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Isochoric p-ρ-T Measurements on 1,1-Difluoroethane (R152a) from 158 to 400 K and 1,1,1-Trifluoroethane (R143a) from 166 to 400 K at Pressures to 35 MPa

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The p-ρ-T relationships have been measured for 1,1-difluoroethane (R152a) and 1,1,1-trifluoroethane (R143a) by an isochoric method with gravimetric determinations of the amount of substance. Temperatures ranged from 158 to 400 K for R152a and from 166 to 400 K for R143a, while pressures were up to 35 MPa. Measurements were conducted on compressed liquid samples. Determinations of saturated liquid densities were made by extrapolating each isochore to the vapor pressure, and determining the temperature and density at the intersection. Published p-ρ-T data are in good agreement with this study. For the p-ρ-T apparatus, the uncertainty of the temperature is ± 0.03 K, and for pressure it is $\pm 0.01\%$ at $p > 3$ MPa and $\pm 0.05\%$ at $p < 3$ MPa. The principal source of uncertainty is the cell volume (~ 28.5 cm^3), which has a standard uncertainty of ± 0.003 cm^3. When all components of experimental uncertainty are considered, the expanded relative uncertainty (with a coverage factor $k = 2$ and thus a two-standard deviation estimate) of the density measurements is estimated to be $\pm 0.05\%$.

KEY WORDS: density; 1,1-difluoroethane; p-ρ-T data; R143a; R152a; saturated liquid; 1,1,1-trifluoroethane.

1. INTRODUCTION

In recently published studies, Outcalt, and McLinden analyzed the available data for R152a [1] and R143a [2] and developed a modified Benedict–Webb–Rubin equation of state for each fluid. Outcalt and

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McLinden noted that published p-ρ-T data in the saturated and compressed liquid phases for these substances were scarce, especially at temperatures below 243 K. In the following discussion, some of the key studies of densities of R152a and R143a are summarized. For liquid and gaseous R152a, Tillner-Roth and Baehr [3, 4] measured densities from 243 to 433 K at pressures to 15.8 MPa, Blanke and Weiß [5] measured densities from 162 to 453 K at pressures to 30.5 MPa, and Defibaugh and Morrison [6] measured densities from 243 to 371 K at pressures to 6.5 MPa. For vapor and supercritical gaseous states for R143a, Weber and Defibaugh [7] measured densities from 276 to 373 K at pressures to 6.6 MPa, and de Vries [8] measured densities from 243 to 393 K at pressures to 18.1 MPa. Densities of the saturated liquid have also been reported. Such data are used to anchor a model for the thermophysical properties to the saturation boundary. For R152a, saturated liquid densities have been reported by Tillner-Roth and Baehr [4] from 243 to 353 K, by Blanke and Weiß [5] from 252 to 308 K, by Defibaugh and Morrison [6] from 243 to 371 K, by Holcomb et al. [9] from 312 to 384 K, and by Higashi et al. [10] from 371 to 386 K. For R143a, saturated liquid densities have been reported by Yokoyama and Takahashi [11] from 248 to 341 K.

In this paper, new p-ρ-T measurements for R152a and R143a are reported for temperatures ranging from just above T_{tr} to a maximum temperature near 400 K, and at pressures up to 35 MPa. Saturated liquid densities for these substances are also reported.

2. MEASUREMENTS

2.1. p-ρ-T Apparatus and Procedures

The apparatus used in this work has been used for studies of both pure fluids and mixtures. Details of the apparatus are available in previous publications [12, 13]. An isochoric technique was employed to measure the single-phase liquid densities in this study. In this method, a sample of fixed mass is confined in a container of nearly fixed volume. Details of this method are available in recent publications [14, 15].

2.2. Samples

High-purity samples were obtained for the measurements. The sample of R152a had the highest purity, 0.99962 mass fraction. The largest impurity was $CHClF_2$ (R22) with a mass fraction of 0.00036. Other impurities included 10 ppm of CH_3CClF_2 (R142b) and 10 ppm of C_2H_6O. The purity of the R143a sample was approximately 0.9993 mass fraction.

An infrared spectrum and three types of chromatographic analyses were recorded for the sample. A small quantity (0.0007 mass fraction) of an unidentified impurity was detected in two of the three chromatographic analyses. The mass spectrum of the impurity is consistent with a substance of slightly higher molecular mass than R143a, but the pattern was too weak to identify the impurity.

