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Study on Isochoric Specific Heat Capacity of Liquid R-410A and HFE-347pcf2

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Abstract The isochoric heat capacity (c_v) of R-410A [a mixture of 49.81 mass% difluoromethane (HFC-32) + 50.19 mass% pentafluoroethane (HFC-125)] and 1,1,2,2-tetrafluoroethyl-2,2,2-trifluoroethylether (HFE-347pcf2) was measured at temperatures from 277 K to 400 K and at pressures up to 30 MPa. The reported density measurements for R-410A and HFE-347pcf2 are in the single-phase region and cover a density range above $0.92\ \mathrm{g \cdot cm^{-3}}$ and $1.33\ \mathrm{g \cdot cm^{-3}}$, respectively. The measured data of R-410A are compared with data reported by other researchers. Also, the measured data of R-410A are examined with an available equation of state. As a result, it is found that the present c_v data for R-410A agree well with those by other researchers and the calculated values with the equation of state in the measurement range except near the critical isochore.

Keywords Difluoromethane (HFC-32) · Heat capacity · Pentafluoroethane (HFC-125) · *pvTx* property · R-410A · 1,1,2,2-Tetrafluoroethyl-2,2,2-trifluoroethylether (HFE-347pcf2)

1 Introduction

Recently, chlorofluorocarbon alternatives have attracted attention due to their mild impact on the environment, especially global warming and ozone depletion. Reliable

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equations of state for these working fluids are necessary to evaluate the cycle performance of environment-friendly refrigeration systems.

In order to develop a reliable equation of state for a fluid, various thermodynamic property measurements of the fluid are required. Among them, specific isochoric heat capacity (c_v) measurements provide a very useful check for calculations of the second derivative of the pressure, p, with respect to temperature, T (also, c_v measurements can be linearly correlated with the Helmholtz free energy), which is important information to develop an equation of state, but the derivative is challenging to measure accurately. However, calorimetric information, especially specific isochoric heat capacity data are very limited. For the present, R-410A which is a near azeotropic mixture having 50 mass% difluoromethane (HFC-32, CH_2F_2) and 50 mass% pentafluoroethane (HFC-125, CHF_2CF_3), is used as a refrigerant of refrigerators and heat pumps. Also, some new hydrofluoroethers are developed as candidates of the new working fluids, including 1,1,2,2-tetrafluoroethyl-2,2,2-trifluoroethylether (HFE-347pcf2, $HCF_2CF_2OCH_2CF_3$) (for example, [1]). For a mixture of 49.99 mass% HFC-32 and 50.01 mass% HFC-125 (R-410A), Perkins and Magee [2] have reported c_v results in a temperature range from 300 K to 400 K. And in previous work by the present authors [3], c_v results for R-410A in a temperature range from 268 K to 328 K have been reported. In this work, to extend and examine these results, c_v and pressure–volume–temperature–composition ($pvTx$) measurements for a mixture of 49.81 mass% HFC-32 and 50.19 mass% HFC-125 were measured at temperatures from 277 K to 395 K, and at pressures up to 30 MPa. The present measurements for R-410A are compared with c_v measurements in the liquid phase reported by the earlier studies and are evaluated with an available equation of state. Also, c_v and pressure–volume–temperature (pvT) measurements for HFE-347pcf2 at temperatures from 280 K to 400 K, and at pressures up to 30 MPa, are reported. The reported density measurements for R-410A and HFE-347pcf2 are in the single-phase region and cover a density range above $0.92\ g \cdot cm^{-3}$ and $1.33\ g \cdot cm^{-3}$, respectively.

2 Measurements

2.1 Experimental Procedures

A twin-cell type adiabatic calorimeter was used for these measurements; it has been described previously in detail by Kuroki et al. [4] and Kitajima et al. [5]. A spherical cell (approximately $33\ cm^3$) contains the sample, and a second identical cell which was made to have the same dimensions as the sample cell, serves as a reference. The calorimeter is capable of reaching 470 K. For the heat-capacity measurements, a precisely measured electrical energy (Q) is applied and the resulting temperature rise ($\Delta T = T_2 - T_1$) is measured. c_v is obtained from

$$c_v = \left(\frac{\partial u}{\partial T}\right)_V \cong \frac{\alpha\left(Q_{\mathrm{diff}} - Q_{\mathrm{diff}\,0}\right) - W_{PV}}{m\Delta T} \quad (1)$$

Table 1 Experimental c_v and pvT properties for R-410A (49.81 mass% HFC-32 + 50.19 mass% HFC-125)

