Thermodynamic Properties of Isobutane for Temperatures from 250 to 600 K and Pressures from 0.1 to 40 MPa

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Tables of isobutane thermodynamic properties are presented for temperatures from 250 to 600 K and pressures from 0.1 to 40 MPa. The tables include saturation and isobaric properties, namely, pressure, specific volume, temperature, internal energy, enthalpy, and entropy. The properties are defined by a specific thermodynamic surface, which is expressed analytically in the form of the Helmholtz energy as a function of temperature and density. The surface is developed from only pressure–density–temperature data. The Appendix to the paper includes a summary of the correlation development and of new isobutane measurements, saturated vapor pressures, and isothermal pressure–density–temperature data for temperatures of 377.59, 394.26, 423.15, and 448.15 K. The data were used to assess the reliability of literature sources used in the correlation. Surface-derived properties are compared with experimental data. In addition, the correlation is compared with a recent isochoric (nonanalytic) correlation by Goodwin and Haynes.

The current search for energy sources and more efficient thermal processing of such energy has rekindled the general question as to what extent thermodynamic properties associated with the thermal process are known. For example, the ongoing design and construction of pilot geothermal power plants has involved the analysis of thermophysical properties as the basis for the selection of the heat exchanger fluid. The low temperatures characteristic of geothermal energy soruces, 420–530 K, require that the thermal cycle be cascaded for the optimum utilization of the thermal energy. The optimization also requires the realization of other thermal criteria. Some of these are as follows: (1) the working pressure in both the boiler and the condenser should be as low as feasible but greater than atmospheric; (2) the critical temperature of the working fluid should be greater than the design condensing temperature, 310 K; and (3) the enthalpy of vaporization and the specific volume of the saturated vapor at the condensing temperature should both be small. Cooperatively, several geothermal research groups evaluated the suitability of different substances for the heat exchanger fluid and, in particular, selected isobutane either as a pure fluid or as part of a fluid mixture as a promixing choice (*1*, *2*). Further, the groups recommended a critical correlation of isobutane which would yield more definitive thermodynamic properties than those of existing correlations. The correlation would use new measurements of sufficient quality as a guide for assessing the relative merit of data sources. Subsequently the Thermophysics Division of the National Bureau of Standards (U.S.) undertook such a program; the new measurements were to be obtained in regions where we already had the experimental capability. In part, on the basis of the new data which we have obtained, we summarize herein the results of this program, namely, as tables of isobutane thermodynamic properties. Complementary background information, such as the functions used to define the isobutane thermodynamic surface and the new measurements, are discussed in the Appendix of this paper. A discussion of the development of the correlation was presented at the Eighth Symposium on Thermophysical Properties (*3*).

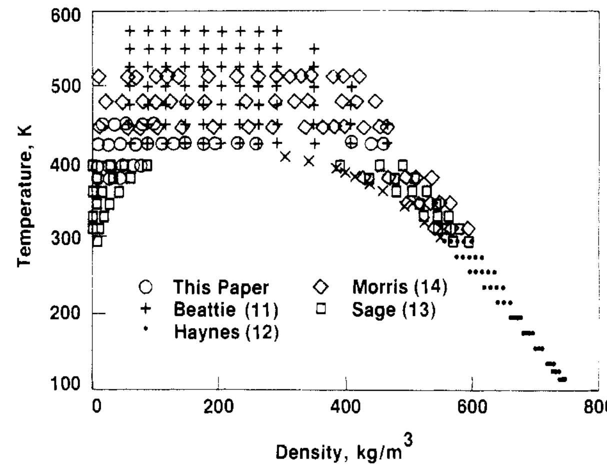

Figure 1. Distribution of P–ρ–T data used in the correlation. × values are based on an analytical representation of saturated liquid densities determined experimentally by Sliwinski (*17*) for 283 ≤ T ≤ 368 K and Haynes (*16*) for 115 ≤ T ≤ 300 K and the critical-point constants given in Table III.

Published correlations of isobutane based on earlier data are cited in ref *2* and *4*–*8*. A recent isochoric (nonanalytic) correlation based on the data used herein is cited in ref *9*; its primary objective is the characterization of isobutane as a component of liquefied natural gas (LNG).

The thermodynamic surface for isobutane is expressed analytically in the form of the Helmholtz energy as a function of temperature and density. The function is applicable, exclusive of the critical region, for temperatures from 250 to 600 K and pressures from 0 to 40 MPa. It is incorporated as part of a Fortran computer program that permits calculation of the equilibrium properties defined by the surface for given input values of two of the three variables: pressure (P), density (ρ), and temperature (T). The properties include energy, enthalpy, entropy, and specific heat. The computer program permits the user to calculate any desired property along isobars, isochores, isotherms, and saturation boundary in any of four commonly used unit systems. The computer program and detailed isobutane thermodynamic tables are listed in an earlier report (*10*), which is available from the National Technical Information Service, Department of Commerce (U.S.).

The distributions of the data sources used in the development of the surface are illustrated in Figure 1. The statistical weight assigned to a particular set of data varied according to our estimate of its relative accuracy as compared to the other data sets. This is discussed in an earlier publication (*3*). In the gas phase for temperatures greater than the critical temperature (T_c = 407.851 K), the surface is generally in accord with selected P–ρ–T data (ref *11* and this paper) to a density deviation of 0.1% or better. For the isothermal temperature of 423 K, the deviations are larger in a localized region for densities near critical density (ρ_c = 227.0 kg/m^3); its cause is discussed in the Appendix. In the liquid phase, the agreement varies with the

Table I. Saturation Properties of Isobutane[a,b]

T, K	P, MPa	v_l, m³/kg	v_v, m³/kg	U_l, kJ/kg	U_{vap}, kJ/kg	U_v, kJ/kg	H_l, kJ/kg	H_{vap}, kJ/kg	H_v, kJ/kg	S_l, kJ/(kg K)	S_{vap}, kJ/(kg K)	S_v, kJ/(kg K)
250	0.0634	0.001 651	0.548 5	−25.2	340.4	315.2	−25.1	375.1	350.0	−0.098	1.500	1.403
252	0.0691	0.001 656	0.508 5	−20.8	338.5	317.7	−20.7	373.4	352.7	−0.081	1.482	1.401
254	0.0752	0.001 662	0.468 4	−16.5	336.6	320.2	−16.3	371.7	355.4	−0.063	1.463	1.400
256	0.0817	0.001 668	0.433 7	−12.1	334.7	322.6	−12.0	370.0	358.0	−0.046	1.445	1.399
258	0.0886	0.001 674	0.402 2	−7.7	332.8	325.1	−7.5	368.3	360.7	−0.029	1.427	1.398
260	0.0959	0.001 681	0.373 4	−3.3	330.9	327.6	−3.1	366.5	363.4	−0.012	1.410	1.398
262	0.1037	0.001 687	0.347 1	1.2	328.9	330.1	1.4	364.8	366.1	0.005	1.392	1.397
264	0.1121	0.001 693	0.323 0	5.6	327.0	332.6	5.8	363.0	368.8	0.022	1.375	1.397
266	0.1209	0.001 699	0.300 9	10.1	325.0	335.2	10.3	361.2	371.5	0.039	1.358	1.397
268	0.1302	0.001 706	0.280 7	14.6	323.1	337.7	14.8	359.4	374.2	0.056	1.341	1.397
270	0.1401	0.001 713	0.262 1	19.1	321.1	340.2	19.3	357.6	376.9	0.073	1.324	1.397
272	0.1506	0.001 719	0.245 0	23.6	319.1	342.7	23.9	355.7	379.6	0.089	1.308	1.397
274	0.1616	0.001 726	0.229 2	28.2	317.1	345.3	28.5	353.9	382.3	0.106	1.292	1.397
276	0.1733	0.001 733	0.214 7	32.7	315.1	347.8	33.0	352.0	385.0	0.123	1.275	1.398
278	0.1856	0.001 740	0.201 3	37.3	313.1	350.4	37.7	350.1	387.8	0.139	1.259	1.398
280	0.1985	0.001 747	0.188 8	41.9	311.0	353.0	42.3	348.2	390.5	0.156	1.243	1.399
282	0.2122	0.001 754	0.177 4	46.6	309.0	355.5	46.9	346.2	393.2	0.172	1.228	1.400
284	0.2265	0.001 762	0.166 7	51.2	306.9	358.1	51.6	344.3	395.9	0.189	1.212	1.401
286	0.2416	0.001 769	0.156 8	55.9	304.8	360.7	56.3	342.3	398.6	0.205	1.197	1.402
288	0.2574	0.001 777	0.147 7	60.6	302.7	363.3	61.0	340.2	401.3	0.221	1.181	1.403
290	0.2740	0.001 784	0.139 1	65.3	300.6	365.8	65.8	338.2	404.0	0.238	1.166	1.404
292	0.2914	0.001 792	0.131 2	70.0	298.4	368.4	70.5	336.1	406.7	0.254	1.151	1.405
294	0.3096	0.001 800	0.123 8	74.8	296.2	371.0	75.3	334.0	409.3	0.270	1.136	1.406
296	0.3286	0.001 808	0.116 9	79.6	294.0	373.6	80.2	331.9	412.0	0.286	1.121	1.408
298	0.3485	0.001 816	0.110 5	84.4	291.8	376.2	85.0	329.7	414.7	0.303	1.106	1.409
300	0.3693	0.001 825	0.104 5	89.2	289.6	378.8	89.9	327.5	417.4	0.319	1.092	1.410
302	0.3911	0.001 833	0.098 86	94.1	287.3	381.4	94.8	325.3	420.0	0.335	1.077	1.412
304	0.4137	0.001 842	0.093 61	98.9	285.0	384.0	99.7	323.0	422.7	0.351	1.063	1.413
306	0.4374	0.001 851	0.088 67	103.8	282.7	386.6	104.7	320.7	425.4	0.367	1.048	1.415
308	0.4620	0.001 860	0.084 05	108.8	280.4	389.2	109.6	318.4	428.0	0.383	1.034	1.417
310	0.4877	0.001 869	0.079 71	113.7	278.0	391.8	114.6	316.0	430.6	0.399	1.019	1.419
312	0.5144	0.001 879	0.075 65	118.7	275.6	394.4	119.7	313.6	433.3	0.415	1.005	1.420
314	0.5422	0.001 889	0.071 82	123.7	273.2	396.9	124.8	311.1	435.9	0.431	0.991	1.422
316	0.5711	0.001 898	0.068 22	128.8	270.8	399.5	129.9	308.6	438.5	0.447	0.977	1.424
318	0.6011	0.001 908	0.064 83	133.8	268.3	402.1	135.0	306.1	441.1	0.463	0.963	1.426
320	0.6323	0.001 919	0.061 64	138.9	265.7	404.7	140.2	303.5	443.7	0.479	0.948	1.428
322	0.6647	0.001 929	0.058 63	144.1	263.2	407.3	145.4	300.9	446.2	0.495	0.934	1.430
324	0.6982	0.001 940	0.055 79	149.2	260.6	409.8	150.6	298.2	448.8	0.511	0.920	1.432
326	0.7330	0.001 951	0.053 11	154.4	258.0	412.4	155.8	295.5	451.3	0.527	0.906	1.434
328	0.7691	0.001 962	0.050 58	159.6	255.3	415.0	161.1	292.7	453.9	0.543	0.892	1.436
330	0.8065	0.001 974	0.048 18	164.9	252.6	417.5	166.5	289.9	456.4	0.559	0.878	1.438
332	0.8452	0.001 986	0.045 91	170.2	249.9	420.1	171.8	287.0	458.9	0.575	0.865	1.440
334	0.8852	0.001 998	0.043 77	175.5	247.1	422.6	177.3	284.1	461.3	0.591	0.851	1.442
336	0.9266	0.002 011	0.041 73	180.8	244.3	425.1	182.7	281.1	463.8	0.607	0.837	1.444
338	0.9695	0.002 023	0.039 81	186.2	241.4	427.6	188.2	278.0	466.2	0.623	0.823	1.446
340	1.0137	0.002 037	0.037 98	191.6	238.5	430.1	193.7	274.9	468.6	0.639	0.809	1.448
342	1.0595	0.002 050	0.036 23	197.1	235.5	432.6	199.3	271.7	471.0	0.655	0.795	1.450
344	1.1067	0.002 064	0.034 58	202.6	232.5	435.1	204.9	268.5	473.4	0.671	0.781	1.452
346	1.1555	0.002 079	0.033 02	208.1	229.4	437.6	210.5	265.2	475.7	0.687	0.766	1.454
348	1.2058	0.002 094	0.031 53	213.7	226.3	440.0	216.2	261.8	478.0	0.704	0.752	1.456
350	1.2577	0.002 109	0.030 11	219.3	223.1	442.4	221.9	258.4	480.3	0.720	0.738	1.458
352	1.3113	0.002 125	0.028 76	224.9	219.9	444.8	227.7	254.8	482.5	0.736	0.724	1.460
354	1.3665	0.002 141	0.027 47	230.6	216.6	447.2	233.5	251.2	484.8	0.752	0.710	1.462
356	1.4234	0.002 158	0.026 24	236.4	213.2	449.6	239.4	247.5	486.9	0.768	0.695	1.463
358	1.4820	0.002 176	0.025 06	242.1	209.8	451.9	245.4	243.7	489.1	0.784	0.681	1.465
360	1.5424	0.002 194	0.023 94	248.0	206.3	454.2	251.3	239.8	491.1	0.801	0.666	1.467
362	1.6045	0.002 213	0.022 87	253.8	202.7	456.5	257.4	235.8	493.2	0.817	0.651	1.469
364	1.6685	0.002 233	0.021 85	259.8	199.0	458.7	263.5	231.7	495.2	0.834	0.637	1.470
366	1.7344	0.002 254	0.020 87	265.7	195.2	460.9	269.6	227.5	497.1	0.850	0.622	1.472
368	1.8021	0.002 276	0.019 92	271.8	191.3	463.1	275.9	223.1	499.0	0.867	0.606	1.473
370	1.8718	0.002 298	0.019 02	277.9	187.3	465.2	282.2	218.6	500.8	0.883	0.591	1.474
372	1.9435	0.002 322	0.018 15	284.0	183.2	467.3	288.5	214.0	502.6	0.900	0.575	1.475
374	2.0172	0.002 347	0.017 32	290.3	179.0	469.3	295.0	209.2	504.2	0.917	0.559	1.476
376	2.0929	0.002 374	0.016 52	296.6	174.7	471.2	301.5	204.3	505.8	0.934	0.543	1.477
378	2.1708	0.002 402	0.015 75	302.9	170.2	473.1	308.1	199.1	507.3	0.951	0.527	1.478
380	2.2508	0.002 431	0.015 00	309.4	165.5	474.9	314.9	193.8	508.7	0.968	0.510	1.478
382	2.3331	0.002 463	0.014 28	315.9	160.7	476.6	321.7	188.2	509.9	0.985	0.493	1.478
384	2.4176	0.002 497	0.013 60	322.6	155.6	478.2	328.6	182.5	511.1	1.003	0.475	1.478
386	2.5044	0.002 534	0.012 92	329.4	150.4	479.7	335.7	176.4	512.1	1.021	0.457	1.478
388	2.5935	0.002 574	0.012 27	336.2	144.9	481.1	342.9	170.0	512.9	1.039	0.438	1.477
390	2.6851	0.002 617	0.011 63	343.3	139.0	482.3	350.3	163.2	513.5	1.057	0.419	1.476
392	2.7793	0.002 665	0.011 01	350.5	132.9	483.3	357.9	156.1	513.9	1.076	0.398	1.474
394	2.8760	0.002 718	0.010 40	357.9	126.3	484.1	365.7	148.4	514.1	1.095	0.377	1.472
396	2.9754	0.002 777	0.009 798	365.5	119.2	484.7	373.8	140.0	513.8	1.115	0.354	1.469
398	3.0775	0.002 846	0.009 199	373.4	111.4	484.9	382.2	131.0	513.2	1.135	0.329	1.464
400	3.1826	0.002 927	0.008 599	381.8	102.8	484.6	391.1	120.9	512.0	1.157	0.302	1.459
402	3.2907	0.003 021	0.007 989	390.6	93.1	483.7	400.6	109.4	510.0	1.180	0.272	1.452
404	3.4020	0.003 148	0.007 354	400.2	81.7	481.9	410.9	96.0	506.9	1.205	0.238	1.442

