However for 1-chlorooctane systems, the effect of increasing the alcohol chain length from C_4 to C_8 is the opposite.

Finally, Figures 3 and 4 show that both the increase in the chloroalkane chain length and the change of the position of the Cl atom from C1 to C2 increase the heat of mixing for the chloroalkane–*n*-alcohol systems.

Acknowledgment

Thanks are due to Mr. R. Shamash for assistance with the experimental work.

Glossary

x	mole fraction
ΔH	heat of mixing per mole of mixture, J/mol

Literature Cited

(1) American Petroleum Institute, Research Project 44, "Selected Values of Properties of Hydrocarbons and Related Compounds", College Station, Tex.
(2) Dictionary of Organic Compounds, Eyre and Spottiswoode Ltd., E. & F. N. Spon Ltd., London, 1965.
(3) Grolier, J.-P. E., Sosnkowska-Kehiaian, K., Kehiaian, H. V., *J. Chim. Phys. Phys.-Chim. Biol.*, **2**, 367 (1973).
(4) Klaus, R. L., Van Ness, H. C., *AIChE J.*, **6**, 1132 (1967).
(5) Nguyen, T. H., Ratcliff, G. A., *J. Chem. Eng. Data*, **20**, 252 (1975).
(6) Savini, C. G., Winterhalter, D. R., Kovach, L. H., Van Ness, H. C., *J. Chem. Eng. Data*, **11**, 40 (1966).

Received for review August 8, 1977. Accepted January 12, 1978. The authors are grateful for financial assistance from the National Research Council of Canada. A complete set of tables for the heats of mixing is available, at a nominal charge, from the Depository of Unpublished Data, CISTI, National Research Council of Canada, Ottawa, Canada, K1A OS2.

Isochoric Pressure–Volume–Temperature Measurements for Compressed Liquid Propane

James F. Ely and Riki Kobayashi*

Department of Chemical Engineering, William Marsh Rice University, Houston, Texas 77001

Isochoric *P–V–T* measurements have been made on compressed liquid propane using a newly constructed Invar cell. The results, which are nearly perfectly isochoric, cover a previously unexplored portion of propane's *P–V–T* surface, viz., densities from ~0.65 to ~0.51 g/cm³, temperatures from 165 to 325 K, and pressures extending to ~42 MPa (6000 psia). The results are tabulated as pseudoisochores and as adjusted true isochores in Table I.

There have been numerous studies of the volumetric behavior of liquid and gaseous propane as recently documented by Goodwin (*1*). None of these studies, unfortunately, extended substantially into the cryogenic region of the phase diagram. Due to the practical importance of this region in LNG density calculations, a study has been undertaken to investigate propane *P–V–T* behavior below 325 K by an apparatus and technique discussed previously (*2*). The subject of the studies selected was Phillips Petroleum research grade propane (99.98%) whose purity was substantiated.

The results of this study are given as smoothed pseudoisochores in Table I, columns 1, 2, and 3. Columns 3 and 4, on the other hand, represent values of temperature and pressure corresponding to the fixed isochoric values tested in the fourth column of the same table. Uncertainties in the densities are

Table I. Smoothed Pseudoisochores and Isochores for Liquid Propane

p, MPa (at pseudoisochore)	ρ, g/cm³	T, K	p, MPa (at isochore)	p, MPa (at pseudo-isochore)	ρ, g/cm³	T, K	p, MPa (at isochore)
			$\rho = 0.651\ 60$				$\rho = 0.651\ 60$
0.70326	0.651 60	166.227	0.70326	20.685	0.651 39	178.373	21.052
2.7642	0.651 58	167.461	2.7963	27.411	0.651 32	182.557	27.916
4.9045	0.651 56	168.747	4.9694	35.720	0.651 24	187.796	26.394
8.7235	0.651 52	171.053	8.8563	38.892	0.651 21	189.817	39.632
14.279	0.651 46	174.434	14.517				
			$\rho = 0.640\ 50$				$\rho = 0.640\ 50$
1.3550	0.640 48	177.351	1.3841	21.735	0.640 27	190.854	22.104
5.1280	0.640 44	179.819	5.2167	27.561	0.640 21	194.795	28.039
7.7509	0.640 41	181.543	7.8855	33.593	0.640 15	198.915	34.186
10.459	0.640 39	183.330	10.626	37.250	0.640 11	201.433	37.922
17.313	0.640 32	187.888	17.596	41.844	0.640 06	204.618	42.619
			$\rho = 0.632\ 34$				$\rho = 0.632\ 34$
0.61631	0.632 34	184.715	0.61631	19.735	0.632 14	198.151	20.031
2.4300	0.632 32	185.973	2.4571	27.955	0.632 05	204.051	28.403
4.2992	0.632 30	187.723	4.3541	34.147	0.631 99	208.548	34.704
8.1375	0.632 26	189.954	8.2489	41.214	0.631 91	213.736	41.922
15.111	0.632 19	194.865	15.328				