2.3. Assessment of Uncertainties

A detailed discussion of the uncertainties in measured quantities is available in recent publications [14, 15]. In the following discussion, the definition for the expanded uncertainty which is two times the standard uncertainty corresponds to a coverage factor $k=2$ and thus a two-standard-deviation estimate. In Refs. 14 and 15, the following uncertainties are estimated: 0.03 K in temperature; up to 0.05% in pressure; 0.0045 cm^3 in cell volume; and 0.002 g in mass. Combining the uncertainty of the measured mass of the sample with the uncertainty of the cell volume, the expanded relative uncertainty of the density is estimated to be $\pm 0.05\%$.

3. RESULTS

3.1. *p*-ρ-*T* Results

The experimental temperatures on the ITS-90, pressures, and densities for liquid R152a are presented in Table I; for R143a, the results are presented in Table II. These tables also present densities calculated with modified Benedict–Webb–Rubin equations of state developed by Outcalt and McLinden [1, 2] alongside deviations of the experimental densities from the calculated values. These deviations are defined by Dev. $= 100(\rho_{exp} - \rho_{calc})/\rho_{calc}$. To illustrate the range of measurements for each of the fluids, the isochoric data for liquid R152a and R143a are plotted in Figs. 1 and 2.

Comparisons of the isochoric p-ρ-T measurements with an equation of state for each substance have been facilitated with the equations developed by Outcalt and McLinden [1, 2]. These formulations are based, in part, on the results of this study along with selected data sets from other laboratories. Outcalt and McLinden graphically depicted the deviations of the calculated density from the experimental density for these selected data and the results of this study. Their comparisons show that there is excellent agreement ($\pm 0.10\%$) of the liquid R152a densities of Tillner-Roth and Baehr [3, 4] and from Blanke and Weiß [5] with the densities from this study. The absolute average deviation of experimental densities from the

Table I. Experimental p-ρ-T Data for 1,1-Difluoroethane (R152a)

T (K)	P (MPa)	ρ_{exp} ($kg \cdot m^{-3}$)	ρ_{calc} [a] ($kg \cdot m^{-3}$)	Dev (%)
158.000	2.053	1187.99	1188.21	−0.018
159.999	6.210	1187.68	1187.81	−0.012
162.001	10.368	1187.38	1187.46	−0.007
163.999	14.498	1187.11	1187.14	−0.003
165.999	18.618	1186.83	1186.84	−0.001
167.999	22.718	1186.57	1186.56	0.001
169.999	26.791	1186.31	1186.27	0.003
172.000	30.840	1186.05	1186.00	0.004
173.999	34.868	1185.80	1185.73	0.006
172.000	4.088	1164.35	1164.42	−0.007
173.998	7.861	1164.06	1164.10	−0.004
176.000	11.638	1163.78	1163.82	−0.003
177.999	15.387	1163.53	1163.54	−0.001
179.998	19.132	1163.27	1163.28	−0.001
182.000	22.855	1163.02	1163.02	0.000
183.999	26.547	1162.77	1162.76	0.001
186.000	30.233	1162.53	1162.51	0.002
188.001	33.892	1162.29	1162.25	0.003
186.000	2.391	1137.17	1137.17	0.000
188.001	5.778	1136.89	1136.88	0.001
190.000	9.158	1136.63	1136.62	0.001
191.998	12.527	1136.38	1136.37	0.001
194.000	15.881	1136.14	1136.12	0.002
196.000	19.222	1135.90	1135.88	0.002
197.999	22.553	1135.67	1135.65	0.002
200.000	25.870	1135.44	1135.41	0.002
201.999	29.167	1135.20	1135.17	0.003
203.999	32.449	1134.98	1134.93	0.004
202.000	2.593	1107.70	1107.60	0.008
203.999	5.601	1107.44	1107.35	0.008
206.000	8.603	1107.20	1107.11	0.009
208.002	11.600	1106.96	1106.87	0.008
209.999	14.583	1106.73	1106.64	0.008
212.000	17.559	1106.51	1106.42	0.008
214.000	20.526	1106.29	1106.20	0.008
215.999	23.474	1106.07	1105.98	0.008
218.001	26.414	1105.85	1105.75	0.009
220.001	29.338	1105.63	1105.53	0.010
222.002	32.254	1105.42	1105.30	0.011
224.001	35.155	1105.21	1105.07	0.012
218.000	2.432	1077.25	1077.07	0.017
220.001	5.104	1077.01	1076.84	0.016
222.000	7.767	1076.78	1076.61	0.015
224.001	10.426	1076.55	1076.39	0.015
225.999	13.076	1076.34	1076.19	0.014