Table I (*Continued*)

P, MPa	T, K	v_l, m^3/kg	v_v, m^3/kg	U_l, kJ/kg	U_{vap}, kJ/kg	U_v, kJ/kg	H_l, kJ/kg	H_{vap}, kJ/kg	H_v, kJ/kg	S_l, kJ/(kg K)	S_{vap}, kJ/(kg K)	S_v, kJ/(kg K)
0.05	244.63	0.001 635	0.684 1	−36.8	345.5	308.7	−36.7	379.6	342.9	−0.145	1.552	1.407
0.10	261.06	0.001 684	0.359 1	−0.9	329.9	328.9	−0.7	365.6	364.9	−0.003	1.400	1.398
0.15	271.89	0.001 719	0.245 8	23.4	319.2	342.6	23.7	355.8	379.5	0.088	1.309	1.397
0.20	280.22	0.001 748	0.187 5	42.4	310.8	353.2	42.8	348.0	390.8	0.157	1.242	1.399
0.25	287.08	0.001 773	0.151 8	58.4	303.7	362.1	58.8	341.2	400.0	0.214	1.188	1.402
0.30	292.96	0.001 796	0.127 6	72.3	297.4	369.7	72.8	335.1	407.9	0.262	1.144	1.406
0.35	298.14	0.001 817	0.110 0	84.7	291.7	376.4	85.4	329.5	414.9	0.304	1.105	1.409
0.40	302.80	0.001 837	0.096 73	96.0	286.4	382.4	96.7	324.4	421.1	0.341	1.071	1.413
0.45	307.03	0.001 856	0.086 25	106.4	281.5	387.9	107.2	319.5	426.7	0.375	1.041	1.416
0.50	310.93	0.001 874	0.077 80	116.1	276.9	393.0	117.0	314.9	431.9	0.407	1.013	1.419
0.55	314.55	0.001 891	0.070 82	125.1	272.5	397.6	126.2	310.4	436.6	0.436	0.987	1.423
0.60	317.93	0.001 908	0.064 95	133.7	268.4	402.0	134.8	306.2	441.0	0.463	0.963	1.426
0.65	321.10	0.001 925	0.059 96	141.8	264.3	406.1	143.0	302.1	445.1	0.488	0.941	1.429
0.70	324.10	0.001 941	0.055 65	149.5	260.5	410.0	150.9	298.1	448.9	0.512	0.920	1.432
0.75	326.95	0.001 956	0.051 89	156.9	256.7	413.6	158.4	294.2	452.5	0.535	0.900	1.435
0.80	329.66	0.001 972	0.048 58	164.0	253.1	417.1	165.6	290.4	455.9	0.557	0.881	1.437
0.85	332.24	0.001 987	0.045 64	170.8	249.6	420.4	172.5	286.7	459.2	0.577	0.863	1.440
0.90	334.72	0.002 003	0.043 02	177.4	246.1	423.5	179.2	283.0	462.2	0.597	0.846	1.443
0.95	337.10	0.002 018	0.040 66	183.8	242.7	426.5	185.7	279.4	465.1	0.616	0.829	1.445
1.00	339.39	0.002 033	0.038 53	190.0	239.4	429.4	192.0	275.9	467.9	0.634	0.813	1.447
1.05	341.59	0.002 047	0.036 59	196.0	236.2	432.1	198.1	272.4	470.5	0.652	0.798	1.450
1.10	343.72	0.002 062	0.034 81	201.8	233.0	434.8	204.1	269.0	473.0	0.669	0.783	1.452
1.15	345.78	0.002 077	0.033 19	207.5	229.8	437.3	209.9	265.6	475.5	0.686	0.768	1.454
1.20	347.77	0.002 092	0.031 69	213.0	226.7	439.7	215.5	262.2	477.8	0.702	0.754	1.456
1.25	349.71	0.002 107	0.030 31	218.5	223.6	442.1	221.1	258.9	480.0	0.717	0.740	1.458
1.30	351.58	0.002 122	0.029 03	223.8	220.6	444.3	226.5	255.6	482.1	0.732	0.727	1.459
1.35	353.41	0.002 136	0.027 84	228.9	217.6	446.5	231.8	252.3	484.1	0.747	0.714	1.461
1.40	355.19	0.002 151	0.026 73	234.0	214.6	448.6	237.0	249.0	486.0	0.762	0.701	1.463
1.45	356.92	0.002 166	0.025 69	239.0	211.6	450.6	242.1	245.8	487.9	0.776	0.689	1.464
1.50	358.60	0.002 181	0.024 72	243.9	208.7	452.6	247.2	242.5	489.7	0.789	0.676	1.466
1.55	360.25	0.002 197	0.023 81	248.7	205.8	454.5	252.1	239.3	491.4	0.803	0.664	1.467
1.60	361.86	0.002 212	0.022 94	253.4	202.9	456.3	257.0	236.1	493.0	0.816	0.652	1.468
1.65	363.43	0.002 228	0.022 13	258.1	200.0	458.1	261.7	232.9	494.6	0.829	0.641	1.470
1.70	364.96	0.002 243	0.021 37	262.6	197.1	459.8	266.5	229.7	496.1	0.841	0.629	1.471
1.75	366.47	0.002 259	0.020 64	267.2	194.3	461.4	271.1	226.4	497.6	0.854	0.618	1.472
1.80	367.94	0.002 275	0.019 95	271.6	191.4	463.0	275.7	223.2	498.9	0.866	0.607	1.473
1.85	369.38	0.002 291	0.019 30	276.0	188.6	464.6	280.2	220.0	500.3	0.878	0.596	1.474
1.90	370.79	0.002 308	0.018 67	280.3	185.7	466.0	284.7	216.8	501.5	0.890	0.585	1.475
1.95	372.18	0.002 324	0.018 08	284.6	182.9	467.5	289.1	213.6	502.7	0.901	0.574	1.475
2.00	373.54	0.002 341	0.017 51	288.8	180.0	468.8	293.5	210.3	503.8	0.913	0.563	1.476
2.05	374.87	0.002 359	0.016 97	293.0	177.1	470.1	297.8	207.1	504.9	0.924	0.552	1.477
2.10	376.18	0.002 376	0.016 45	297.1	174.3	471.4	302.1	203.8	505.9	0.935	0.542	1.477
2.15	377.47	0.002 394	0.015 95	301.2	171.4	472.6	306.4	200.5	506.9	0.946	0.531	1.477
2.20	378.74	0.002 412	0.015 47	305.3	168.5	473.8	310.6	197.2	507.8	0.957	0.521	1.478
2.25	379.98	0.002 431	0.015 01	309.3	165.6	474.9	314.8	193.9	508.7	0.968	0.510	1.478
2.30	381.20	0.002 450	0.014 57	313.3	162.7	475.9	318.9	190.5	509.5	0.978	0.500	1.478
2.35	382.41	0.002 470	0.014 14	317.2	159.7	476.9	323.0	187.1	510.2	0.989	0.489	1.478
2.40	383.59	0.002 490	0.013 74	321.2	156.7	477.9	327.2	183.7	510.9	0.999	0.479	1.478
2.45	384.75	0.002 511	0.013 34	325.1	153.7	478.8	331.3	180.2	511.5	1.010	0.468	1.478
2.50	385.90	0.002 532	0.012 96	329.0	150.6	479.7	335.3	176.7	512.1	1.020	0.458	1.478
2.55	387.03	0.002 554	0.012 58	332.9	147.6	480.5	339.4	173.1	512.5	1.030	0.447	1.477
2.60	388.14	0.002 577	0.012 22	336.7	144.5	481.2	343.4	169.5	513.0	1.040	0.437	1.477
2.65	389.24	0.002 600	0.011 87	340.6	141.3	481.9	347.5	165.9	513.3	1.050	0.426	1.476
2.70	390.32	0.002 624	0.011 53	344.4	138.1	482.5	351.5	162.1	513.6	1.060	0.415	1.476
2.75	391.38	0.002 649	0.011 20	348.2	134.8	483.0	355.5	158.3	513.8	1.070	0.405	1.475
2.80	392.43	0.002 676	0.010 88	352.1	131.5	483.5	359.6	154.4	514.0	1.080	0.394	1.474
2.85	393.47	0.002 703	0.010 56	355.9	128.1	484.0	363.6	150.5	514.1	1.090	0.382	1.472
2.90	394.49	0.002 732	0.010 25	359.7	124.6	484.3	367.6	146.4	514.0	1.100	0.371	1.471
2.95	395.49	0.002 762	0.009 949	363.6	121.0	484.6	371.7	142.2	513.9	1.110	0.360	1.469
3.00	396.49	0.002 793	0.009 652	367.4	117.3	484.8	375.8	137.9	513.7	1.120	0.348	1.468
3.05	397.47	0.002 827	0.009 359	371.3	113.6	484.8	379.9	133.5	513.4	1.130	0.336	1.466
3.10	398.43	0.002 862	0.009 070	375.2	109.6	484.8	384.1	128.9	513.0	1.140	0.323	1.463
3.15	399.39	0.002 900	0.008 784	379.2	105.6	484.7	388.3	124.1	512.4	1.150	0.311	1.461
3.20	400.33	0.002 941	0.008 501	383.2	101.3	484.5	392.6	119.1	511.7	1.160	0.298	1.458
3.25	401.25	0.002 985	0.008 218	387.2	96.9	484.1	396.9	113.9	510.8	1.171	0.284	1.455
3.30	402.17	0.003 033	0.007 936	391.4	92.2	483.6	401.4	108.4	509.8	1.182	0.269	1.451
3.35	403.07	0.003 086	0.007 652	395.7	87.2	482.9	406.0	102.5	508.5	1.193	0.254	1.447
3.40	403.97	0.003 146	0.007 365	400.1	81.9	481.9	410.8	96.2	507.0	1.204	0.238	1.442
3.45	404.85	0.003 213	0.007 072	404.7	76.1	480.7	415.7	89.4	505.1	1.216	0.221	1.437