0021-9568/78/1723-0221$01.00/0

Table I (*Continued*)

p, MPa (at pseudoisochore)	ρ, g/cm^3	T, K	p, MPa (at isochore)	p, MPa (at pseudo-isochore)	ρ, g/cm^3	T, K	p, MPa (at isochore)
			$\rho = 0.624\ 21$				$\rho = 0.624\ 21$
0.9624	0.624 19	192.615	0.94095	18.768	0.624 01	205.926	19.043
1.5904	0.624 19	193.111	1.6152	23.477	0.623 96	209.500	23.829
5.3735	0.624 15	195.904	5.4500	28.232	0.623 91	213.137	28.666
7.0407	0.624 13	197.140	7.1437	30.672	0.623 88	215.014	31.155
10.065	0.624 10	199.390	10.209	33.610	0.623 85	217.285	34.145
14.366	0.624 05	202.609	14.581	37.257	0.623 81	220.119	37.863
			$\rho = 0.616\ 96$				$\rho = 0.616\ 96$
0.53778	0.616 96	199.157	0.53778	22.326	0.616 73	216.347	22.6298
2.2353	0.616 94	200.472	2.2588	22.430	0.616 72	216.464	22.7470
5.2383	0.616 91	202.817	5.2982	28.031	0.616 66	221.205	28.4402
9.7993	0.616 86	206.391	9.9222	34.043	0.616 60	225.885	34.5493
15.602	0.616 80	210.980	15.8054	40.366	0.616 53	231.094	40.9913
			$\rho = 0.611\ 06$				$\rho = 0.611\ 06$
1.7649	0.611 05	205.755	1.7761	25.432	0.610 80	225.334	25.765
3.6606	0.611 03	207.297	3.6944	28.052	0.610 78	227.547	28.416
6.2801	0.611 01	209.435	6.3370	31.906	0.610 73	230.819	32.344
10.049	0.610 97	212.526	10.154	37.055	0.610 68	235.224	37.574
14.956	0.610 91	216.578	15.137	39.489	0.610 65	237.320	40.056
19.259	0.610 87	220.157	19.494				
			$\rho = 0.603\ 95$				$\rho = 0.603\ 95$
0.40745	0.603 95	211.641	0.40745	21.774	0.603 72	230.231	22.047
1.6320	0.603 94	212.694	1.6425	27.406	0.603 66	235.520	28.062
3.2652	0.603 92	214.101	3.2969	34.162	0.603 59	241.297	34.621
7.6602	0.603 87	217.902	7.7473	38.022	0.603 56	244.776	38.531
12.473	0.603 82	222.089	12.619	41.076	0.603 51	247.542	41.659
16.314	0.603 78	225.450	16.509				
			$\rho = 0.596\ 04$				$\rho = 0.596\ 04$
0.77793	0.596 03	218.855	0.78750	15.056	0.595 88	231.940	15.226
1.5821	0.596 02	219.585	1.6015	17.993	0.595 85	234.664	18.198
3.3908	0.596 00	221.230	3.4300	21.661	0.595 81	238.083	21.916
6.0763	0.595 98	223.680	6.1361	26.248	0.595 76	242.385	26.567
8.7463	0.595 95	226.125	8.8378	30.820	0.595 71	246.702	31.207
10.515	0.595 93	227.750	10.628	35.682	0.595 66	251.325	36.140
11.722	0.595 92	228.861	11.846	41.182	0.595 60	256.596	41.730
12.525	0.595 91	229.601	12.660				
			$\rho = 0.587\ 17$				$\rho = 0.587\ 17$