Table I. *(Continued)*

T (K)	P (MPa)	ρ_{exp} (kg · m^{-3})	ρ_{calc} [a] (kg · m^{-3})	Dev (%)
228.000	15.722	1076.12	1075.98	0.013
229.999	18.353	1075.91	1075.77	0.013
232.001	20.973	1075.71	1075.55	0.014
234.000	23.585	1075.50	1075.35	0.014
236.000	26.189	1075.30	1075.14	0.014
237.999	28.783	1075.09	1074.93	0.015
240.002	31.372	1074.89	1074.72	0.016
242.000	33.942	1074.69	1074.50	0.017
238.002	2.516	1038.41	1038.14	0.025
240.002	4.808	1038.18	1037.93	0.025
242.000	7.096	1037.97	1037.72	0.024
244.000	9.380	1037.77	1037.52	0.023
246.000	11.657	1037.56	1037.32	0.023
248.001	13.929	1037.36	1037.13	0.023
249.999	16.192	1037.17	1036.93	0.022
252.002	18.454	1036.97	1036.74	0.022
254.001	20.708	1036.78	1036.55	0.022
255.998	22.950	1036.58	1036.36	0.022
257.999	25.191	1036.39	1036.17	0.021
259.999	27.420	1036.21	1035.98	0.022
262.000	29.645	1036.02	1035.78	0.023
264.002	31.863	1035.82	1035.58	0.023
266.000	34.071	1035.64	1035.39	0.024
264.000	3.165	986.60	986.06	0.056
265.999	5.039	986.41	985.87	0.055
268.001	6.911	986.21	985.69	0.054
269.998	8.775	986.03	985.51	0.053
272.000	10.639	985.84	985.32	0.053
274.001	12.500	985.66	985.15	0.052
276.000	14.358	985.48	984.99	0.050
278.000	16.211	985.30	984.81	0.049
280.000	18.055	985.12	984.64	0.049
282.000	19.896	984.95	984.46	0.049
284.000	21.739	984.77	984.30	0.048
286.001	23.576	984.59	984.13	0.047
288.001	25.405	984.42	983.96	0.047
290.002	27.232	984.24	983.78	0.046
292.001	29.052	984.07	983.62	0.046
293.999	30.863	983.90	983.44	0.046
296.001	32.674	983.72	983.27	0.046
298.002	34.472	983.55	983.08	0.048
290.000	3.181	928.67	928.26	0.044
294.001	6.173	928.32	927.93	0.042
298.001	9.162	927.98	927.62	0.039
302.001	12.142	927.65	927.31	0.037

Table I. *(Continued)*

T (K)	P (MPa)	ρ_{exp} (kg · m^{-3})	ρ_{calc} [a] (kg · m^{-3})	Dev (%)
306.000	15.117	927.32	927.01	0.033
310.000	18.082	926.99	926.72	0.030
314.002	21.038	926.67	926.43	0.027
318.001	23.980	926.35	926.13	0.024
322.002	26.907	926.03	925.82	0.023
326.001	29.821	925.71	925.51	0.022
322.000	2.989	844.86	844.56	0.035
325.998	5.150	844.56	844.32	0.029
330.002	7.313	844.26	844.06	0.023
334.000	9.475	843.97	843.82	0.017
338.000	11.638	843.68	843.58	0.012
342.001	13.793	843.39	843.30	0.011
346.000	15.951	843.13	843.06	0.008
349.999	18.109	842.84	842.82	0.002
354.000	20.264	842.55	842.58	−0.003
358.000	22.411	842.26	842.33	−0.008
362.001	24.556	841.97	842.09	−0.013
366.002	26.694	841.69	841.83	−0.017
370.000	28.826	841.40	841.58	−0.022
373.999	30.954	841.11	841.35	−0.028
378.001	33.076	840.82	841.10	−0.034
382.001	35.191	840.53	840.86	−0.040
350.001	3.005	748.82	748.21	0.082
352.000	3.740	748.69	748.14	0.073
356.001	5.217	748.44	748.00	0.059
359.998	6.700	748.18	747.85	0.044
363.999	8.190	747.93	747.70	0.031
368.000	9.684	747.68	747.53	0.019
372.002	11.181	747.43	747.36	0.010
376.000	12.681	747.18	747.16	0.002
379.998	14.182	746.93	746.97	−0.006
384.001	15.686	746.68	746.76	−0.012
387.999	17.192	746.42	746.58	−0.020
391.998	18.696	746.17	746.36	−0.025
395.998	20.203	745.92	746.16	−0.033
400.000	21.708	745.66	745.95	−0.038
372.000	3.774	640.37	639.84	0.084
376.000	4.716	640.17	639.66	0.080
380.000	5.671	639.96	639.58	0.060
384.001	6.638	639.76	639.56	0.031
388.002	7.612	639.55	639.50	0.007
391.999	8.593	639.34	639.46	−0.018
396.001	9.581	639.13	639.37	−0.037
400.000	10.573	638.92	639.26	−0.054