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
277.15	11.982	1.2055	0.917	309.15	15.917	1.1121	0.957
278.15	12.826	1.2054	0.909	310.15	16.564	1.1120	0.947
279.15	13.669	1.2052	0.915	311.15	17.212	1.1119	0.949
280.15	14.512	1.2051	0.918	312.15	17.859	1.1117	0.941
281.15	15.355	1.2049	0.910	313.15	18.506	1.1116	0.946
282.15	16.198	1.2048	0.914	314.15	19.153	1.1115	0.951
283.15	17.040	1.2046	0.906	315.15	19.798	1.1113	0.954
284.15	17.881	1.2045	0.932	316.15	20.443	1.1112	0.941
285.15	18.722	1.2043	0.911	317.15	21.088	1.1111	0.944
286.15	19.563	1.2042	0.909	318.15	21.733	1.1109	0.943
287.15	20.403	1.2040	0.910	319.15	22.377	1.1108	0.934
288.15	21.239	1.2038	0.907	320.15	23.021	1.1107	0.952
289.15	22.077	1.2037	0.923	321.15	23.665	1.1105	0.940
291.15	23.750	1.2034	0.920	322.15	24.307	1.1104	0.941
292.15	24.585	1.2032	0.919	323.15	24.949	1.1103	0.959
293.15	25.420	1.2030	0.903	324.15	25.590	1.1101	0.936
294.15	26.254	1.2029	0.913	325.15	26.231	1.1100	0.941
295.15	27.085	1.2027	0.898	326.15	26.871	1.1098	0.937
296.15	27.917	1.2025	0.926	327.15	27.511	1.1097	0.932
297.15	28.747	1.2023	0.911	328.15	28.150	1.1095	0.938
298.15	29.575	1.2022	0.908	329.15	28.790	1.1094	0.944
297.15	8.118	1.1135	0.920	330.15	29.426	1.1092	0.935
299.15	9.422	1.1133	0.942	331.15	30.065	1.1091	0.962
300.15	10.072	1.1132	0.954	300.15	10.089	1.1131	0.911
301.15	10.723	1.1131	0.949	301.15	10.737	1.1130	0.962
302.15	11.374	1.1130	0.952	302.15	11.385	1.1129	0.926
303.15	12.024	1.1129	0.952	303.15	12.032	1.1128	0.945
304.15	12.672	1.1128	0.948	304.15	12.680	1.1127	0.946
305.15	13.320	1.1126	0.957	305.15	13.327	1.1125	0.950
306.15	13.970	1.1125	0.950	306.15	13.973	1.1124	0.949
307.15	14.620	1.1124	0.944	307.15	14.620	1.1123	0.940
308.15	15.268	1.1123	0.959	308.15	15.268	1.1122	0.937
309.15	15.915	1.1121	0.944	344.15	11.413	0.9200	0.971
310.15	16.562	1.1119	0.943	345.15	11.784	0.9199	0.982
311.15	17.208	1.1118	0.951	346.15	12.155	0.9198	0.968
312.15	17.853	1.1117	0.948	347.15	12.527	0.9197	0.995
313.15	18.499	1.1116	0.919	348.15	12.899	0.9196	0.965
314.15	19.144	1.1114	0.942	349.15	13.271	0.9196	0.976
315.15	19.788	1.1113	0.941	350.15	13.643	0.9195	0.965