1.1092	0.587 16	226.866	1.1182	22.019	0.586 94	247.394	22.256
2.9726	0.587 14	228.670	2.9995	24.779	0.586 91	250.151	25.052
5.3514	0.587 12	230.980	5.3974	29.269	0.586 86	254.663	29.604
8.5084	0.587 08	234.058	8.5929	32.860	0.586 82	258.294	33.247
11.881	0.587 06	237.362	11.987	36.469	0.586 76	261.963	36.932
16.696	0.587 00	242.108	16.865	40.001	0.586 74	265.574	40.497
			$\rho = 0.580\ 71$				$\rho = 0.580\ 71$
1.1792	0.580 70	232.965	1.1875	12.915	0.580 58	245.001	13.034
2.7885	0.580 69	239.603	2.8055	17.302	0.580 53	249.556	17.472
2.8562	0.580 69	234.672	2.8731	21.615	0.580 48	254.065	21.839
4.4938	0.580 67	236.343	4.5282	26.221	0.580 43	258.913	26.503
6.2641	0.580 65	238.154	6.3164	30.610	0.580 38	263.566	30.952
7.8622	0.580 63	239.793	7.9328	35.339	0.580 33	268.618	35.746
10.377	0.580 60	242.380	10.476	39.466	0.580 28	273.058	39.939
			$\rho = 0.576\ 47$				$\rho = 0.576\ 47$
0.45701	0.576 47	235.542	0.45701	13.466	0.576 33	249.203	13.590
1.0563	0.576 46	236.163	1.0642	16.944	0.576 29	252.921	17.107
1.9745	0.576 45	237.116	1.9906	20.283	0.576 25	256.518	20.487
2.8112	0.576 44	237.986	2.8357	24.149	0.576 21	260.718	24.397
4.3844	0.576 43	239.626	4.4173	27.549	0.576 17	264.442	27.843
6.8363	0.576 40	242.193	6.8950	30.763	0.576 13	267.990	31.103
10.063	0.576 37	245.592	10.149				
			$\rho = 0.563\ 27$				$\rho = 0.563\ 27$
1.5453	0.563 26	247.820	1.5522	19.001	0.563 07	268.171	19.165
2.2614	0.563 26	248.646	2.2684	21.550	0.563 04	271.181	21.743
3.7322	0.563 24	250.345	3.7537	25.815	0.562 99	276.240	26.058
5.2754	0.563 22	252.131	5.3117	30.173	0.562 94	281.440	30.469
7.0999	0.563 20	254.247	7.1518	34.760	0.562 89	286.945	35.112
9.2827	0.563 18	256.785	9.3507	34.779	0.562 89	286.968	35.131
11.713	0.563 15	259.619	11.806	38.172	0.562 85	291.062	38.571
14.184	0.563 12	262.510	14.302	42.779	0.562 80	296.653	43.241
16.728	0.563 09	265.495	16.873				
			$\rho = 0.561\ 87$				$\rho = 0.561\ 87$
0.25707	0.561 87	247.621	0.25707	9.6241	0.561 77	258.548	9.6990
0.35457	0.561 87	247.734	0.35457	13.781	0.561 72	263.440	13.897
1.0065	0.561 87	248.490	1.0065	17.793	0.561 68	268.197	17.946
1.1642	0.561 86	248.673	1.1713	22.125	0.561 63	273.360	22.325
1.7130	0.561 86	249.310	1.7201	26.307	0.561 58	278.376	26.557
2.5934	0.561 85	250.333	2.6075	30.330	0.561 53	283.231	30.632
3.2424	0.561 84	251.088	3.2637	34.826	0.561 48	288.691	35.184