[a] From Ref. 1.

Table II. Experimental *p*-ρ-*T* Data for 1,1,1-Trifluoroethane (R143a)

T (K)	*P* (MPa)	ρ_{exp} (kg · m^{-3})	ρ_{calc} [a] (kg · m^{-3})	Dev (%)
165.999	3.134	1323.76	1323.50	0.019
167.998	6.290	1323.17	1322.87	0.022
169.999	9.562	1322.76	1322.45	0.023
172.000	12.854	1322.40	1322.13	0.021
174.000	16.131	1322.07	1321.85	0.017
176.000	19.413	1321.77	1321.62	0.011
177.999	22.677	1321.48	1321.42	0.005
179.999	25.936	1321.19	1321.24	−0.004
181.999	29.174	1320.91	1321.07	−0.012
183.998	32.386	1320.64	1320.89	−0.019
183.999	5.750	1284.86	1284.74	0.010
186.000	8.604	1284.47	1284.32	0.011
187.999	11.472	1284.14	1284.00	0.011
190.001	14.341	1283.83	1283.71	0.009
191.999	17.205	1283.54	1283.47	0.005
194.002	20.057	1283.26	1283.25	0.001
195.999	22.899	1282.99	1283.05	−0.005
197.999	25.737	1282.73	1282.87	−0.011
200.000	28.560	1282.47	1282.69	−0.018
201.999	31.372	1282.21	1282.52	−0.024
204.001	34.169	1281.96	1282.35	−0.030
204.002	4.725	1235.02	1234.79	0.018
206.001	7.104	1234.64	1234.35	0.023
207.999	9.507	1234.31	1234.01	0.024
209.999	11.915	1234.02	1233.72	0.025
212.001	14.324	1233.75	1233.47	0.023
213.999	16.726	1233.49	1233.24	0.020
215.999	19.122	1233.23	1233.04	0.015
217.999	21.506	1232.98	1232.85	0.011
220.000	23.889	1232.74	1232.66	0.006
222.000	26.261	1232.50	1232.50	0.001
224.000	28.620	1232.27	1232.32	−0.004
225.998	30.976	1232.03	1232.16	−0.010
227.999	33.322	1231.81	1231.99	−0.015
222.000	3.043	1186.00	1185.63	0.032
223.999	5.019	1185.52	1185.08	0.037
225.999	7.039	1185.19	1184.69	0.042
228.000	9.069	1184.89	1184.37	0.044
230.000	11.101	1184.63	1184.10	0.045
232.002	13.128	1184.37	1183.84	0.045
234.000	15.155	1184.13	1183.63	0.043
236.000	17.175	1183.89	1183.42	0.040
238.001	19.195	1183.67	1183.24	0.036
240.001	21.207	1183.43	1183.07	0.031
242.002	23.215	1183.21	1182.91	0.026
243.999	25.212	1183.00	1182.75	0.021
246.001	27.207	1182.78	1182.59	0.016
247.999	29.194	1182.56	1182.44	0.010
250.001	31.178	1182.34	1182.30	0.004