[a] The symbol v denotes the specific volume, U the internal energy, H the enthalpy, and S the entropy, and the subscripts l and v refer to the liquid and vapor phases, respectively. The subscripted abbreviation vap refers to liquid vaporization. [b] The reference states for the derived enthalpy and entropy properties from the surface are adjusted to be those of the liquid at the normal boiling temperature defined by the surface (T = 261.395 K for P = 0.101325 MPa).

Table II. Isobaric Thermodynamic Properties of Isobutane[a,b]

T, K	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)
	Pressure = 0.1 MPa				Pressure = 0.101325 MPa				Pressure = 0.2 MPa			
250	0.001650	−25.2	−25.1	−0.098	0.001650	−25.2	−25.1	−0.098	0.001650	−25.3	−25.0	−0.098
260	0.001681	−3.3	−3.1	−0.012	0.001681	−3.3	−3.1	−0.012	0.001680	−3.3	−3.0	−0.012
261.06	0.001684	−0.9	−0.8	−0.003								
261.06	0.3592	328.9	364.8	1.398								
261.39					0.001685	−0.2	0.0	0.000				
261.39					0.3547	329.4	365.3	1.398				
270	0.3729	341.4	378.7	1.450	0.3679	341.3	378.6	1.448	0.001712	19.1	19.4	0.072
280	0.3882	355.7	394.5	1.507	0.3830	355.6	394.5	1.505	0.001747	41.9	42.3	0.156
280.22									0.001748	42.4	42.8	0.157
280.22									0.1875	353.2	390.8	1.399
290	0.4034	370.4	410.8	1.564	0.3980	370.4	410.7	1.562	0.1955	367.9	407.0	1.456
300	0.4185	385.6	427.5	1.621	0.4129	385.6	427.4	1.619	0.2036	383.3	424.0	1.514
310	0.4335	401.3	444.6	1.677	0.4277	401.3	444.6	1.675	0.2115	399.2	441.5	1.571
320	0.4485	417.4	462.3	1.733	0.4425	417.4	462.2	1.731	0.2194	415.4	459.3	1.628
330	0.4634	434.0	480.3	1.789	0.4572	434.0	480.3	1.787	0.2272	432.1	477.6	1.684
340	0.4782	451.0	498.9	1.844	0.4718	451.0	498.8	1.842	0.2349	449.3	496.3	1.740
350	0.4930	468.5	517.8	1.899	0.4864	468.5	517.8	1.897	0.2425	466.9	515.4	1.795
360	0.5077	486.5	537.3	1.954	0.5010	486.5	537.3	1.952	0.2502	485.0	535.0	1.850
370	0.5224	504.9	557.2	2.008	0.5155	504.9	557.2	2.006	0.2577	503.5	555.0	1.905
380	0.5371	523.8	577.6	2.063	0.5300	523.8	577.5	2.061	0.2653	522.4	575.5	1.960
390	0.5518	543.2	598.4	2.117	0.5445	543.2	598.3	2.115	0.2728	541.8	596.4	2.014
400	0.5664	563.0	619.6	2.171	0.5589	563.0	619.6	2.169	0.2803	561.7	617.8	2.068
410	0.5810	583.2	641.4	2.224	0.5734	583.2	641.3	2.222	0.2878	582.0	639.6	2.122
420	0.5956	603.9	663.5	2.278	0.5878	603.9	663.5	2.276	0.2952	602.8	661.8	2.176
430	0.6102	625.1	686.1	2.331	0.6022	625.1	686.1	2.329	0.3026	624.0	684.5	2.229
440	0.6248	646.7	709.1	2.384	0.6165	646.6	709.1	2.382	0.3100	645.6	707.6	2.282
450	0.6393	668.7	732.6	2.436	0.6309	668.7	732.6	2.435	0.3174	667.6	731.1	2.335
460	0.6538	691.1	756.5	2.489	0.6452	691.1	756.5	2.487	0.3248	690.1	755.1	2.388
470	0.6684	713.9	780.8	2.541	0.6596	713.9	780.8	2.539	0.3322	713.0	779.4	2.440
480	0.6829	737.2	805.5	2.593	0.6739	737.2	805.5	2.591	0.3395	736.3	804.2	2.492
490	0.6974	760.9	830.6	2.645	0.6882	760.9	830.6	2.643	0.3469	760.0	829.3	2.544
500	0.7118	784.9	856.1	2.697	0.7025	784.9	856.1	2.695	0.3542	784.1	854.9	2.596
510	0.7263	809.4	882.0	2.748	0.7168	809.4	882.0	2.746	0.3615	808.5	880.9	2.647
520	0.7408	834.3	908.3	2.799	0.7311	834.2	908.3	2.797	0.3689	833.4	907.2	2.698
530	0.7552	859.5	935.0	2.850	0.7453	859.5	935.0	2.848	0.3762	858.7	933.9	2.749
540	0.7697	885.1	962.1	2.900	0.7596	885.1	962.0	2.898	0.3835	884.3	961.0	2.800
550	0.7841	911.1	989.5	2.951	0.7739	911.1	989.5	2.949	0.3908	910.3	988.5	2.850
560	0.7986	937.4	1017.3	3.001	0.7881	937.4	1017.3	2.999	0.3981	936.7	1016.3	2.900
570	0.8130	964.1	1045.4	3.050	0.8024	964.1	1045.4	3.049	0.4053	963.4	1044.4	2.950
580	0.8274	991.1	1073.9	3.100	0.8166	991.1	1073.9	3.098	0.4126	990.4	1073.0	3.000
590	0.8419	1018.5	1102.7	3.149	0.8308	1018.5	1102.7	3.147	0.4199	1017.9	1101.8	3.049
600	0.8563	1046.3	1131.9	3.198	0.8451	1046.3	1131.9	3.196	0.4272	1045.6	1131.0	3.098
	Pressure = 0.4 MPa				Pressure = 0.6 MPa				Pressure = 0.8 MPa			
250	0.001649	−25.4	−24.8	−0.099	0.001649	−25.6	−24.6	−0.099	0.001648	−25.7	−24.4	−0.100
260	0.001679	−3.5	−2.8	−0.013	0.001678	−3.7	−2.7	−0.013	0.001677	−3.8	−2.5	−0.014
270	0.001711	18.9	19.6	0.072	0.001710	18.7	19.7	0.071	0.001709	18.5	19.9	0.070
280	0.001746	41.7	42.4	0.155	0.001745	41.5	42.6	0.154	0.001743	41.3	42.7	0.153
290	0.001783	65.1	65.9	0.237	0.001782	64.9	66.0	0.236	0.001781	64.7	66.1	0.236
300	0.001825	89.2	89.9	0.319	0.001823	88.9	90.0	0.318	0.001821	88.6	90.1	0.317
302.80	0.001837	96.0	96.8	0.341								
302.80	0.09672	382.4	421.1	1.413								
310	0.1000	394.2	434.2	1.455	0.001868	113.6	114.7	0.399	0.001866	113.3	114.8	0.398
317.93					0.001908	133.7	134.8	0.463				
317.93					0.06496	402.0	441.0	1.426				
320	0.1044	411.0	452.7	1.514	0.06566	405.7	445.0	1.439	0.001917	138.7	140.2	0.478
329.66									0.001972	164.0	165.6	0.557
329.66									0.04858	417.1	455.9	1.437
330	0.1087	428.0	471.5	1.572	0.06894	423.3	464.7	1.499	0.04868	417.7	456.7	1.440
340	0.1130	445.5	490.7	1.629	0.07208	441.2	484.5	1.558	0.05138	436.3	477.4	1.502
350	0.1171	463.4	510.2	1.686	0.07512	459.4	504.5	1.616	0.05393	455.1	498.2	1.562
360	0.1212	481.6	530.1	1.742	0.07808	478.0	524.9	1.673	0.05637	474.1	519.2	1.621
370	0.1253	500.3	550.5	1.797	0.08098	497.0	545.6	1.730	0.05873	493.4	540.4	1.679
380	0.1293	519.5	571.2	1.853	0.08382	516.4	566.6	1.786	0.06102	513.0	561.8	1.736
390	0.1332	539.1	592.3	1.908	0.08662	536.1	588.1	1.842	0.06325	533.0	583.6	1.793
400	0.1372	559.1	613.9	1.962	0.08939	556.3	609.9	1.897	0.06545	553.4	605.7	1.849
410	0.1411	579.5	635.9	2.017	0.09212	576.9	632.1	1.952	0.06760	574.1	628.2	1.904
420	0.1450	600.4	658.3	2.071	0.09482	597.9	654.7	2.007	0.06972	595.3	651.0	1.959
430	0.1488	621.6	681.2	2.124	0.09750	619.3	677.8	2.061	0.07182	616.8	674.3	2.014
440	0.1527	643.4	704.4	2.178	0.1002	641.1	701.2	2.115	0.07389	638.7	697.8	2.068
450	0.1565	665.5	728.1	2.231	0.1028	663.3	725.0	2.168	0.07595	661.1	721.8	2.122
460	0.1603	688.0	752.2	2.284	0.1054	685.9	749.2	2.221	0.07798	683.8	746.2	2.176

Table II (*Continued*)