Table I (*Continued*)

p, MPa (at pseudoisochore)	ρ, g/cm^3	T, K	p, MPa (at isochore)	p, MPa (at pseudo-isochore)	ρ, g/cm^3	T, K	p, MPa (at isochore)
4.8612	0.561 82	252.974	4.8971	38.439	0.561 44	293.107	38.844
7.4466	0.561 79	255.995	7.5054	42.295	0.561 40	297.847	42.750
			ρ = 0.559 53				ρ = 0.559 53
0.77669	0.559 53	250.200	0.77669	11.783	0.559 40	263.239	11.880
1.5143	0.559 52	251.067	1.5211	15.766	0.559 36	268.014	15.898
2.2426	0.559 51	251.924	2.2563	22.612	0.559 28	276.292	22.817
3.9104	0.559 49	253.890	3.9381	28.499	0.559 21	283.484	28.774
7.6451	0.559 45	258.311	7.7025	37.369	0.559 11	294.455	37.755
11.755	0.559 40	263.206	11.852				
			ρ = 0.548 84				ρ = 0.548 84
0.75502	0.548 83	258.574	0.76117	23.623	0.548 57	288.215	23.827
2.0907	0.548 82	260.283	2.1029	27.527	0.548 53	293.359	27.769
5.5231	0.548 78	264.687	5.5614	30.896	0.548 49	297.819	31.177
9.0289	0.548 74	269.204	9.0949	32.915	0.548 46	300.501	33.225
12.134	0.548 70	273.221	12.229	36.580	0.548 42	305.386	36.933
16.463	0.548 65	278.846	16.597	40.641	0.548 37	310.827	41.049
20.235	0.548 61	283.771	20.403				
			ρ = 0.536 01				ρ = 0.536 01
0.40412	0.536 01	267.752	0.40412	9.4447	0.535 90	280.521	9.5090
0.83702	0.536 00	268.361	0.84230	11.712	0.535 88	283.740	11.790
1.5169	0.536 00	269.318	1.5222	14.693	0.535 84	287.984	14.798
2.0268	0.535 99	270.036	2.0373	18.607	0.535 80	293.573	18.742
2.8457	0.535 98	271.190	2.8620	22.457	0.535 75	299.091	22.631
4.2877	0.535 96	273.224	4.3153	26.395	0.535 70	304.757	26.610
5.7722	0.535 95	275.321	5.8059	31.891	0.535 64	312.701	32.162
7.3345	0.535 93	277.531	7.3800	39.479	0.535 55	323.740	39.839
			ρ = 0.521 97				ρ = 0.521 97
0.55168	0.521 97	277.973	0.55168	11.224	0.521 84	294.597	11.291
0.74186	0.521 97	278.268	0.74186	14.662	0.521 80	299.983	14.754
2.1805	0.521 95	280.501	2.1897	19.978	0.521 74	308.342	20.110
4.2392	0.521 93	283.701	4.2582	27.300	0.526 15	319.913	27.500
7.6082	0.521 88	288.949	7.6529				
			ρ = 0.507 93				ρ = 0.507 93
0.99499	0.507 93	288.263	0.99499	9.8936	0.507 82	303.696	9.9424
1.4087	0.507 92	288.981	1.4126	11.876	0.507 79	307.131	11.940
2.7986	0.507 91	291.393	2.8065	13.978	0.507 77	310.771	14.053
4.0067	0.507 89	293.489	4.0229	15.946	0.507 74	314.179	16.038
5.7744	0.507 87	296.555	5.7993	18.038	0.507 72	317.799	18.142
7.8212	0.507 84	300.104	7.8599	20.160	0.507 69	321.470	20.282

Table II. Saturated Liquid Densities

T, K	ρ, g/cm^3	ρ,[a] g/cm^3	Dev,[b] %
165.809	0.651 60	0.651 50	0.015
176.472	0.640 50	0.640 39	0.017
184.294	0.632 34	0.632 15	0.030
191.936	0.624 21	0.624 02	0.030
198.748	0.616 96	0.616 70	0.042
204.329	0.611 06	0.610 64	0.069
211.320	0.603 95	0.602 97	0.162
218.200	0.596 04	0.595 31	0.122
225.876	0.587 17	0.586 62	0.094
231.875	0.580 71	0.579 72	0.170
235.183	0.576 47	0.575 86	0.106
246.260	0.563 27	0.562 68	0.105
247.555	0.561 87	0.561 10	0.137
249.523	0.559 53	0.558 70	0.148
257.991	0.548 84	0.548 17	0.122
267.737	0.536 01	0.535 60	0.076
277.971	0.521 97	0.521 79	0.034
287.784	0.507 93	0.507 84	0.018
		Av dev	0.083

[a] Data from ref 1. [b] $(\rho - \rho(\text{ref 1}))/\rho \times 100$.

thought to be smaller than ±0.1% and those in pressure to be less than 80 Pa. This latter estimate of uncertainty in pressure was arrived at during the smoothing of the pseudoisochores. Temperature uncertainties are about 0.002 K.

Table II lists the saturated liquid densities obtained by extrapolating the pseudoisochores to the vapor pressure curve obtained by fitting current and smoothed values of previous measurements. A comparison of the values so obtained and the saturated liquid densities interpolated from the tabulation of Goodwin (*1*) is given in Table II, column 4.

Acknowledgment

The research grade propane and the cryostat bath fluids were supplied gratis by the Phillips Petroleum Co. The substantial contributions of Mrs. Patsy S. Chappelear, Mr. Ray Martin, and the late Mr. Walter Ruska are acknowledged.

Literature Cited

(1) Goodwin, R. D., "Provisional Thermodynamic Functions of Propane, from 85 to 70 °K at Pressures to 700 Bar, Cryogenics Division, National Bureau of Standards, NBSIR 77-860.
(2) Vennix, A. J., Leland, T. W., Kobayashi, R., *J. Chem. Eng. Data*, **15**, 238–243 (1970).

Received for review November 18, 1977. Accepted March 13, 1978. The authors acknowledge generous financial support from the National Science Foundation, the Columbia Gas Corp., and the American Gas Association.