Table II. *(Continued)*

T (K)	P (MPa)	ρ_{exp} (kg·m^{-3})	ρ_{calc} [a] (kg·m^{-3})	Dev (%)
252.000	33.154	1182.13	1182.15	−0.002
254.000	35.125	1181.92	1182.00	−0.007
244.000	3.828	1129.16	1128.51	0.058
247.999	7.150	1128.51	1127.72	0.070
251.999	10.496	1128.01	1127.16	0.075
256.000	13.843	1127.55	1126.73	0.073
260.000	17.179	1127.12	1126.38	0.067
264.001	20.500	1126.70	1126.06	0.057
267.999	23.806	1126.29	1125.77	0.046
272.002	27.100	1125.90	1125.51	0.035
276.000	30.378	1125.49	1125.26	0.021
279.998	33.635	1125.10	1125.00	0.009
264.000	4.064	1072.25	1071.60	0.061
268.000	6.808	1071.70	1070.85	0.079
272.001	9.572	1071.23	1070.32	0.084
276.000	12.336	1070.81	1069.92	0.083
280.001	15.094	1070.41	1069.56	0.078
284.002	17.843	1070.02	1069.26	0.071
288.001	20.585	1069.63	1068.99	0.059
292.000	23.317	1069.26	1068.75	0.048
295.998	26.038	1068.88	1068.51	0.035
300.001	28.753	1068.51	1068.29	0.022
304.000	31.454	1068.14	1068.05	0.009
308.000	34.148	1067.78	1067.83	−0.004
283.999	4.117	1008.59	1008.05	0.054
288.001	6.337	1008.09	1007.37	0.072
292.000	8.563	1007.67	1006.85	0.081
295.999	10.792	1007.27	1006.44	0.082
300.002	13.023	1006.90	1006.11	0.079
304.001	15.250	1006.54	1005.82	0.072
307.999	17.472	1006.19	1005.56	0.063
312.000	19.682	1005.84	1005.27	0.056
316.000	21.898	1005.49	1005.06	0.043
320.000	24.108	1005.15	1004.84	0.030
324.000	26.311	1004.80	1004.63	0.018
328.001	28.506	1004.46	1004.39	0.006
331.999	30.694	1004.12	1004.17	−0.005
336.000	32.877	1003.78	1003.94	−0.016
340.001	35.050	1003.44	1003.69	−0.025
304.000	3.884	932.03	931.63	0.044
307.999	5.592	931.59	930.99	0.064
312.000	7.311	931.20	930.52	0.073
316.001	9.033	930.85	930.13	0.077
320.000	10.754	930.50	929.79	0.077
324.001	12.476	930.17	929.48	0.075
328.002	14.203	929.86	929.22	0.069
332.000	15.929	929.55	928.99	0.061
335.999	17.656	929.23	928.78	0.049
340.002	19.380	928.92	928.55	0.040

Table II. *(Continued)*

T (K)	P (MPa)	ρ_{exp} (kg · m^{-3})	ρ_{calc} [a] (kg · m^{-3})	Dev (%)
344.000	21.103	928.61	928.34	0.029
348.000	22.823	928.30	928.12	0.019
351.999	24.543	927.99	927.92	0.007
355.999	26.255	927.67	927.69	−0.002
359.999	27.964	927.36	927.44	−0.009
363.999	29.668	927.05	927.19	−0.016
367.999	31.370	926.74	926.95	−0.023
372.000	33.067	926.42	926.69	−0.029
376.001	34.760	926.11	926.43	−0.035
320.000	3.721	854.60	854.01	0.070
323.998	5.026	854.23	853.46	0.090
328.000	6.340	853.89	853.02	0.103
332.000	7.661	853.57	852.70	0.103
336.000	8.988	853.26	852.42	0.099
340.001	10.319	852.95	852.18	0.091
344.002	11.654	852.66	851.96	0.082
348.000	12.991	852.36	851.76	0.072
351.999	14.330	852.07	851.55	0.061
356.000	15.671	851.78	851.34	0.051
360.000	17.009	851.50	851.11	0.045
364.000	18.349	851.21	850.88	0.039
368.002	19.690	850.92	850.65	0.032
372.001	21.028	850.64	850.41	0.027
375.998	22.365	850.35	850.16	0.023
379.999	23.701	850.07	849.90	0.019
384.001	25.037	849.78	849.64	0.017
387.999	26.369	849.50	849.37	0.015
392.000	27.702	849.21	849.11	0.012
395.998	29.032	848.92	848.85	0.009
400.000	30.360	848.63	848.58	0.006
340.000	4.076	719.11	718.16	0.132
344.000	4.886	718.81	717.84	0.135
348.000	5.707	718.54	717.69	0.119
352.000	6.537	718.28	717.58	0.098
356.001	7.375	718.03	717.49	0.075
359.999	8.218	717.78	717.39	0.054
363.999	9.066	717.53	717.26	0.038
368.000	9.919	717.29	717.11	0.025
372.001	10.772	717.05	716.88	0.023
375.998	11.630	716.80	716.66	0.020
380.001	12.490	716.57	716.42	0.021
384.000	13.352	716.33	716.16	0.023
388.000	14.217	716.09	715.91	0.025
391.999	15.082	715.85	715.63	0.032
396.000	15.948	715.61	715.34	0.037
399.999	16.816	715.37	715.06	0.044

[a] From Ref. 2.