T, K	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)
470	0.1641	711.0	776.6	2.337	0.1080	709.0	773.8	2.274	0.08000	706.9	770.9	2.229
480	0.1679	734.4	801.5	2.389	0.1106	732.4	798.8	2.327	0.08200	730.4	796.0	2.282
490	0.1716	758.1	826.8	2.441	0.1132	756.2	824.2	2.379	0.08399	754.3	821.5	2.334
500	0.1754	782.3	852.4	2.493	0.1158	780.5	849.9	2.431	0.08597	778.6	847.4	2.386
510	0.1792	806.8	878.5	2.544	0.1183	805.1	876.1	2.483	0.08794	803.3	873.7	2.438
520	0.1829	831.7	904.9	2.596	0.1209	830.1	902.6	2.535	0.08990	828.3	900.3	2.490
530	0.1866	857.1	931.7	2.647	0.1234	855.4	929.5	2.586	0.09185	853.8	927.2	2.541
540	0.1904	882.7	958.9	2.698	0.1260	881.1	956.7	2.637	0.09379	879.5	954.6	2.593
550	0.1941	908.8	986.4	2.748	0.1285	907.2	984.3	2.687	0.09573	905.7	982.2	2.643
560	0.1978	935.2	1014.3	2.798	0.1310	933.7	1012.3	2.738	0.09765	932.2	1010.3	2.694
570	0.2015	961.9	1042.5	2.848	0.1335	960.5	1040.6	2.788	0.09957	959.0	1038.7	2.744
580	0.2052	989.0	1071.1	2.898	0.1361	987.6	1069.2	2.838	0.1015	986.2	1067.4	2.794
590	0.2089	1016.5	1100.0	2.948	0.1386	1015.1	1098.2	2.887	0.1034	1013.2	1096.4	2.844
600	0.2126	1044.3	1129.3	2.997	0.1411	1042.9	1127.5	2.936	0.1053	1041.5	1125.8	2.893
	Pressure = 1.0 MPa				Pressure = 1.2 MPa				Pressure = 1.4 MPa			
250	0.001647	−25.9	−24.2	−0.101	0.001646	−26.0	−24.0	−0.101	0.001646	−26.2	−23.9	−0.102
260	0.001677	−4.0	−2.3	−0.015	0.001676	−4.1	−2.1	−0.015	0.001675	−4.3	−2.0	−0.016
270	0.001708	18.3	20.0	0.070	0.001707	18.2	20.2	0.069	0.001706	18.0	20.4	0.068
280	0.001742	41.1	42.9	0.153	0.001741	40.9	43.0	0.152	0.001740	40.7	43.2	0.151
290	0.001779	64.5	66.2	0.235	0.001778	64.2	66.4	0.234	0.001777	64.0	66.5	0.233
300	0.001820	88.4	90.2	0.316	0.001818	88.1	90.3	0.315	0.001816	87.9	90.4	0.314
310	0.001864	113.0	114.8	0.397	0.001862	112.7	114.9	0.396	0.001860	112.4	115.0	0.395
320	0.001914	138.3	140.2	0.477	0.001912	138.0	140.3	0.476	0.001909	137.7	140.3	0.475
330	0.001971	164.5	166.5	0.558	0.001968	164.1	166.5	0.557	0.001965	163.7	166.5	0.556
339.39	0.002033	190.0	192.0	0.634								
339.39	0.03853	429.4	467.9	1.447								
340	0.03868	430.6	469.2	1.451	0.002033	191.2	193.6	0.638	0.002029	190.7	193.6	0.637
347.77					0.002092	213.0	215.5	0.702				
347.77					0.03170	439.7	477.8	1.456				
350	0.04102	450.1	491.1	1.515	0.03219	444.3	482.9	1.471	0.002105	218.9	221.8	0.718
355.19									0.002151	234.0	237.0	0.762
355.19									0.02673	448.6	486.0	1.463
360	0.04321	469.7	512.9	1.576	0.03427	464.7	505.9	1.535	0.02772	459.0	497.8	1.496
370	0.04527	489.4	534.7	1.636	0.03620	485.1	528.5	1.597	0.02959	480.2	521.6	1.561
380	0.04726	509.4	556.7	1.694	0.03800	505.5	551.1	1.657	0.03131	501.2	545.1	1.623
390	0.04917	529.7	578.9	1.752	0.03972	526.2	573.8	1.716	0.03292	522.3	568.4	1.684
400	0.05103	550.3	601.3	1.809	0.04138	547.0	596.7	1.774	0.03444	543.6	591.8	1.743
410	0.05285	571.2	624.1	1.865	0.04299	568.2	619.8	1.831	0.03590	565.1	615.3	1.801
420	0.05464	592.6	647.2	1.921	0.04455	589.8	643.2	1.888	0.03732	586.8	639.1	1.858
430	0.05639	614.3	670.6	1.976	0.04608	611.6	666.9	1.944	0.03869	608.9	663.0	1.915
440	0.05811	636.3	694.4	2.031	0.04758	633.8	690.9	1.999	0.04003	631.3	687.3	1.971
450	0.05982	658.8	718.6	2.085	0.04905	656.4	715.3	2.053	0.04135	654.0	711.9	2.026
460	0.06150	681.6	743.1	2.139	0.05050	679.4	740.0	2.108	0.04264	677.1	736.8	2.081
470	0.06317	704.8	768.0	2.192	0.05194	702.7	765.0	2.162	0.04391	700.5	762.0	2.135
480	0.06482	728.4	793.3	2.245	0.05335	726.4	790.4	2.215	0.04516	724.3	787.5	2.189
490	0.06645	752.4	818.9	2.298	0.05476	750.5	816.2	2.268	0.04639	748.5	813.4	2.242
500	0.06808	776.8	844.9	2.351	0.05615	774.9	842.3	2.321	0.04762	773.0	839.6	2.295
510	0.06969	801.5	871.2	2.403	0.05752	799.7	868.7	2.373	0.04883	797.9	866.2	2.348
520	0.07130	826.6	897.9	2.455	0.05889	824.9	895.5	2.425	0.05003	823.1	893.1	2.400
530	0.07289	852.1	925.0	2.506	0.06025	850.4	922.7	2.477	0.05122	848.7	920.4	2.452
540	0.07448	877.9	952.4	2.558	0.06160	876.3	950.2	2.528	0.05240	874.6	948.0	2.503
550	0.07605	904.1	980.1	2.609	0.06294	902.5	978.0	2.580	0.05357	900.9	975.9	2.555
560	0.07762	930.6	1008.3	2.659	0.06427	929.1	1006.2	2.630	0.05473	927.5	1004.2	2.606
570	0.07919	957.5	1036.7	2.710	0.06560	956.0	1034.7	2.681	0.05589	954.5	1032.8	2.656
580	0.08075	984.7	1065.5	2.760	0.06692	983.3	1063.6	2.731	0.05704	981.8	1061.7	2.706
590	0.08230	1012.3	1094.6	2.809	0.06823	1010.9	1092.8	2.781	0.05819	1009.5	1090.9	2.756
600	0.08385	1040.2	1124.0	2.859	0.06954	1038.8	1122.3	2.830	0.05932	1037.4	1120.5	2.806
	Pressure = 1.6 MPa				Pressure = 1.8 MPa				Pressure = 2.0 MPa			
250	0.001645	−26.3	−23.7	−0.102	0.001644	−26.4	−23.5	−0.103	0.001643	−26.6	−23.3	−0.103
260	0.001674	−4.5	−1.8	−0.016	0.001673	−4.6	−1.6	−0.017	0.001672	−4.8	−1.4	−0.018
270	0.001705	17.8	20.5	0.068	0.001704	17.6	20.7	0.067	0.001703	17.5	20.9	0.066
280	0.001739	40.6	43.3	0.151	0.001738	40.4	43.5	0.150	0.001737	40.2	43.6	0.149
290	0.001775	63.8	66.6	0.232	0.001774	63.6	66.8	0.232	0.001773	63.4	66.9	0.231
300	0.001815	87.6	90.5	0.313	0.001813	87.4	90.7	0.313	0.001812	87.2	90.8	0.312
310	0.001859	112.1	115.1	0.394	0.001857	111.8	115.2	0.393	0.001855	111.6	115.3	0.392
320	0.001907	137.3	140.4	0.474	0.001905	137.0	140.4	0.473	0.001903	136.7	140.5	0.472
330	0.001962	163.3	166.5	0.554	0.001959	163.0	166.5	0.553	0.001956	162.6	166.5	0.552
340	0.002025	190.3	193.5	0.635	0.002021	189.8	193.4	0.634	0.002018	189.4	193.4	0.632
350	0.002100	218.3	221.7	0.717	0.002095	217.7	221.5	0.715	0.002090	217.2	221.4	0.714
360	0.002192	247.7	251.3	0.800	0.002185	247.0	250.9	0.798	0.002177	246.3	250.7	0.796
361.86	0.002212	253.4	257.0	0.816								
361.86	0.02294	456.3	493.0	1.468								

Table II (*Continued*)

T, K	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)
367.94					0.002 275	271.6	275.7	0.866				
367.94					0.019 95	463.0	498.9	1.473				
370	0.024 50	474.6	513.8	1.525	0.020 35	468.0	504.6	1.488	0.002 291	277.2	281.8	0.881
373.54									0.002 341	288.8	293.5	0.913
373.54									0.017 51	468.8	503.8	1.476
380	0.026 20	496.5	538.4	1.591	0.022 12	491.1	531.0	1.558	0.018 71	484.9	522.3	1.525
390	0.027 75	518.2	562.6	1.654	0.023 66	513.6	556.2	1.624	0.020 30	508.6	549.2	1.595
400	0.029 19	539.9	586.6	1.714	0.025 06	535.9	581.0	1.687	0.021 70	531.6	575.0	1.660
410	0.030 56	561.7	610.6	1.774	0.026 37	558.2	605.6	1.748	0.022 98	554.3	600.3	1.723
420	0.031 87	583.7	634.7	1.832	0.027 61	580.5	630.2	1.807	0.024 17	577.1	625.4	1.783
430	0.033 13	606.0	659.0	1.889	0.028 79	603.1	654.9	1.865	0.025 30	600.0	650.6	1.842
440	0.034 36	628.6	683.6	1.945	0.029 94	625.9	679.7	1.922	0.026 38	623.0	675.8	1.900
450	0.035 56	651.5	708.4	2.001	0.031 05	648.9	704.8	1.978	0.027 43	646.3	701.1	1.957
460	0.036 73	674.7	733.5	2.056	0.032 13	672.3	730.1	2.034	0.028 44	669.8	726.7	2.013
470	0.037 88	698.3	758.9	2.111	0.033 18	696.0	755.7	2.089	0.029 42	693.7	752.5	2.069
480	0.039 01	722.2	784.6	2.165	0.034 22	720.0	781.6	2.144	0.030 38	717.8	778.6	2.124
490	0.040 12	746.4	810.6	2.219	0.035 24	744.4	807.8	2.198	0.031 33	742.3	804.9	2.178
500	0.041 22	771.0	837.0	2.272	0.036 24	769.1	834.3	2.251	0.032 25	767.1	831.6	2.232
510	0.042 30	796.0	863.7	2.325	0.037 23	794.1	861.1	2.304	0.033 17	792.2	858.5	2.285
520	0.043 38	821.3	890.7	2.377	0.038 21	819.5	888.3	2.357	0.034 07	817.7	885.9	2.338
530	0.044 44	847.0	918.1	2.429	0.039 17	845.2	915.7	2.409	0.034 95	843.4	913.4	2.391
540	0.045 50	873.0	945.8	2.481	0.040 13	871.3	943.5	2.461	0.035 83	869.6	941.2	2.443
550	0.046 54	899.3	973.8	2.533	0.041 08	897.7	971.6	2.513	0.036 70	896.0	969.4	2.495
560	0.047 58	926.0	1002.1	2.584	0.042 01	924.4	1000.0	2.564	0.037 56	922.8	998.0	2.546
570	0.048 61	953.0	1030.8	2.634	0.042 95	951.5	1028.8	2.615	0.038 42	950.0	1026.8	2.597
580	0.049 63	980.4	1059.8	2.685	0.043 87	978.9	1057.9	2.665	0.039 26	977.4	1055.9	2.648
590	0.050 65	1008.0	1089.1	2.735	0.044 79	1006.6	1087.2	2.716	0.040 10	1005.2	1085.4	2.698
600	0.051 66	1036.0	1118.7	2.785	0.045 70	1034.7	1116.9	2.766	0.040 94	1033.3	1115.1	2.748
	Pressure = 2.2 MPa				Pressure = 2.4 MPa				Pressure = 2.6 MPa			
250	0.001 643	−26.7	−23.1	−0.104	0.001 642	−26.9	−22.9	−0.105	0.001 641	−27.0	−22.7	−0.105
260	0.001 672	−4.9	−1.2	−0.018	0.001 671	−5.1	−1.1	−0.019	0.001 670	−5.2	−0.9	−0.019
270	0.001 702	17.3	21.0	0.066	0.001 702	17.1	21.2	0.065	0.001 701	17.0	21.4	0.065
280	0.001 736	40.0	43.8	0.149	0.001 735	39.8	43.9	0.148	0.001 733	39.6	44.1	0.147
290	0.001 771	63.2	67.1	0.230	0.001 770	62.9	67.2	0.229	0.001 769	62.7	67.3	0.229
300	0.001 810	86.9	90.9	0.311	0.001 809	86.7	91.0	0.310	0.001 807	86.4	91.1	0.309
310	0.001 853	111.3	115.4	0.391	0.001 851	111.0	115.5	0.390	0.001 849	110.8	115.6	0.389
320	0.001 900	136.4	140.5	0.471	0.001 898	136.1	140.6	0.470	0.001 896	135.7	140.7	0.469
330	0.001 953	162.2	166.5	0.551	0.001 951	161.8	166.5	0.550	0.001 948	161.5	166.5	0.549
340	0.002 014	188.9	193.4	0.631	0.002 011	188.5	193.3	0.630	0.002 007	188.1	193.3	0.629
350	0.002 085	216.6	221.2	0.712	0.002 080	216.1	221.1	0.710	0.002 076	215.6	221.0	0.709
360	0.002 171	245.6	250.4	0.794	0.002 164	245.0	250.2	0.792	0.002 158	244.3	249.9	0.790
370	0.002 280	276.3	281.3	0.879	0.002 270	275.4	280.9	0.876	0.002 260	274.6	280.4	0.874
378.74	0.002 412	305.3	310.6	0.957								
378.74	0.015 47	473.8	507.8	1.478								
380	0.015 73	477.2	511.8	1.488	0.002 417	308.4	314.2	0.965	0.002 400	307.1	313.3	0.962
383.59					0.002 490	321.2	327.2	0.999				
383.59					0.013 74	477.9	510.9	1.478				
388.14									0.002 577	336.7	343.4	1.040
388.14									0.012 22	481.2	513.0	1.477
390	0.017 46	502.7	541.2	1.565	0.014 96	495.8	531.7	1.532	0.012 63	487.1	519.9	1.495
400	0.018 90	526.8	568.4	1.633	0.016 49	521.4	561.0	1.606	0.014 36	515.2	552.6	1.577
410	0.020 17	550.2	594.6	1.698	0.017 79	545.8	588.5	1.674	0.015 72	540.8	581.7	1.649
420	0.021 34	573.5	620.4	1.760	0.018 95	569.6	615.1	1.738	0.016 89	565.4	609.4	1.716
430	0.022 43	596.7	646.0	1.821	0.020 01	593.2	641.3	1.800	0.017 95	589.6	636.3	1.779
440	0.023 46	620.0	671.6	1.880	0.021 02	616.9	667.3	1.860	0.018 93	613.6	662.9	1.840
450	0.024 45	643.5	697.3	1.937	0.021 97	640.7	693.4	1.918	0.019 85	637.7	689.3	1.900
460	0.025 41	667.3	723.2	1.994	0.022 88	664.6	719.5	1.976	0.020 73	661.9	715.8	1.958
470	0.026 34	691.3	749.2	2.050	0.023 76	688.8	745.8	2.032	0.021 58	686.3	742.4	2.015
480	0.027 24	715.5	775.5	2.105	0.024 62	713.2	772.3	2.088	0.022 40	710.9	769.1	2.072
490	0.028 12	740.1	802.0	2.160	0.025 45	737.9	799.0	2.143	0.023 19	735.7	796.0	2.127
500	0.028 99	765.0	828.8	2.214	0.026 27	763.0	826.0	2.198	0.023 97	760.9	823.2	2.182
510	0.029 84	790.2	855.9	2.268	0.027 07	788.3	853.2	2.252	0.024 72	786.3	850.6	2.236
520	0.030 68	815.8	883.3	2.321	0.027 86	813.9	880.8	2.305	0.025 47	812.0	878.2	2.290
530	0.031 50	841.7	911.0	2.374	0.028 63	839.9	908.6	2.358	0.026 20	838.0	906.1	2.343
540	0.032 32	867.9	939.0	2.426	0.029 39	866.1	936.7	2.410	0.026 91	864.4	934.4	2.396
550	0.033 13	894.4	967.3	2.478	0.030 14	892.7	965.1	2.463	0.027 62	891.0	962.9	2.448
560	0.033 92	921.2	995.9	2.530	0.030 89	919.6	993.8	2.514	0.028 32	918.0	991.6	2.500
570	0.034 71	948.4	1024.8	2.581	0.031 62	946.9	1022.8	2.566	0.029 01	945.3	1020.7	2.551
580	0.035 49	975.9	1054.0	2.632	0.032 35	974.4	1052.1	2.617	0.029 70	972.9	1050.1	2.603
590	0.036 27	1003.7	1083.5	2.682	0.033 08	1002.3	1081.6	2.667	0.030 37	1000.8	1079.8	2.653
600	0.037 04	1031.9	1113.3	2.732	0.033 79	1030.4	1111.5	2.717	0.031 04	1029.0	1109.7	2.704