Table 1 continued

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
316.15	20.432	1.1112	0.943	351.15	14.015	0.9194	0.973
317.15	21.075	1.1110	0.942	352.15	14.387	0.9193	0.966
318.15	21.719	1.1109	0.932	353.15	14.761	0.9192	0.983
319.15	22.362	1.1107	0.940	354.15	15.133	0.9191	0.971
320.15	23.005	1.1106	0.959	355.15	15.507	0.9190	0.971
321.15	23.648	1.1105	0.923	356.15	15.880	0.9190	0.962
322.15	24.289	1.1103	0.965	357.15	16.254	0.9189	0.962
323.15	24.930	1.1102	0.941	358.15	16.628	0.9188	0.973
324.15	25.571	1.1100	0.946	359.15	17.003	0.9187	0.980
325.15	26.210	1.1099	0.930	360.15	17.377	0.9187	0.943
326.15	26.850	1.1098	0.944	361.15	17.752	0.9186	0.983
327.15	27.488	1.1096	0.943	362.15	18.127	0.9185	0.979
328.15	28.127	1.1094	0.944	363.15	18.501	0.9184	0.957
329.15	28.764	1.1093	0.951	364.15	18.876	0.9183	0.974
330.15	29.402	1.1091	0.936	365.15	19.250	0.9183	0.960
330.15	6.255	0.9212	0.995	366.15	19.625	0.9182	0.966
331.15	6.620	0.9211	0.978	367.15	20.000	0.9181	0.961
332.15	6.987	0.9210	1.008	368.15	20.375	0.9180	0.959
333.15	7.355	0.9210	0.988	369.15	20.750	0.9179	0.963
334.15	7.723	0.9209	0.977	370.15	21.125	0.9178	0.954
335.15	8.090	0.9208	0.999	371.15	21.500	0.9177	0.988
336.15	8.457	0.9207	0.956	372.15	21.875	0.9176	0.958
337.15	8.826	0.9206	0.984	373.15	22.250	0.9176	0.979
338.15	9.194	0.9205	0.982	374.15	22.625	0.9175	0.968
339.15	9.563	0.9204	0.982	375.15	23.000	0.9174	0.995
340.15	9.933	0.9203	0.968	376.15	23.375	0.9173	0.977
341.15	10.302	0.9202	0.976	377.15	23.750	0.9172	0.985
342.15	10.672	0.9201	0.971	378.15	24.125	0.9171	0.988
343.15	11.043	0.9201	0.983	379.15	24.500	0.9170	0.976
380.15	24.875	0.9169	0.985	352.15	14.409	0.9196	0.947
381.15	25.250	0.9168	0.985	353.15	14.783	0.9195	0.941
382.15	25.625	0.9167	0.987	354.15	15.157	0.9194	0.942
383.15	26.000	0.9166	0.987	355.15	15.531	0.9193	0.958
384.15	26.375	0.9165	1.002	356.15	15.904	0.9192	0.949
385.15	26.750	0.9165	0.996	357.15	16.277	0.9191	0.955
386.15	27.125	0.9164	1.001	358.15	16.652	0.9191	0.951
387.15	27.500	0.9163	1.012	359.15	17.027	0.9190	0.934
388.15	27.874	0.9162	1.014	360.15	17.401	0.9189	0.958
389.15	28.249	0.9161	1.016	361.15	17.776	0.9188	0.942
390.15	28.624	0.9160	1.028	362.15	18.151	0.9187	0.950
391.15	28.998	0.9159	1.001	363.15	18.526	0.9186	0.960

Table 1 continued

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
392.15	29.373	0.9158	0.981	364.15	18.899	0.9185	0.948
329.15	5.904	0.9214	0.992	365.15	19.274	0.9184	0.964
330.15	6.269	0.9213	0.951	366.15	19.649	0.9184	0.949
331.15	6.635	0.9212	0.965	367.15	20.025	0.9183	0.942
332.15	7.002	0.9211	0.983	368.15	20.400	0.9182	0.946
333.15	7.370	0.9211	0.951	369.15	20.776	0.9181	0.945
334.15	7.736	0.9210	0.980	370.15	21.150	0.9180	0.952
335.15	8.104	0.9209	0.970	371.15	21.525	0.9179	0.943
336.15	8.472	0.9208	0.975	372.15	21.901	0.9178	0.955
337.15	8.840	0.9208	0.955	373.15	22.277	0.9178	0.957
338.15	9.209	0.9207	0.955	374.15	22.654	0.9177	0.952
339.15	9.579	0.9206	0.957	375.15	23.029	0.9176	0.965
340.15	9.949	0.9205	0.948	376.15	23.406	0.9175	0.964
341.15	10.320	0.9204	0.965	377.15	23.780	0.9174	0.975
342.15	10.691	0.9204	0.943	378.15	24.155	0.9173	0.970
343.15	11.061	0.9203	0.964	379.15	24.531	0.9172	0.966
344.15	11.431	0.9202	0.949	380.15	24.906	0.9171	0.975
345.15	11.802	0.9201	0.954	381.15	25.282	0.9170	0.948
346.15	12.174	0.9201	0.944	382.15	25.657	0.9169	0.958
347.15	12.547	0.9200	0.954	383.15	26.033	0.9168	0.962
348.15	12.919	0.9199	0.947	384.15	26.408	0.9167	0.963
349.15	13.292	0.9198	0.955	385.15	26.784	0.9166	0.953
350.15	13.664	0.9197	0.953	386.15	27.159	0.9166	0.942
351.15	14.036	0.9196	0.942	387.15	27.533	0.9165	0.972
388.15	27.907	0.9164	0.950	359.15	16.990	0.9188	0.961
389.15	28.282	0.9163	0.966	360.15	17.365	0.9187	0.955
390.15	28.657	0.9162	0.967	361.15	17.739	0.9186	0.964
391.15	29.032	0.9161	0.969	362.15	18.113	0.9185	0.955
392.15	29.407	0.9160	0.947	363.15	18.487	0.9184	0.971
393.15	29.782	0.9159	0.993	364.15	18.862	0.9184	0.952
329.15	5.865	0.9212	0.966	365.15	19.236	0.9183	0.957
330.15	6.231	0.9211	1.015	366.15	19.610	0.9182	0.963
331.15	6.598	0.9210	0.972	367.15	19.985	0.9181	0.950
332.15	6.965	0.9210	1.007	368.15	20.360	0.9180	0.954
333.15	7.333	0.9209	0.982	369.15	20.734	0.9179	0.955
334.15	7.700	0.9208	0.979	370.15	21.109	0.9178	0.974
335.15	8.069	0.9207	0.977	371.15	21.484	0.9177	0.967
336.15	8.438	0.9207	0.973	372.15	21.859	0.9176	0.969
337.15	8.807	0.9206	0.977	373.15	22.234	0.9175	0.961
338.15	9.176	0.9205	0.977	374.15	22.609	0.9175	0.971
339.15	9.546	0.9204	0.972	375.15	22.984	0.9174	0.986