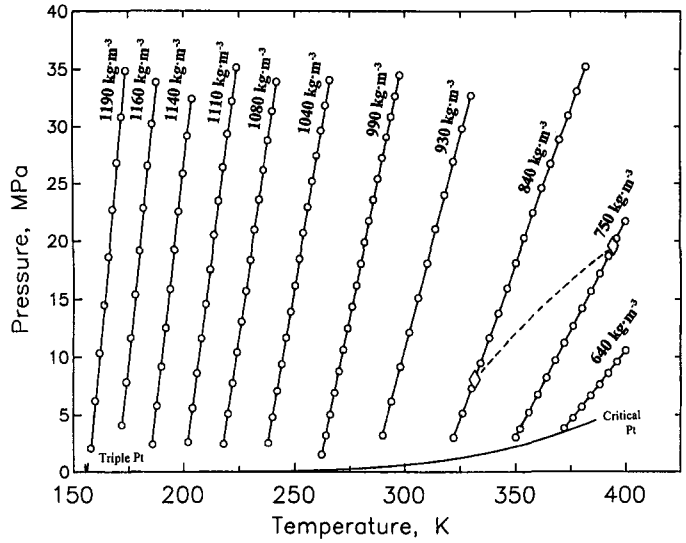

Fig. 1. Range of p-ρ-T measurements (○) for liquid 1,1-difluoroethane (R152a) and inflection points (◇) defined by $(\partial^2 p/\partial T^2)_\rho = 0$.

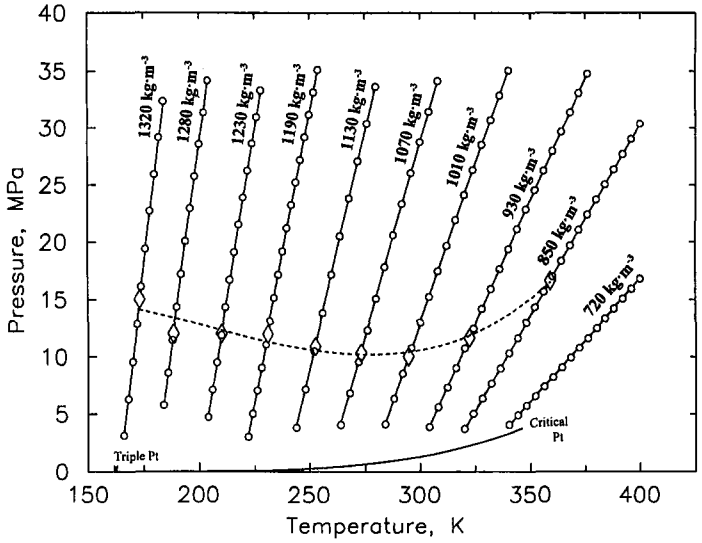

Fig. 2. Range of p-ρ-T measurements (○) for liquid 1,1,1-trifluoroethane (R143a) and inflection points (◇) defined by $(\partial^2 p/\partial T^2)_\rho = 0$.

equation of Outcalt and McLinden [1] is less than 0.024% for this work and also for Refs. 3–5, with no evidence of bias greater than ±0.015%. For liquid R143a, liquid densities of de Vries [8] agree with this study within ±0.10%. In this case, the absolute average deviation of experimental densities from the equation of Outcalt and McLinden [2] is less than 0.04% for this work and is 0.05% for Ref. 8. The bias of the two data sets is evidence of a small but systematic difference between this work and Ref. 8.