Table II (*Continued*)

T, K	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)
	Pressure = 2.8 MPa				Pressure = 3.0 MPa				Pressure = 3.2 MPa			
250	0.001640	−27.1	−22.5	−0.106	0.001640	−27.3	−22.3	−0.106	0.001639	−27.4	−22.2	−0.107
260	0.001669	−5.4	−0.7	−0.020	0.001668	−5.5	−0.5	−0.021	0.001668	−5.7	−0.3	−0.021
270	0.011700	16.8	21.6	0.064	0.001669	16.6	21.7	0.063	0.001698	16.5	21.9	0.063
280	0.001732	39.4	44.3	0.147	0.001731	39.2	44.4	0.146	0.001730	39.0	44.6	0.145
290	0.001768	62.5	67.5	0.228	0.001766	62.3	67.6	0.227	0.001765	62.1	67.8	0.227
300	0.001806	86.2	91.3	0.309	0.001804	86.0	91.4	0.308	0.001803	85.7	91.5	0.307
310	0.001848	110.5	115.7	0.389	0.001846	110.2	115.8	0.388	0.001844	110.0	115.9	0.387
320	0.001894	135.4	140.7	0.468	0.001892	135.1	140.8	0.467	0.001890	134.8	140.9	0.466
330	0.001945	161.1	166.6	0.548	0.001943	160.8	166.6	0.547	0.001940	160.4	166.6	0.546
340	0.002004	187.6	193.3	0.627	0.002001	187.2	193.2	0.626	0.001997	186.8	193.2	0.625
350	0.002071	215.1	220.9	0.707	0.002067	214.6	220.8	0.706	0.002063	214.1	220.7	0.705
360	0.002152	243.7	249.7	0.789	0.002146	243.1	249.5	0.787	0.002140	242.5	249.3	0.785
370	0.002251	273.7	280.0	0.872	0.002243	272.9	279.7	0.869	0.002234	272.2	279.3	0.867
380	0.002384	305.9	312.5	0.958	0.002370	304.7	311.8	0.955	0.002357	303.6	311.2	0.952
390	0.002595	342.0	349.2	1.054	0.002563	339.9	347.6	1.048	0.002535	338.1	346.3	1.043
392.43	0.002676	352.1	359.6	1.080								
392.43	0.01088	483.5	514.0	1.474								
396.49					0.002793	367.4	375.8	1.120				
396.49					0.009652	484.8	513.7	1.468				
400	0.01242	507.8	542.6	1.546	0.01053	498.2	529.8	1.508	0.002916	381.3	390.6	1.156
400.33									0.002941	383.2	392.6	1.160
400.33									0.008501	484.5	511.7	1.458
410	0.01389	535.3	574.2	1.624	0.01223	529.0	565.7	1.597	0.01068	521.4	555.5	1.566
420	0.01510	560.9	603.2	1.694	0.01351	556.0	596.5	1.671	0.01207	550.4	589.1	1.647
430	0.01616	585.7	631.0	1.759	0.01459	581.6	625.4	1.739	0.01319	577.1	619.3	1.718
440	0.01713	610.2	658.2	1.822	0.01556	606.6	653.3	1.803	0.01417	602.8	648.1	1.785
450	0.01803	634.6	685.1	1.882	0.01645	631.4	680.8	1.865	0.01505	628.1	676.2	1.848
460	0.01889	659.1	712.0	1.941	0.01728	656.2	708.0	1.925	0.01587	653.2	703.9	1.909
470	0.01970	683.7	738.8	1.999	0.01807	681.0	735.2	1.983	0.01664	678.2	731.5	1.968
480	0.02049	708.4	765.8	2.056	0.01883	706.0	762.5	2.041	0.01738	703.4	759.0	2.026
490	0.02125	733.4	792.9	2.112	0.01957	731.1	789.8	2.097	0.01809	728.8	786.7	2.083
500	0.02199	758.7	820.3	2.167	0.02028	756.5	817.4	2.153	0.01878	754.3	814.4	2.139
510	0.02271	784.2	847.8	2.222	0.02097	782.2	845.1	2.208	0.01944	780.1	842.3	2.194
520	0.02342	810.1	875.6	2.276	0.02164	808.1	873.0	2.262	0.02009	806.1	870.4	2.249
530	0.02411	836.2	903.7	2.329	0.02230	834.3	901.2	2.316	0.02072	832.4	898.7	2.303
540	0.02479	862.6	932.0	2.382	0.02295	860.8	929.7	2.369	0.02134	859.0	927.3	2.356
550	0.02546	889.3	960.6	2.434	0.02359	887.6	958.4	2.421	0.02195	885.9	956.1	2.409
560	0.02612	916.4	989.5	2.486	0.02422	914.7	987.4	2.474	0.02255	913.1	985.2	2.461
570	0.02678	943.7	1018.7	2.538	0.02484	942.1	1016.6	2.525	0.02314	940.5	1014.6	2.513
580	0.02742	971.4	1048.2	2.589	0.02545	969.8	1046.2	2.577	0.02372	968.3	1044.2	2.565
590	0.02806	999.3	1077.9	2.640	0.02605	997.9	1076.0	2.628	0.02430	996.4	1074.1	2.616
600	0.02869	1027.6	1107.9	2.691	0.02665	1026.2	1106.1	2.678	0.02487	1024.7	1104.3	2.667
	Pressure = 3.4 MPa				Pressure = 3.6 MPa				Pressure = 3.8 MPa[c]			
250	0.001638	−27.5	−22.0	−0.107	0.001638	−27.7	−21.8	−0.108	0.001637	−27.8	−21.6	−0.108
260	0.001667	−5.8	−0.2	−0.022	0.001666	−6.0	0.0	−0.022	0.001665	−6.1	0.2	−0.023
270	0.001697	16.3	22.1	0.062	0.001696	16.1	22.2	0.061	0.001695	16.0	22.4	0.061
280	0.001729	38.9	44.7	0.144	0.001728	38.7	44.9	0.144	0.001727	38.5	45.1	0.143
290	0.001764	61.9	67.9	0.226	0.001763	61.7	68.0	0.225	0.001762	61.5	68.2	0.224
300	0.001802	85.5	91.6	0.306	0.001800	85.3	91.8	0.305	0.001799	85.0	91.9	0.305
310	0.001843	109.7	116.0	0.386	0.001841	109.4	116.1	0.385	0.001839	109.2	116.2	0.384
320	0.001888	134.5	141.0	0.465	0.001886	134.2	141.0	0.464	0.001884	133.9	141.1	0.463
330	0.001938	160.1	166.7	0.544	0.001935	159.7	166.7	0.543	0.001933	159.4	166.8	0.542
340	0.001994	186.4	193.2	0.624	0.001991	186.0	193.2	0.622	0.001988	185.6	193.2	0.621
350	0.002059	213.6	220.6	0.703	0.002055	213.2	220.6	0.702	0.002051	212.7	220.5	0.700
360	0.002135	241.9	249.2	0.784	0.002129	241.3	249.0	0.782	0.002124	240.8	248.8	0.780
370	0.002226	271.4	279.0	0.865	0.002219	270.7	278.7	0.863	0.002212	270.0	278.4	0.861
380	0.002344	302.6	310.6	0.950	0.002333	301.7	310.1	0.947	0.002322	300.7	309.5	0.944
390	0.002511	336.5	345.1	1.039	0.002490	335.0	344.0	1.035	0.002470	333.7	343.0	1.031
400	0.002821	376.7	386.3	1.143	0.002757	373.4	383.3	1.135	0.002709	370.7	381.0	1.127
403.97	0.003146	400.1	410.8	1.204								
403.97	0.007365	481.9	507.0	1.442								
410	0.009150	511.6	542.7	1.530	0.007462	497.0	523.8	1.480	0.003608	429.9	443.7	1.282
420	0.01075	544.1	580.7	1.622	0.009502	536.8	571.0	1.594	0.008292	527.8	559.3	1.562
430	0.01193	572.2	612.8	1.697	0.01078	566.9	605.7	1.676	0.009710	560.9	597.8	1.652
440	0.01292	598.7	642.7	1.766	0.01180	594.4	636.9	1.747	0.01078	589.7	630.7	1.728
450	0.01381	624.5	671.5	1.831	0.01269	620.8	666.5	1.814	0.01169	616.9	661.3	1.797
460	0.01462	650.0	699.7	1.893	0.01350	646.8	695.4	1.877	0.01250	643.4	690.8	1.862
470	0.01538	675.4	727.7	1.953	0.01425	672.5	723.8	1.938	0.01324	669.4	719.7	1.924
480	0.01610	700.8	755.6	2.012	0.01496	698.1	752.0	1.998	0.01393	695.4	748.3	1.984
490	0.01679	726.4	783.4	2.069	0.01563	723.9	780.1	2.056	0.01459	721.4	776.8	2.043
500	0.01745	752.1	811.4	2.126	0.01627	749.8	808.3	2.113	0.01522	747.4	805.2	2.100
510	0.01809	778.0	839.5	2.181	0.01690	775.8	836.6	2.169	0.01582	773.6	833.7	2.157