Table 1 continued

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
340.15	9.916	0.9203	0.967	376.15	23.359	0.9173	0.985
341.15	10.286	0.9203	0.969	377.15	23.734	0.9172	0.980
342.15	10.657	0.9202	0.960	378.15	24.109	0.9171	0.991
343.15	11.028	0.9201	0.965	379.15	24.484	0.9170	0.991
344.15	11.399	0.9201	0.964	380.15	24.858	0.9169	0.992
345.15	11.770	0.9200	0.960	381.15	25.233	0.9168	0.995
346.15	12.143	0.9199	0.967	382.15	25.608	0.9167	0.970
347.15	12.515	0.9198	0.969	383.15	25.983	0.9166	0.995
348.15	12.887	0.9198	0.950	384.15	26.358	0.9165	1.000
349.15	13.259	0.9197	0.961	385.15	26.733	0.9164	0.998
350.15	13.631	0.9196	0.955	386.15	27.107	0.9163	0.996
351.15	14.004	0.9195	0.964	387.15	27.482	0.9162	1.012
352.15	14.377	0.9194	0.950	388.15	27.856	0.9161	1.014
353.15	14.750	0.9193	0.964	389.15	28.231	0.9160	1.019
354.15	15.123	0.9192	0.956	390.15	28.605	0.9159	1.019
355.15	15.496	0.9191	0.958	391.15	28.979	0.9158	1.015
356.15	15.869	0.9191	0.971	392.15	29.354	0.9157	1.001
357.15	16.243	0.9190	0.941	393.15	29.728	0.9156	1.018
358.15	16.617	0.9189	0.960				

where U is the internal energy, $Q_{\mathrm{diff}\,0}$ is the energy difference between the sample cell and reference cell when both cells are charged with a dilute nitrogen, Q_{diff} refers to the energy added during an experiment with a sample in the sample cell and a blank (vacuum) in the reference cell, W_{PV} is the change-of-volume work due to the slight dilation of the cell, α which was determined to be 0.940, is the available electrical energy supplied to the heater wire, and m is the mass of the sample in the sample cell.

2.2 Materials

High-purity samples of HFC-32 and HFC-125 were obtained to prepare the mixtures. The HFC-32 was certified to have a minimum purity of 0.9997 mole fraction by gas chromatographic analysis, and the minimum purity of HFC-125 was 0.9990. Also, the minimum purity of HFE-347pcf2 was 99.9 mass%. The mixture of this study was prepared inside the calorimeter cell. A quantity of each pure component was filled into its own lightweight cylinder (75 cm^3) and was weighed with a digital balance having a 0.1 mg uncertainty. After both components of the mixture were introduced into the cell from these cylinders, the cell was cooled by liquid nitrogen. The remaining mass in each cylinder was weighed, and the composition of the sample in the cell was calculated from the mass values charged into the cell. The R-410A composition in this study consists of 49.81 mass% HFC-32 and 50.19 mass% HFC-125 which is slightly