3.2. Densities of the Saturated Liquid

Saturated-liquid densities derived in this study were obtained by extrapolating the isochoric data to their intersection with the vapor pressure equation presented by Outcalt and McLinden [1, 2]. The uncertainty of the extrapolation depends primarily on the difference in the slope of the experimental isochore and the vapor pressure curve. At the high densities of this work, the uncertainty of the temperature intersection is approximately 0.01 K. This leads to a relative uncertainty of 0.10% in the density of the saturated liquid, including the experimental uncertainty of the single-phase density measurement. The results of the saturated liquid density extrapolations are presented in Table III for R152a and in Table IV for R143a. Tables III and IV present experimental temperatures on the ITS-90, saturated liquid densities, densities calculated with an ancillary equation fitted by Outcalt and McLinden [1, 2], and deviations defined by Dev. $= 100(\rho_{\text{sat, exp}} - \rho_{\text{sat, calc}})/\rho_{\text{sat, calc}}$. These deviations are depicted in Fig. 3 for R152a and in Fig. 4 for R143a. At the temperatures which overlap the study of Blanke and Weiß [5] (252 to 282 K) for R152a, the agreement of their results with this study is ±0.1%. In the overlapping range of

Table III. Saturated Liquid Density of 1,1-Difluoroethane (R152a)

T (K)	$\rho_{\text{sat, exp}}$ (kg·m^{-3})	$\rho_{\text{sat, calc}}$[a] (kg·m^{-3})	Dev. (%)
157.024	1188.2	1188.4	−0.013
169.859	1164.7	1164.7	−0.008
184.601	1137.2	1137.4	−0.011
200.298	1107.9	1107.8	0.012
216.207	1077.5	1077.3	0.020
235.872	1038.6	1038.3	0.021
260.823	986.86	986.32	0.055
286.335	928.87	928.51	0.039
318.455	845.08	844.61	0.055

[a] From Ref. 1.

Table IV. Saturated Liquid Density of 1,1,1-Trifluoroethane (R143a)

T (K)	$\rho_{sat,exp}$ (kg·m^{-3})	$\rho_{sat,calc}$ [a] (kg·m^{-3})	Dev. (%)
164.121	1324.0	1323.9	0.007
179.961	1285.8	1285.8	0.000
200.151	1235.4	1235.5	−0.012
218.626	1187.6	1187.6	0.003
238.996	1131.4	1131.5	−0.008
258.136	1074.9	1074.7	0.017
277.979	1009.2	1009.4	−0.019
298.001	932.36	932.68	−0.034

[a] From Ref. 2.

temperatures (243 to 318 K), agreement of this study with Tillner-Roth and Baehr [3] is ±0.07% and with Defibaugh and Morrison [6] is ±0.06%. Though the overlapping temperature range of Holcomb et al. [9] is short (312 to 317 K), their data agree within ±0.1%. The Higashi et al. [10] data are at temperatures above the range of this work.

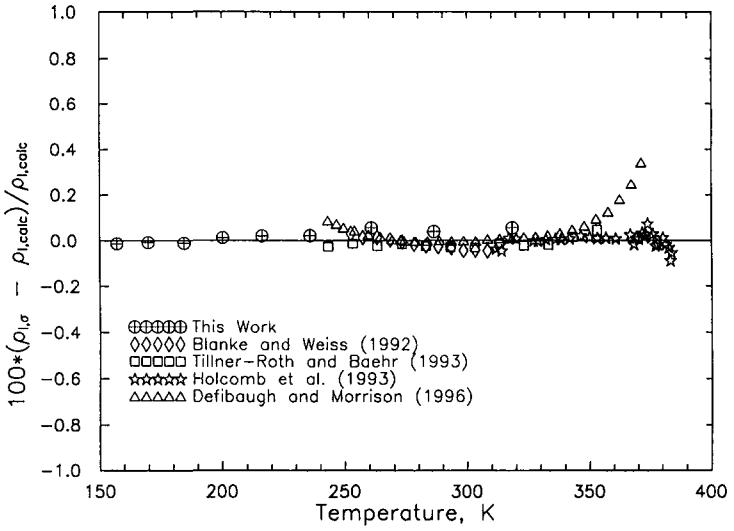

Fig. 3. Percentage deviations of the experimental saturated liquid densities for 1,1-difluoroethane (R152a) obtained in this work (⊕), by Blanke and Weiß [5] (◇), by Tillner-Roth and Baehr [4] (□), by Defibaugh and Morrison [6] (△), and by Holcomb et al. [9] (☆) from the values calculated with the ancillary equation of Outcalt and McLinden [1].