Table II (*Continued*)

T, K	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)
520	0.018 72	804.1	867.8	2.236	0.017 50	802.1	865.1	2.224	0.016 41	800.0	862.4	2.212
530	0.019 33	830.5	896.2	2.290	0.018 09	828.6	893.7	2.279	0.016 98	826.6	891.2	2.267
540	0.019 92	957.2	924.9	2.344	0.018 66	855.4	922.5	2.333	0.017 53	853.5	920.1	2.321
550	0.020 51	884.2	953.9	2.397	0.019 22	882.4	951.6	2.386	0.018 08	880.6	949.3	2.375
560	0.021 08	911.4	983.1	2.450	0.019 78	909.7	980.9	2.439	0.018 61	908.0	978.7	2.428
570	0.021 65	938.9	1012.5	2.502	0.020 32	937.3	1010.5	2.491	0.019 13	935.7	1008.4	2.480
580	0.022 20	966.8	1042.2	2.554	0.020 85	965.2	1040.3	2.543	0.019 64	963.6	1038.3	2.532
590	0.022 75	994.9	1072.2	2.605	0.021 38	993.4	1070.3	2.594	0.020 15	991.9	1068.4	2.584
600	0.023 30	1023.3	1102.5	2.656	0.021 90	1021.8	1100.7	2.645	0.020 65	1020.4	1098.8	2.635
	Pressure = 4.0 MPa				Pressure = 4.2 MPa				Pressure = 4.4 MPa			
250	0.001 636	−27.9	−21.4	−0.109	0.001 636	−28.1	−21.2	−0.110	0.001 635	−28.2	−21.0	−0.110
260	0.001 664	−6.3	0.4	−0.024	0.001 664	−6.4	0.6	−0.024	0.001 663	−6.6	0.8	−0.025
270	0.001 694	15.8	22.6	0.060	0.001 694	15.6	22.7	0.060	0.001 693	15.5	22.9	0.059
280	0.001 726	38.3	45.2	0.142	0.001 725	38.1	45.4	0.142	0.001 724	37.9	45.5	0.141
290	0.001 761	61.3	68.3	0.224	0.001 759	61.1	68.5	0.223	0.001 758	60.9	68.6	0.222
300	0.001 798	84.8	92.0	0.304	0.001 796	84.6	92.1	0.303	0.001 795	84.4	92.3	0.302
310	0.001 838	108.9	116.3	0.383	0.001 836	108.7	116.4	0.383	0.001 835	108.4	116.5	0.382
320	0.001 882	133.7	141.2	0.463	0.001 880	133.4	141.3	0.462	0.001 878	133.1	141.3	0.461
330	0.001 931	159.1	166.8	0.541	0.001 928	158.8	166.8	0.540	0.001 926	158.4	166.9	0.539
340	0.001 985	185.3	193.2	0.620	0.001 982	184.9	193.2	0.619	0.001 979	184.5	193.2	0.618
350	0.002 047	212.3	220.5	0.699	0.002 043	211.8	220.4	0.698	0.002 040	211.4	220.4	0.697
360	0.002 119	240.2	248.7	0.779	0.002 114	239.7	248.6	0.777	0.002 109	239.2	248.4	0.776
370	0.002 205	269.3	278.1	0.859	0.002 198	268.6	277.9	0.857	0.002 192	268.0	277.6	0.856
380	0.002 311	299.8	309.1	0.942	0.002 301	299.0	308.6	0.939	0.002 292	298.1	308.2	0.937
390	0.002 453	332.4	342.2	1.028	0.002 437	331.2	341.4	1.025	0.002 422	330.0	340.7	1.021
400	0.002 669	368.4	379.1	1.121	0.002 635	366.4	377.5	1.116	0.002 606	364.6	376.1	1.111
410	0.003 182	415.5	428.2	1.242	0.003 031	409.2	422.0	1.226	0.002 936	405.0	417.9	1.214
420	0.007 057	515.9	544.2	1.522	0.005 710	498.5	522.5	1.467	0.004 373	473.7	492.9	1.395
430	0.008 711	554.1	589.0	1.628	0.007 761	546.3	578.9	1.600	0.006 846	537.0	567.1	1.570
440	0.009 843	584.7	624.1	1.708	0.008 978	579.2	616.9	1.688	0.008 172	573.1	609.1	1.666
450	0.010 77	612.8	655.9	1.780	0.009 934	608.4	650.1	1.763	0.009 164	603.7	644.1	1.745
460	0.011 58	639.8	686.2	1.846	0.010 76	636.1	681.3	1.831	0.009 997	632.2	676.2	1.815
470	0.012 32	666.3	715.6	1.910	0.011 49	663.1	711.3	1.896	0.010 74	659.7	706.9	1.882
480	0.013 01	692.6	744.6	1.971	0.012 17	689.7	740.8	1.958	0.011 41	686.7	736.9	1.945
490	0.013 65	718.8	773.4	2.030	0.012 81	716.1	769.9	2.018	0.012 04	713.4	766.4	2.005
500	0.014 27	745.0	802.1	2.088	0.013 41	742.6	798.9	2.076	0.012 63	740.1	795.7	2.065
510	0.014 86	771.4	830.8	2.145	0.013 99	769.1	827.9	2.134	0.013 20	766.8	824.9	2.122
520	0.015 43	797.9	859.6	2.201	0.014 54	795.8	856.9	2.190	0.013 74	793.7	854.1	2.179
530	0.015 98	824.7	888.6	2.256	0.015 08	822.7	886.0	2.245	0.014 26	820.6	883.4	2.235
540	0.016 52	851.6	917.7	2.311	0.015 60	849.7	915.3	2.300	0.014 77	847.8	912.8	2.290
550	0.017 04	878.8	947.0	2.364	0.016 11	877.0	944.7	2.354	0.015 27	875.2	942.4	2.344
560	0.017 56	906.3	976.6	2.418	0.016 61	904.6	974.4	2.408	0.015 75	902.9	972.2	2.398
570	0.018 06	934.1	1006.3	2.470	0.017 10	932.4	1004.2	2.460	0.016 22	930.7	1002.1	2.451
580	0.018 56	962.1	1036.3	2.522	0.017 58	960.5	1034.3	2.513	0.016 69	958.9	1032.3	2.503
590	0.019 05	990.3	1066.5	2.574	0.018 05	988.8	1064.6	2.565	0.017 14	987.3	1062.7	2.555
600	0.019 53	1018.9	1097.0	2.625	0.018 51	1017.4	1095.2	2.616	0.017 59	1016.0	1093.4	2.607
	Pressure = 4.6 MPa				Pressure = 4.8 MPa				Pressure = 5.0 MPa			
250	0.001 634	−28.3	−20.8	−0.111	0.001 634	−28.5	−20.6	−0.111	0.001 633	−28.6	−20.4	−0.112
260	0.001 662	−6.7	0.9	−0.025	0.001 661	−6.9	1.1	−0.026	0.001 661	−7.0	1.3	−0.026
270	0.001 692	15.3	23.1	0.058	0.001 691	15.2	23.3	0.058	0.001 690	15.0	23.4	0.057
280	0.001 723	37.8	45.7	0.141	0.001 722	37.6	45.9	0.140	0.001 721	37.4	46.0	0.139
290	0.001 757	60.7	68.8	0.222	0.001 756	60.5	68.9	0.221	0.001 755	60.3	69.1	0.220
300	0.001 794	84.1	92.4	0.302	0.001 792	83.9	92.5	0.301	0.001 791	83.7	92.7	0.300
310	0.001 833	108.2	116.6	0.381	0.001 831	107.9	116.7	0.380	0.001 830	107.7	116.8	0.379
320	0.001 876	132.8	141.4	0.460	0.001 874	132.5	141.5	0.459	0.001 872	132.2	141.6	0.458
330	0.001 924	158.1	167.0	0.538	0.001 921	157.8	167.0	0.537	0.001 919	157.5	167.1	0.536
340	0.001 977	184.1	193.2	0.617	0.001 974	183.8	193.2	0.616	0.001 971	183.4	193.3	0.614
350	0.002 036	210.9	220.3	0.695	0.002 033	210.5	220.3	0.694	0.002 029	210.1	220.2	0.693
360	0.002 105	238.6	248.3	0.774	0.002 100	238.1	248.2	0.773	0.002 096	237.6	248.1	0.771
370	0.002 185	267.4	277.4	0.854	0.002 179	266.8	277.2	0.852	0.002 174	266.2	277.0	0.850
380	0.002 283	297.3	307.8	0.935	0.002 275	296.6	307.5	0.933	0.002 266	295.8	307.1	0.931
390	0.002 408	328.9	340.0	1.019	0.002 395	327.9	339.4	1.016	0.002 382	326.9	338.8	1.013
400	0.002 581	363.0	374.8	1.107	0.002 558	361.5	373.7	1.103	0.002 537	360.0	372.7	1.099
410	0.002 868	401.6	414.8	1.205	0.002 814	398.9	412.4	1.198	0.002 769	396.5	410.3	1.192
420	0.003 683	455.9	472.8	1.345	0.003 387	446.3	462.6	1.319	0.003 220	440.1	456.2	1.302
430	0.005 967	525.9	553.4	1.535	0.005 156	513.2	537.9	1.496	0.004 493	500.2	522.7	1.459
440	0.007 418	566.4	600.6	1.643	0.006 715	559.1	591.3	1.619	0.006 063	551.0	581.3	1.593
450	0.008 453	598.8	637.6	1.727	0.007 795	593.4	630.8	1.708	0.007 185	587.8	623.7	1.689
460	0.009 301	628.2	671.0	1.800	0.008 660	623.9	665.5	1.784	0.008 068	619.4	659.8	1.768
470	0.010 04	656.2	702.4	1.868	0.009 405	652.6	697.8	1.853	0.008 819	648.9	693.0	1.839
480	0.010 71	683.6	732.9	1.932	0.010 07	680.5	728.8	1.919	0.009 487	677.2	724.6	1.906
490	0.011 33	710.7	762.8	1.993	0.010 69	707.8	759.2	1.981	0.010 10	705.0	755.4	1.970
500	0.011 92	737.6	792.4	2.053	0.011 27	735.0	789.1	2.042	0.010 67	732.4	785.7	2.031
510	0.012 47	764.5	821.9	2.111	0.011 81	762.1	818.8	2.101	0.011 20	759.7	815.7	2.090
520	0.013 00	791.5	851.3	2.169	0.012 33	789.3	848.5	2.158	0.011 72	787.0	845.6	2.148

Table II (*Continued*)