Table 2 Experimental c_v and pvT properties for HFE-347pcf2

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
280.15	6.663	1.5349	0.939	288.15	14.722	1.5332	0.965
281.15	7.673	1.5346	0.971	289.15	15.720	1.5330	0.966
282.15	8.685	1.5344	0.953	290.15	16.717	1.5328	0.979
283.15	9.695	1.5342	0.959	291.15	17.711	1.5326	0.968
284.15	10.704	1.5340	0.967	292.15	18.703	1.5325	0.965
285.15	11.710	1.5338	0.958	293.15	19.694	1.5323	0.977
286.15	12.714	1.5336	0.969	294.15	20.683	1.5321	0.966
287.15	13.718	1.5334	0.965	295.15	21.669	1.5319	0.968
288.15	14.719	1.5332	0.961	296.15	22.654	1.5318	0.979
289.15	15.719	1.5330	0.968	297.15	23.636	1.5316	0.972
290.15	16.716	1.5328	0.967	298.15	24.617	1.5314	0.969
291.15	17.712	1.5326	0.972	299.15	25.596	1.5313	0.982
292.15	18.704	1.5324	0.965	300.15	26.573	1.5311	0.969
293.15	19.694	1.5323	0.967	301.15	27.548	1.5310	0.979
294.15	20.683	1.5321	0.974	302.15	28.521	1.5309	0.975
295.15	21.669	1.5319	0.962	303.15	29.493	1.5307	0.984
296.15	22.653	1.5318	0.975	302.15	7.147	1.4842	0.982
297.15	23.636	1.5316	0.969	303.15	8.010	1.4840	0.970
298.15	24.616	1.5314	0.969	304.15	8.873	1.4838	0.976
299.15	25.595	1.5313	0.977	305.15	9.734	1.4836	0.988
300.15	26.572	1.5311	0.970	306.15	10.594	1.4834	0.980
301.15	27.548	1.5310	0.981	307.15	11.452	1.4832	0.985
302.15	28.522	1.5309	0.968	308.15	12.308	1.4831	0.981
303.15	29.493	1.5307	0.983	309.15	13.163	1.4829	0.987
279.15	5.663	1.5352	0.949	310.15	14.016	1.4827	0.982
280.15	6.673	1.5349	0.957	311.15	14.867	1.4825	0.985
281.15	7.685	1.5347	0.946	312.15	15.718	1.4824	0.986
282.15	8.696	1.5345	0.968	313.15	16.566	1.4822	0.985
283.15	9.705	1.5343	0.962	314.15	17.414	1.4820	0.984
284.15	10.712	1.5340	0.959	315.15	18.260	1.4818	0.982
285.15	11.717	1.5338	0.968	316.15	19.105	1.4817	0.989
286.15	12.720	1.5336	0.958	317.15	19.949	1.4815	0.992
287.15	13.722	1.5334	0.973	318.15	20.791	1.4814	0.993
319.15	21.632	1.4812	0.988	324.15	25.816	1.4805	1.003
320.15	22.471	1.4811	0.996	325.15	26.650	1.4804	0.995
321.15	23.311	1.4809	0.992	326.15	27.482	1.4802	1.004
322.15	24.148	1.4808	0.990	327.15	28.313	1.4801	0.998
323.15	24.983	1.4806	0.995	328.15	29.144	1.4800	1.003
324.15	25.819	1.4805	1.005	329.15	29.973	1.4799	1.008
325.15	26.653	1.4804	0.985	329.15	7.678	1.4203	0.991
326.15	27.484	1.4802	0.999	330.15	8.385	1.4201	1.033

