a wide temperature range using the differential capillary rise method at 3 nominal mass fractions. The uncertainty of the surface tension measurements was estimated to be within $\pm 0.15\ \mathrm{mN \cdot m^{-1}}$. The experimental data were then used to develop correlations for the surface tension of the binary mixture HFC-143a/227ea, and pure HFC-143a and HFC-227ea.

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