T, K	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	v, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)
530	0.013 52	818.6	880.8	2.225	0.012 83	816.5	878.1	2.215	0.012 21	814.5	875.5	2.205
540	0.014 01	845.9	910.4	2.280	0.013 32	844.0	907.9	2.270	0.012 68	842.0	905.4	2.261
550	0.014 49	873.4	940.1	2.335	0.013 79	871.6	937.7	2.325	0.013 14	869.7	935.4	2.316
560	0.014 96	901.1	970.0	2.388	0.014 24	899.4	967.7	2.379	0.013 58	897.6	965.5	2.370
570	0.015 42	929.1	1000.0	2.442	0.014 69	927.4	997.9	2.433	0.014 02	925.7	995.8	2.424
580	0.015 87	957.3	1030.3	2.494	0.015 13	955.7	1028.3	2.486	0.014 45	954.1	1026.3	2.477
590	0.016 32	985.8	1060.8	2.546	0.015 56	984.2	1058.9	2.538	0.014 86	982.7	1057.0	2.529
600	0.016 75	1014.5	1091.5	2.598	0.015 98	1013.0	1089.7	2.590	0.015 27	1011.5	1087.9	2.581
	Pressure = 5.2 MPa				Pressure = 5.4 MPa				Pressure = 5.6 MPa			
250	0.001 632	−28.7	−20.2	−0.112	0.001 632	−28.9	−20.1	−0.113	0.001 631	−29.0	−19.9	−0.113
260	0.001 660	−7.1	1.5	−0.027	0.001 659	−7.3	1.7	−0.028	0.001 659	−7.4	1.9	−0.028
270	0.001 689	14.8	23.6	0.057	0.001 688	14.7	23.8	0.056	0.001 688	14.5	24.0	0.055
280	0.001 720	37.2	46.2	0.139	0.001 720	37.1	46.3	0.138	0.001 719	36.9	46.5	0.137
290	0.001 754	60.1	69.2	0.219	0.001 753	59.9	69.4	0.219	0.001 752	59.7	69.5	0.218
300	0.001 790	83.5	92.8	0.299	0.001 788	83.3	92.9	0.299	0.001 787	83.1	93.1	0.298
310	0.001 828	107.4	116.9	0.378	0.001 827	107.2	117.1	0.378	0.001 825	106.9	117.2	0.377
320	0.001 871	132.0	141.7	0.457	0.001 869	131.7	141.8	0.456	0.001 867	131.4	141.9	0.455
330	0.001 917	157.2	167.1	0.535	0.001 915	156.8	167.2	0.534	0.001 913	156.5	167.3	0.533
340	0.001 968	183.0	193.3	0.613	0.001 966	182.7	193.3	0.612	0.001 963	182.3	193.3	0.611
350	0.002 026	209.7	220.2	0.691	0.002 023	209.3	220.2	0.690	0.002 020	208.9	220.2	0.689
360	0.002 092	237.2	248.0	0.770	0.002 088	236.7	247.9	0.768	0.002 084	236.2	247.9	0.767
370	0.002 168	265.6	276.8	0.849	0.002 162	265.0	276.7	0.847	0.002 157	264.4	276.5	0.846
380	0.002 259	295.1	306.8	0.929	0.002 251	294.4	306.5	0.927	0.002 244	293.7	306.2	0.925
390	0.002 371	326.0	338.3	1.010	0.002 360	325.1	337.8	1.008	0.002 350	324.2	337.3	1.006
400	0.002 518	358.7	371.8	1.095	0.002 501	357.5	371.0	1.092	0.002 484	356.3	370.2	1.089
410	0.002 731	394.3	408.5	1.186	0.002 699	392.4	407.0	1.181	0.002 669	390.7	405.6	1.176
420	0.003 108	435.5	451.7	1.290	0.003 024	431.9	448.2	1.280	0.002 958	428.8	445.4	1.272
430	0.004 025	489.1	510.0	1.427	0.003 717	480.5	500.6	1.403	0.003 509	473.9	493.6	1.385
440	0.005 473	542.3	570.8	1.567	0.004 961	533.5	560.3	1.541	0.004 537	525.1	550.5	1.516
450	0.006 622	581.7	616.2	1.669	0.006 107	575.4	608.4	1.649	0.005 641	568.8	600.4	1.628
460	0.007 521	614.8	653.9	1.752	0.007 017	609.9	647.8	1.735	0.006 553	604.9	641.5	1.719
470	0.008 278	645.0	688.1	1.825	0.007 778	641.0	683.0	1.811	0.007 317	636.9	677.9	1.797
480	0.008 945	673.9	720.4	1.893	0.008 445	670.5	716.1	1.881	0.007 983	667.0	711.7	1.868
490	0.009 552	702.0	751.7	1.958	0.009 048	699.0	747.8	1.946	0.008 582	695.9	744.0	1.935
500	0.010 11	729.7	782.3	2.020	0.009 605	727.0	778.9	2.009	0.009 133	724.3	775.4	1.998
510	0.010 64	757.3	812.6	2.080	0.010 13	754.8	809.5	2.070	0.009 649	752.3	806.3	2.060
520	0.011 15	784.8	842.8	2.138	0.010 62	782.5	839.9	2.129	0.010 14	780.2	837.0	2.119
530	0.011 63	812.3	872.8	2.196	0.011 09	810.2	870.1	2.186	0.010 60	808.1	867.4	2.177
540	0.012 09	840.0	902.9	2.252	0.011 55	838.0	900.4	2.243	0.011 05	836.0	897.9	2.234
550	0.012 54	867.8	933.0	2.307	0.011 99	865.9	930.7	2.298	0.011 48	864.0	928.3	2.290
560	0.012 98	895.8	963.3	2.362	0.012 41	894.0	961.1	2.353	0.011 89	892.2	958.9	2.345
570	0.013 40	924.0	993.7	2.415	0.012 83	922.3	991.6	2.407	0.012 30	920.6	989.5	2.399
580	0.013 82	952.5	1024.3	2.469	0.013 24	950.8	1022.3	2.461	0.012 70	949.2	1020.3	2.453
590	0.014 22	981.1	1055.1	2.521	0.013 63	979.6	1053.2	2.513	0.013 08	978.0	1051.3	2.506
600	0.014 62	1010.0	1086.1	2.573	0.014 02	1008.5	1084.2	2.566	0.013 46	1007.0	1082.4	2.558
	Pressure = 5.8 MPa				Pressure = 6.0 MPa				Pressure = 7.0 MPa			
250	0.001 631	−29.1	−19.7	−0.114	0.001 630	−29.3	−19.5	−0.114	0.001 627	−29.9	−18.5	−0.117
260	0.001 658	−7.6	2.0	−0.029	0.001 657	−7.7	2.2	−0.029	0.001 654	−8.4	3.2	−0.032
270	0.001 687	14.4	24.1	0.055	0.001 686	14.2	24.3	0.054	0.001 682	13.4	25.2	0.051
280	0.001 718	36.7	46.7	0.137	0.001 717	36.5	46.8	0.136	0.001 712	35.7	47.7	0.133
290	0.001 751	59.5	69.7	0.217	0.001 749	59.3	69.8	0.217	0.001 744	58.4	70.6	0.213
300	0.001 786	82.8	93.2	0.297	0.001 785	82.6	93.3	0.296	0.001 779	81.6	94.0	0.293
310	0.001 824	106.7	117.3	0.376	0.001 823	106.5	117.4	0.375	0.001 816	105.3	118.0	0.371
320	0.001 865	131.2	142.0	0.454	0.001 864	130.9	142.1	0.454	0.001 855	129.6	142.6	0.449
330	0.001 911	156.2	167.3	0.532	0.001 909	155.9	167.4	0.532	0.001 899	154.5	167.8	0.527
340	0.001 961	182.0	193.4	0.610	0.001 958	181.7	193.4	0.609	0.001 946	180.0	193.6	0.604
350	0.002 017	208.5	220.2	0.688	0.002 014	208.1	220.2	0.687	0.001 999	206.2	220.2	0.681
360	0.002 080	235.7	247.8	0.766	0.002 076	235.3	247.7	0.764	0.002 058	233.1	247.5	0.758
370	0.002 152	263.9	276.4	0.844	0.002 147	263.3	276.2	0.842	0.002 124	260.8	275.6	0.835
380	0.002 237	293.0	306.0	0.923	0.002 230	292.3	305.7	0.921	0.002 200	289.3	304.7	0.913
390	0.002 340	323.3	336.9	1.003	0.002 330	322.5	336.5	1.001	0.002 288	318.8	334.8	0.991
400	0.002 469	355.2	369.5	1.086	0.002 455	354.1	368.8	1.083	0.002 395	349.3	366.1	1.070
410	0.002 643	389.1	404.4	1.172	0.002 620	387.6	403.3	1.168	0.002 527	381.2	398.9	1.151
420	0.002 904	426.2	443.0	1.265	0.002 858	423.8	441.0	1.259	0.002 699	414.8	433.7	1.235
430	0.003 361	468.8	488.3	1.371	0.003 250	464.5	484.0	1.360	0.002 934	450.5	471.1	1.323
440	0.004 201	517.4	541.7	1.494	0.003 942	510.7	534.3	1.476	0.003 275	488.9	511.8	1.416
450	0.005 227	562.2	592.6	1.609	0.004 867	555.7	584.9	1.589	0.003 761	529.3	555.7	1.515
460	0.006 129	599.7	635.2	1.702	0.005 743	594.4	628.9	1.686	0.004 367	569.3	599.9	1.612
470	0.006 891	632.7	672.7	1.783	0.006 499	628.4	667.4	1.769	0.004 998	606.6	641.6	1.702
480	0.007 555	663.4	707.2	1.856	0.007 159	659.7	702.7	1.843	0.005 595	640.9	680.1	1.783
490	0.008 150	692.8	740.0	1.923	0.007 750	689.6	736.1	1.912	0.006 145	673.2	716.2	1.857
500	0.008 696	721.5	771.9	1.988	0.008 291	718.6	768.4	1.977	0.006 651	704.0	750.6	1.927
510	0.009 205	749.8	803.1	2.050	0.008 793	747.2	799.9	2.040	0.007 121	734.0	783.9	1.993
520	0.009 685	777.9	834.0	2.110	0.009 267	775.5	831.1	2.100	0.007 561	763.5	816.4	2.056
530	0.010 14	805.9	864.7	2.168	0.009 716	803.7	862.0	2.159	0.007 977	792.6	848.4	2.117

Table II (*Continued*)