Table 2 continued

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
327.15	28.315	1.4801	0.993	331.15	9.091	1.4200	1.019
328.15	29.145	1.4800	1.009	332.15	9.796	1.4198	1.026
329.15	29.975	1.4799	1.001	333.15	10.500	1.4196	1.024
301.15	6.294	1.4844	0.985	334.15	11.204	1.4195	1.029
303.15	8.015	1.4840	0.988	335.15	11.908	1.4193	1.031
304.15	8.874	1.4838	0.972	336.15	12.610	1.4192	1.026
305.15	9.734	1.4836	0.989	337.15	13.313	1.4190	1.042
306.15	10.592	1.4834	0.977	338.15	14.014	1.4188	1.021
307.15	11.449	1.4832	0.986	339.15	14.714	1.4187	1.042
308.15	12.303	1.4830	0.976	340.15	15.413	1.4185	1.035
309.15	13.157	1.4828	0.987	341.15	16.111	1.4184	1.035
310.15	14.009	1.4827	0.978	342.15	16.809	1.4183	1.035
311.15	14.859	1.4825	0.982	343.15	17.505	1.4181	1.035
312.15	15.708	1.4823	0.990	344.15	18.201	1.4180	1.042
313.15	16.557	1.4821	0.984	345.15	18.896	1.4178	1.038
314.15	17.405	1.4820	0.990	346.15	19.590	1.4177	1.044
315.15	18.252	1.4818	0.995	347.15	20.282	1.4175	1.042
316.15	19.097	1.4817	0.987	348.15	20.974	1.4174	1.049
317.15	19.942	1.4815	1.004	349.15	21.666	1.4173	1.050
318.15	20.785	1.4814	0.991	350.15	22.357	1.4171	1.043
319.15	21.626	1.4812	0.989	351.15	23.047	1.4170	1.049
320.15	22.467	1.4811	1.002	352.15	23.735	1.4169	1.054
321.15	23.306	1.4809	0.996	353.15	24.423	1.4168	1.051
322.15	24.144	1.4808	0.995	354.15	25.110	1.4166	1.054
323.15	24.980	1.4806	0.998	355.15	25.797	1.4165	1.055
356.15	26.482	1.4164	1.059	356.15	26.486	1.4164	1.063
357.15	27.166	1.4163	1.056	357.15	27.171	1.4163	1.051
358.15	27.851	1.4162	1.061	358.15	27.855	1.4162	1.057
359.15	28.535	1.4161	1.064	359.15	28.538	1.4161	1.052
360.15	29.217	1.4159	1.070	360.15	29.220	1.4160	1.063
361.15	29.899	1.4158	1.067	361.15	29.902	1.4159	1.056
329.15	7.689	1.4203	1.008	359.15	5.632	1.3344	1.044
330.15	8.394	1.4201	1.018	360.15	6.174	1.3342	1.098
331.15	9.099	1.4199	1.016	361.15	6.718	1.3341	1.091
332.15	9.803	1.4198	1.017	362.15	7.261	1.3339	1.079
333.15	10.506	1.4196	1.021	363.15	7.803	1.3338	1.091
334.15	11.209	1.4195	1.023	364.15	8.346	1.3336	1.095
335.15	11.912	1.4193	1.025	365.15	8.888	1.3335	1.083
336.15	12.614	1.4191	1.021	366.15	9.430	1.3333	1.089
337.15	13.315	1.4190	1.033	367.15	9.971	1.3332	1.087
338.15	14.016	1.4188	1.023	368.15	10.512	1.3331	1.095

Table 2 continued

T (K)	p (MPa)	ρ ($g \cdot cm^{-3}$)	c_v ($J \cdot g^{-1} \cdot K^{-1}$)	T (K)	p (MPa)	ρ ($g \cdot cm^{-3}$)	c_v ($J \cdot g^{-1} \cdot K^{-1}$)
339.15	14.716	1.4187	1.030	369.15	11.053	1.3329	1.106
340.15	15.416	1.4185	1.034	370.15	11.593	1.3328	1.094
341.15	16.114	1.4184	1.040	371.15	12.133	1.3327	1.093
342.15	16.812	1.4183	1.023	372.15	12.673	1.3325	1.094
343.15	17.508	1.4181	1.047	373.15	13.212	1.3324	1.098
344.15	18.203	1.4180	1.034	374.15	13.752	1.3323	1.097
345.15	18.898	1.4178	1.042	375.15	14.290	1.3322	1.089
346.15	19.592	1.4177	1.047	376.15	14.828	1.3320	1.104
347.15	20.287	1.4176	1.046	377.15	15.366	1.3319	1.100
348.15	20.978	1.4174	1.040	378.15	15.904	1.3318	1.092
349.15	21.671	1.4173	1.043	379.15	16.441	1.3317	1.094
350.15	22.360	1.4172	1.049	380.15	16.977	1.3315	1.096
351.15	23.050	1.4170	1.046	381.15	17.514	1.3314	1.096
352.15	23.739	1.4169	1.052	382.15	18.050	1.3313	1.099
353.15	24.426	1.4168	1.040	383.15	18.585	1.3312	1.106
354.15	25.114	1.4167	1.062	384.15	19.120	1.3311	1.103
355.15	25.801	1.4165	1.047	385.15	19.655	1.3309	1.094
386.15	20.189	1.3308	1.105	373.15	13.216	1.3324	1.089
387.15	20.723	1.3307	1.118	374.15	13.756	1.3323	1.088
388.15	21.256	1.3306	1.123	375.15	14.294	1.3322	1.095
389.15	21.789	1.3305	1.128	376.15	14.831	1.3320	1.094
390.15	22.322	1.3304	1.134	377.15	15.369	1.3319	1.092
391.15	22.855	1.3303	1.142	378.15	15.906	1.3318	1.098
392.15	23.386	1.3302	1.135	379.15	16.443	1.3317	1.099
393.15	23.917	1.3300	1.141	380.15	16.980	1.3315	1.097
394.15	24.448	1.3299	1.131	381.15	17.515	1.3314	1.086
395.15	24.978	1.3298	1.133	382.15	18.051	1.3313	1.098
396.15	25.507	1.3297	1.145	383.15	18.586	1.3312	1.107
397.15	26.037	1.3296	1.140	384.15	19.121	1.3311	1.110
398.15	26.566	1.3295	1.145	385.15	19.656	1.3309	1.103
399.15	27.094	1.3294	1.135	386.15	20.189	1.3308	1.105
400.15	27.622	1.3293	1.143	387.15	20.723	1.3307	1.123
401.15	28.150	1.3292	1.148	388.15	21.256	1.3306	1.120
402.15	28.677	1.3291	1.133	389.15	21.789	1.3305	1.124
403.15	29.204	1.3290	1.146	390.15	22.322	1.3304	1.124
404.15	29.730	1.3290	1.139	391.15	22.854	1.3303	1.123
359.15	5.637	1.3344	1.063	392.15	23.385	1.3302	1.125
360.15	6.180	1.3342	1.085	393.15	23.917	1.3301	1.132
361.15	6.724	1.3341	1.083	394.15	24.448	1.3299	1.118
362.15	7.266	1.3339	1.082	395.15	24.978	1.3298	1.125
363.15	7.809	1.3338	1.077	396.15	25.508	1.3297	1.134