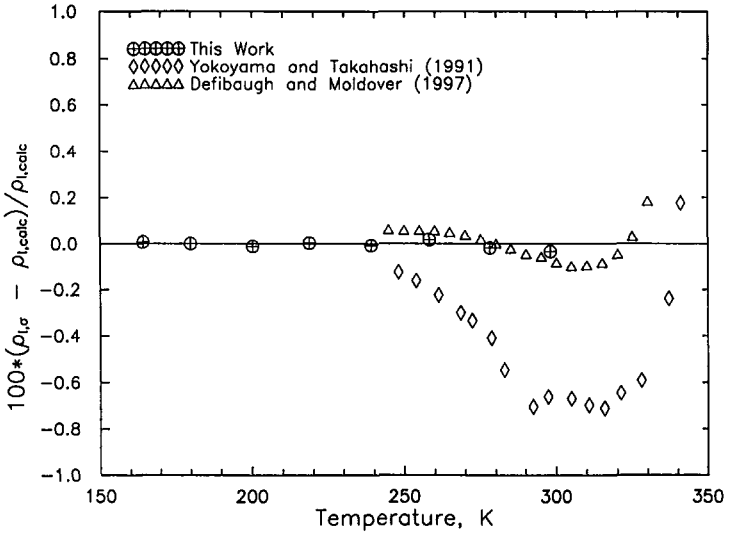

Fig. 4. Percentage deviations of the experimental saturated liquid densities for 1,1,1-trifluoroethane (R143a) obtained in this work (⊕), by Yokoyama and Takahashi [11] (◇), and by Defibaugh and Moldover [16] (△) from the values calculated with the ancillary equation of Outcalt and McLinden [2].

Unfortunately, the agreement for R143a is not nearly so good. In the temperature range of overlap (248 to 315 K), saturated-liquid densities from this work differ with those of Yokoyama and Takahashi [11] by up to ±0.7%, with significant scatter of these deviations. This falls far outside the combined uncertainties of the two data sets. Outcalt and McLinden [2] recognized this discrepancy and selected the results in Table IV and two data of Ref. 11 (336.8 and 340.9 K) to fit the ancillary equation for the saturated liquid density of R143a. Recent results that have been calculated by Defibaugh and Moldover [16] may resolve this discrepancy. These results which are given in Table V of Ref. 16 were obtained by extrapolating their equation of state for R143a to the vapor pressure. Defibaugh and Moldover state that their uncertainty for the calculated saturated liquid densities is ±0.05%, the same as their underlying single-phase density data. As shown in Fig. 4, agreement of this work with Ref. 16 is within ±0.07% at temperatures from 245 to 295 K. This is within the uncertainty claimed for the saturated liquid densities in Table IV. Evidently, this work and Ref. 16 report the most reliable saturated liquid densities for R143a.

3.3. Inflection Points

Magee and Kobayashi [17] have discussed methods for determining the locus of isochoric inflection points from compressed-gas and liquid p-ρ-T measurements. Since each p-ρ-T inflection point is defined by $(\partial^2 P/\partial T^2)_\rho = 0 = -\rho^2/T(\partial C_v/\partial \rho)_T$, it is the state condition where the isochoric heat capacity has an extremum. The locus of such inflection points maps the state conditions where a density change results in no change in the energy storage per mole. At a fixed temperature, the sign of the derivative $(\partial C_v/\partial \rho)_T$ changes at the locus of inflection points. This is a fundamental molecular property which is closely tied to the interactions of molecules in a condensed phase, where molecular packing is sufficient for neighboring molecules to affect one another. The inflection points are plotted in Fig. 1 for R152a and in Fig. 2 for R143a. The shape of the locus of inflection points for R143a has the same general appearance as reported previously for R134a [14], for R32 [15], and for R125 [15]. On the other hand, the shape of the locus of inflection points for R152a is a departure from the usual behavior of this class of highly polar hydrofluorocarbon substances. A companion paper on the C_v behavior [18] showed that liquid heat capacities of R152a were anomalously large for this class of substances. Hindered molecular rotation of molecules in the liquid state is a plausible explanation for the observed behavior of the heat capacity.

4. CONCLUSIONS

For 1,1-difluoroethane (R152a), 134 p-ρ-T state conditions and 8 saturated liquid densities have been reported. For 1,1,1-trifluoroethane (R143a), 144 p-ρ-T state conditions and 9 saturated liquid densities have been reported. The uncertainty of pressure is 0.05%, that of density is 0.05%, and that of temperature is 0.03 K. For saturated liquid densities of R152a, agreement with published values is $\pm 0.1\%$. This falls within the combined uncertainty of the results and shows the very good agreement with the other four data sets. For saturated-liquid densities of R143a, agreement with published values from one source is $\pm 0.07\%$, while poor agreement with another was found. For single-phase liquid densities of both R152a and R143a, agreement with published data is $\pm 0.1\%$.

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