Table 2 continued

T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})	T (K)	p (MPa)	ρ (g · cm^{-3})	c_v (J · g^{-1} · K^{-1})
364.15	8.350	1.3336	1.080	397.15	26.038	1.3296	1.130
365.15	8.892	1.3335	1.079	398.15	26.567	1.3295	1.135
366.15	9.434	1.3334	1.084	399.15	27.096	1.3294	1.139
367.15	9.976	1.3332	1.072	400.15	27.623	1.3293	1.142
368.15	10.516	1.3331	1.082	401.15	28.151	1.3292	1.138
369.15	11.057	1.3329	1.085	402.15	28.678	1.3292	1.136
370.15	11.598	1.3328	1.087	403.15	29.205	1.3291	1.139
371.15	12.137	1.3327	1.094	404.15	29.732	1.3290	1.149
372.15	12.677	1.3326	1.079				

shifted from the nominal composition of R-410A (50 mass% HFC-32 and 50 mass% HFC-125). To ensure complete homogenization prior to measurements, the sample temperature was rapidly increased until the sample pressure reached 20 MPa, then it was cooled.

2.3 Assessment of Uncertainties

The experimental expanded uncertainty (with a coverage factor $k = 2$) of the absolute temperature measurement is 13 mK, by considering the calibration report of the PRTs (±2 mK), temperature gradients in the cell, and the uncertainty of each instrument. That ($k = 2$) of the pressure measurement is 8 kPa, based on the pressure transducer's specifications and the uncertainty of the instruments. The standard uncertainty of the inner volume of the cell is 0.025 cm^3, estimated by calibration with distilled water, and that of the mass measurement is 0.15 mg, based on the balance's specifications and the standard uncertainty of air buoyancy estimation. The estimated expanded uncertainty of the density is 0.16 %, as derived from the standard uncertainties of the inner volume of the cell and the mass measurement.

The expanded uncertainty of c_v is estimated from a combination of the standard uncertainty of the elapsed time required for a 1 K temperature rise (0.65 %), that of the change-of-volume work (20 %) which contributes 0.3 % to the uncertainty of c_v, the experimental standard deviation of α of 0.6 %, the uncertainty of the density, and the temperature fluctuation of adiabatic shields which contributes an amount of $0.4/(mc_v)$ J · g^{-1} · K^{-1} to the uncertainty of c_v. The resulting expanded uncertainty ($k = 2$) of c_v ranges from 3.0 % to 4.5 % in the liquid.

3 Results

The experimental c_v and $pvTx$ results at temperatures spaced by 1 K for R-410A and HFE-347pcf2 are presented in Tables 1 and 2, respectively. Figure 1 shows the pressure

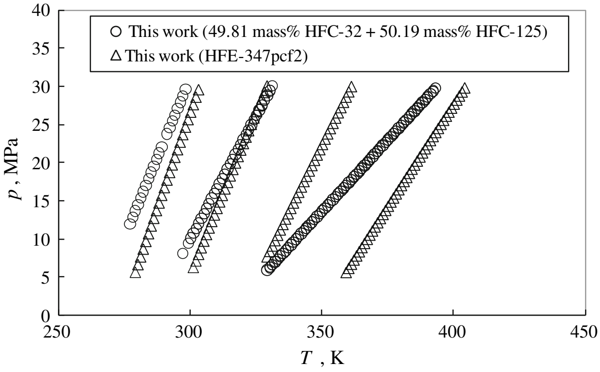

Fig. 1 Range of experimental measurements for this work

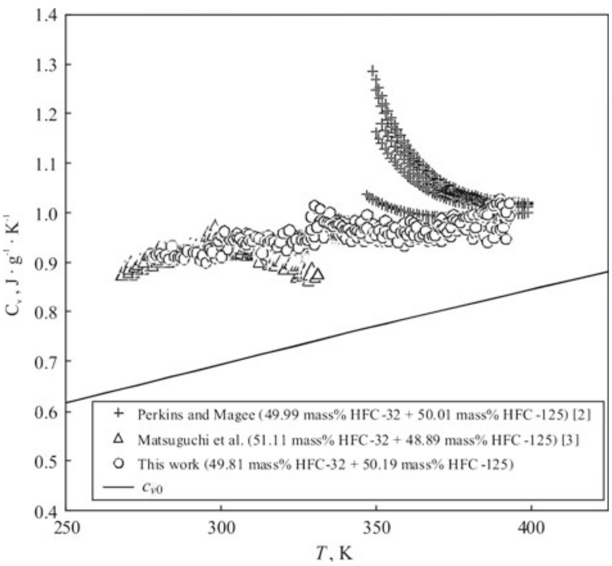

Fig. 2 Isochoric heat capacities for R-410A at liquid-phase states

and temperature diagram of these measurements for R-410A and HFE-347pcf2. Three isochores for R-410A and four isochores for HFE-347pcf2 were obtained.

Figure 2 shows the behavior of the present c_v data of R-410A, and calculated specific heat capacity of the ideal gas, c_{v0}, by using selected correlations by Lemmon and Jacobsen [6]. Figure 3 shows deviations of the present c_v data for R-410A from calculated values by using a mixing rule which was proposed by Lemmon and Jacobsen [6]. Also, the data measured with a calorimeter by Perkins and Magee [2] and previous work of the current authors [3] are superimposed in Figs. 2 and 3. The present c_v data for $\rho > 0.92\,\mathrm{g \cdot cm^{-3}}$ from 277 K to 393 K agree well with the calculated values within the experimental expanded uncertainty as well as the data reported by Perkins and Magee and previously presented by the authors.

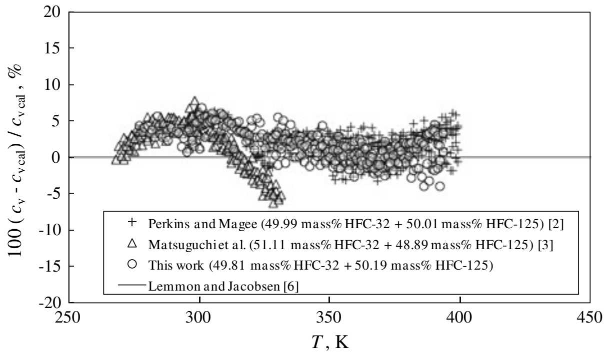

Fig. 3 Deviations of measured c_v for R-410A from calculations with a mixing rule by Lemmon and Jacobsen [6]

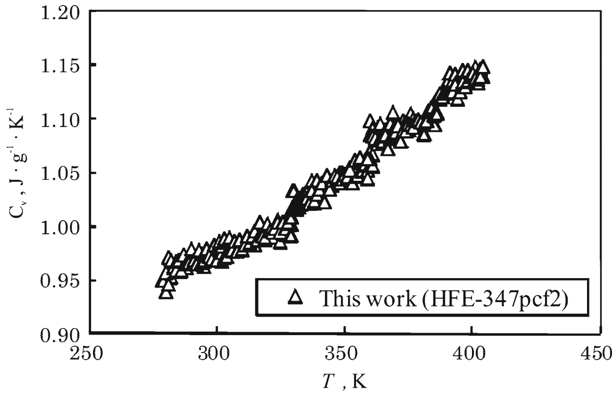

Fig. 4 Isochoric heat capacities for HFE-347pcf2 at liquid-phase states

Figure 4 shows the behavior of the present c_v data for HFE-347pcf2. In the measurement range, the data show a monotonic increase. At present, there is no experimental calorimetric information for this fluid in the literature that can be compared with the data. It is expected that the measured values are useful for preparation of a new equation of state and for design of industrial applications.

4 Conclusions

Measurements of c_v and $pvTx$ properties were reported for the mixture of 49.81 mass% HFC-32 and 50.19 mass% HFC-125 and the pure substance of HFE-347pcf2 in the liquid phase. The published equation of state for R-410A represents the observed behavior of c_v measurements over the measurement range. So the calorimetric information is very useful; these data will be essential to develop new accurate equations of state to represent thermodynamic properties for the binary mixture of the fluids and the new hydrofluoroethers.

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