T, K	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)	*v*, m³/kg	*U*, kJ/kg	*H*, kJ/kg	*S*, kJ/(kg K)
540	0.010 58	834.0	895.3	2.225	0.010 15	831.9	892.8	2.217	0.008 374	821.6	880.2	2.176
550	0.011 00	862.1	926.0	2.281	0.010 56	860.2	923.6	2.273	0.008 754	850.5	911.8	2.234
560	0.011 41	890.4	956.6	2.337	0.010 96	888.6	954.4	2.329	0.009 120	879.5	943.3	2.291
570	0.011 81	918.9	987.4	2.391	0.011 35	917.2	985.3	2.383	0.009 474	908.5	974.8	2.347
580	0.012 20	947.6	1018.3	2.445	0.011 73	945.9	1016.3	2.437	0.009 818	937.7	1006.4	2.402
590	0.012 57	976.4	1049.4	2.498	0.012 10	974.9	1047.5	2.491	0.010 15	967.0	1038.0	2.456
600	0.012 94	1005.5	1080.6	2.550	0.012 46	1004.0	1078.8	2.543	0.010 48	996.5	1069.8	2.509
	Pressure = 8.0 MPa				Pressure = 9.0 MPa				Pressure = 10.0 MPa			
250	0.001 624	−30.5	−17.5	−0.120	0.001 621	−31.1	−16.6	−0.122	0.001 618	−31.7	−15.6	−0.125
260	0.001 650	−9.1	+4.1	−0.035	0.001 647	−9.8	5.0	−0.037	0.001 644	−10.4	6.0	−0.040
270	0.001 678	12.7	26.1	0.048	0.001 675	11.9	27.0	0.045	0.001 671	11.2	27.9	0.043
280	0.001 708	34.9	48.5	0.130	0.001 704	34.1	49.4	0.127	0.001 700	33.3	50.3	0.124
290	0.001 739	57.5	71.4	0.210	0.001 735	56.6	72.2	0.207	0.001 730	55.7	73.0	0.204
300	0.001 773	80.6	94.8	0.289	0.001 767	79.6	95.5	0.286	0.001 762	78.6	96.3	0.282
310	0.001 809	104.2	118.7	0.368	0.001 803	103.1	119.3	0.364	0.001 796	102.0	120.0	0.360
320	0.001 848	128.3	143.1	0.445	0.001 840	127.1	143.7	0.441	0.001 833	126.0	144.3	0.437
330	0.001 890	153.1	168.2	0.522	0.001 881	151.7	168.7	0.518	0.001 873	150.4	169.2	0.514
340	0.001 935	178.4	193.9	0.599	0.001 925	176.9	194.2	0.594	0.001 915	175.5	194.6	0.590
350	0.001 986	204.4	220.3	0.676	0.001 973	202.7	220.5	0.670	0.001 962	201.1	220.7	0.666
360	0.002 041	231.0	247.4	0.752	0.002 026	229.1	247.3	0.746	0.002 012	227.3	247.4	0.741
370	0.002 103	258.4	275.2	0.828	0.002 084	256.2	275.0	0.822	0.002 068	254.1	274.8	0.816
380	0.002 173	286.5	303.9	0.905	0.002 150	284.0	303.3	0.897	0.002 129	281.6	302.9	0.891
390	0.002 254	315.4	333.5	0.982	0.002 224	312.5	332.5	0.973	0.002 198	309.8	331.8	0.966
400	0.002 348	345.3	364.1	1.059	0.002 309	341.8	362.6	1.049	0.002 275	338.6	361.4	1.041
410	0.002 460	376.2	395.9	1.138	0.002 407	371.9	393.6	1.126	0.002 364	368.2	391.9	1.116
420	0.002 598	408.3	429.0	1.217	0.002 524	403.0	425.7	1.203	0.002 466	398.6	423.3	1.192
430	0.002 771	441.7	463.9	1.299	0.002 664	435.1	459.1	1.282	0.002 585	429.8	455.7	1.268
440	0.002 998	476.7	500.7	1.384	0.002 837	468.3	493.9	1.362	0.002 727	461.9	489.1	1.345
450	0.003 296	513.2	539.6	1.471	0.003 051	502.6	530.1	1.443	0.002 895	494.7	523.7	1.422
460	0.003 676	550.6	580.0	1.560	0.003 314	537.7	567.5	1.526	0.003 095	528.3	559.2	1.501
470	0.004 120	587.6	620.5	1.647	0.003 627	573.1	605.7	1.608	0.003 330	562.3	595.6	1.579
480	0.004 593	623.1	659.8	1.730	0.003 979	608.2	644.0	1.688	0.003 596	596.4	632.4	1.656
490	0.005 062	656.9	697.4	1.808	0.004 352	642.4	681.6	1.766	0.003 888	630.3	669.1	1.732
500	0.005 511	689.4	733.4	1.880	0.004 729	675.6	718.2	1.840	0.004 195	663.6	705.5	1.805
510	0.005 937	720.7	768.2	1.949	0.005 099	707.9	753.8	1.910	0.004 507	696.2	741.3	1.876
520	0.006 340	751.2	802.0	2.015	0.005 458	739.3	788.5	1.978	0.004 818	728.2	776.4	1.945
530	0.006 723	781.3	835.1	2.078	0.005 803	770.2	822.5	2.042	0.005 123	759.7	810.9	2.010
540	0.007 087	811.1	867.8	2.139	0.006 135	800.7	856.0	2.105	0.005 421	790.8	845.0	2.074
550	0.007 437	840.7	900.2	2.199	0.006 454	831.0	889.1	2.166	0.005 710	821.6	878.7	2.136
560	0.007 773	870.2	932.4	2.257	0.006 763	861.1	921.9	2.225	0.005 991	852.2	912.1	2.196
570	0.008 098	899.8	964.5	2.313	0.007 061	891.1	954.6	2.283	0.006 264	882.6	945.3	2.255
580	0.008 413	929.4	996.7	2.369	0.007 350	921.1	987.3	2.340	0.006 529	913.1	978.4	2.312
590	0.008 718	959.1	1028.8	2.424	0.007 631	951.2	1019.9	2.395	0.006 787	943.5	1011.4	2.369
600	0.009 017	988.9	1061.0	2.478	0.007 905	981.4	1052.5	2.450	0.007 039	974.0	1044.4	2.424
	Pressure = 15.0 MPa				Pressure = 20.0 MPa				Pressure = 25.0 MPa			
250	0.001 605	−34.6	−10.6	−0.137	0.001 593	−37.3	−5.5	−0.149	0.001 583	−39.9	−0.3	−0.160
260	0.001 629	−13.6	10.9	−0.053	0.001 616	−16.5	15.8	−0.065	0.001 605	−19.2	20.9	−0.076
270	0.001 655	7.8	32.6	0.029	0.001 640	4.7	37.5	0.017	0.001 627	1.7	42.4	0.005
280	0.001 681	29.5	54.7	0.110	0.001 665	26.1	59.4	0.097	0.001 651	23.0	64.3	0.084
290	0.001 709	51.7	77.3	0.189	0.001 691	48.0	81.8	0.175	0.001 675	44.6	86.5	0.162
300	0.001 738	74.2	100.3	0.267	0.001 718	70.2	104.6	0.252	0.001 700	66.6	109.1	0.239
310	0.001 769	97.2	123.7	0.344	0.001 747	92.9	127.8	0.328	0.001 727	89.0	132.2	0.314
320	0.001 802	120.6	147.7	0.420	0.001 776	116.0	151.5	0.404	0.001 754	111.8	155.6	0.389
330	0.001 837	144.6	172.1	0.495	0.001 808	139.5	175.7	0.428	0.001 783	135.0	179.6	0.463
340	0.001 874	169.0	197.1	0.569	0.001 840	163.5	200.3	0.552	0.001 813	158.7	204.0	0.536
350	0.001 913	194.0	222.7	0.643	0.001 875	188.0	225.5	0.625	0.001 844	182.8	228.9	0.608
360	0.001 955	219.4	248.7	0.717	0.001 912	212.9	251.1	0.697	0.001 876	207.3	254.2	0.679
370	0.002 000	245.4	275.4	0.790	0.001 950	238.3	277.3	0.768	0.001 910	232.3	280.1	0.750
380	0.002 048	271.8	302.6	0.862	0.001 991	264.1	303.9	0.840	0.001 946	257.7	306.4	0.820
390	0.002 101	298.8	330.3	0.935	0.002 034	290.4	331.1	0.910	0.001 983	283.5	333.1	0.889
400	0.002 157	326.3	358.6	1.006	0.002 080	317.1	358.7	0.980	0.002 023	309.7	360.3	0.958
410	0.002 219	354.3	387.5	1.078	0.002 129	344.3	386.8	1.049	0.002 064	336.3	387.9	1.027
420	0.002 285	382.7	417.0	1.149	0.002 180	371.8	415.4	1.118	0.002 107	363.3	416.0	1.094
430	0.002 358	411.7	447.1	1.219	0.002 235	399.8	444.5	1.187	0.002 152	390.7	444.5	1.161
440	0.002 438	441.1	477.7	1.290	0.002 294	428.1	474.0	1.254	0.002 199	418.4	473.4	1.228
450	0.002 525	471.0	508.8	1.360	0.002 356	456.8	503.9	1.322	0.002 248	446.5	502.7	1.293
460	0.002 621	501.2	540.5	1.429	0.002 422	485.9	534.3	1.389	0.002 300	474.8	532.3	1.359
470	0.002 725	531.9	572.7	1.499	0.002 492	515.2	565.1	1.455	0.002 354	503.5	562.4	1.423
480	0.002 839	562.8	605.4	1.567	0.002 567	544.9	596.3	1.520	0.002 411	532.5	592.8	1.487
490	0.002 962	594.0	638.5	1.636	0.002 645	574.9	627.8	1.585	0.002 470	561.8	623.5	1.551
500	0.003 094	625.4	671.8	1.703	0.002 728	605.1	659.7	1.650	0.002 531	591.3	654.6	1.613
510	0.003 235	657.0	705.5	1.770	0.002 815	635.5	691.8	1.713	0.002 595	621.1	686.0	1.676
520	0.003 383	688.6	739.3	1.835	0.002 906	666.2	724.3	1.777	0.002 661	651.2	717.7	1.737
530	0.003 537	720.2	773.3	1.900	0.003 001	697.0	757.0	1.839	0.002 730	681.5	749.7	1.798
540	0.003 696	751.8	807.3	1.964	0.003 099	728.0	790.0	1.900	0.002 800	712.0	782.0	1.858

Table II (*Continued*)

T, K	υ, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	υ, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)	υ, m³/kg	U, kJ/kg	H, kJ/kg	S, kJ/(kg K)
550	0.003 859	783.4	841.3	2.026	0.003 200	759.2	823.2	1.961	0.002 873	742.7	814.5	1.918
560	0.004 024	815.0	875.3	2.087	0.003 304	790.4	856.5	2.021	0.002 947	773.6	847.2	1.977
570	0.004 190	846.5	909.4	2.148	0.003 411	821.9	890.1	2.081	0.003 023	804.7	880.2	2.036
580	0.004 356	878.1	943.4	2.207	0.003 519	853.4	923.8	2.139	0.003 101	835.9	913.5	2.093
590	0.004 522	909.6	977.4	2.265	0.003 629	885.0	957.6	2.197	0.003 180	867.4	946.9	2.150
600	0.004 687	941.2	1011.5	2.322	0.003 740	916.8	991.6	2.254	0.003 261	899.0	980.5	2.207
	Pressure = 30.0 MPa				Pressure = 35.0 MPa				Pressure = 40.0 MPa			
250	0.001 573	−42.2	5.0	−0.170	0.001 565	−44.5	10.3	−0.180	0.001 556	−46.6	15.7	−0.190
260	0.001 594	−21.7	26.1	−0.087	0.001 585	−24.1	31.3	−0.098	0.001 576	−26.4	36.7	−0.108
270	0.001 616	−1.0	47.5	−0.006	0.001 605	−3.5	52.7	−0.017	0.001 595	−5.9	57.9	−0.027
280	0.001 638	20.1	69.3	0.073	0.001 626	17.4	74.3	0.062	0.001 615	14.9	79.5	0.051
290	0.001 661	41.5	91.4	0.150	0.001 648	38.7	96.3	0.139	0.001 636	36.0	101.4	0.128
300	0.001 685	63.3	113.8	0.226	0.001 670	60.2	118.7	0.215	0.001 657	57.4	123.7	0.204
310	0.001 709	85.5	136.7	0.301	0.001 694	82.2	141.5	0.289	0.001 679	79.2	146.4	0.278
320	0.001 735	108.0	160.1	0.376	0.001 717	104.6	164.7	0.363	0.001 702	101.4	169.5	0.351
330	0.001 761	131.0	183.8	0.449	0.001 742	127.3	188.3	0.436	0.001 725	124.0	193.0	0.424
340	0.001 789	154.4	208.1	0.521	0.001 768	150.5	212.4	0.508	0.001 749	147.0	216.9	0.495
350	0.001 817	178.2	232.7	0.593	0.001 794	174.1	236.9	0.579	0.001 773	170.4	241.3	0.566
360	0.001 847	202.5	257.9	0.663	0.001 821	198.1	261.8	0.649	0.001 798	194.2	266.1	0.636
370	0.001 877	227.1	283.4	0.733	0.001 849	222.5	287.2	0.718	0.001 824	218.4	291.3	0.705
380	0.001 909	252.2	309.5	0.803	0.001 878	247.3	313.0	0.787	0.001 851	243.0	317.0	0.773
390	0.001 942	277.6	335.9	0.871	0.001 908	272.5	339.3	0.855	0.001 878	267.9	343.1	0.841
400	0.001 977	303.5	362.8	0.940	0.001 939	298.1	365.9	0.923	0.001 907	293.3	369.6	0.908
410	0.002 013	329.7	390.1	1.007	0.001 971	324.0	393.0	0.990	0.001 936	319.0	396.4	0.974
420	0.002 050	356.3	417.8	1.074	0.002 004	350.3	420.5	1.056	0.001 965	345.1	423.7	1.040
430	0.002 089	383.3	445.9	1.140	0.002 038	377.0	448.3	1.121	0.001 996	371.5	451.4	1.105
440	0.002 129	410.6	474.4	1.205	0.002 073	404.0	476.5	1.186	0.002 027	398.3	479.4	1.170
450	0.002 170	438.2	503.3	1.270	0.002 109	431.3	505.1	1.251	0.002 060	425.4	507.8	1.233
460	0.002 214	466.1	532.5	1.335	0.002 147	458.9	534.1	1.314	0.002 093	452.8	536.5	1.296
470	0.002 258	494.4	562.1	1.398	0.002 185	486.9	563.4	1.377	0.002 126	480.5	565.6	1.359
480	0.002 305	523.0	592.1	1.461	0.002 225	515.1	593.0	1.440	0.002 161	508.5	595.0	1.421
490	0.002 352	551.8	622.4	1.524	0.002 265	543.7	623.0	1.501	0.002 197	536.9	624.7	1.482
500	0.002 402	580.9	653.0	1.586	0.002 307	572.5	653.3	1.563	0.002 233	565.5	654.8	1.543
510	0.002 453	610.3	683.9	1.647	0.002 350	601.6	683.9	1.623	0.002 270	594.4	685.2	1.603
520	0.002 505	640.0	715.1	1.707	0.002 393	631.0	714.8	1.683	0.002 308	623.5	715.8	1.663
530	0.002 559	669.9	746.6	1.767	0.002 438	660.6	746.0	1.743	0.002 346	653.0	746.8	1.722
540	0.002 614	700.0	778.4	1.827	0.002 484	690.5	777.4	1.801	0.002 385	682.6	778.1	1.780
550	0.002 671	730.4	810.5	1.886	0.002 531	720.6	809.2	1.860	0.002 425	712.6	809.6	1.838
560	0.002 729	761.0	842.8	1.944	0.002 578	751.0	841.3	1.917	0.002 466	742.6	841.4	1.895
570	0.002 788	791.8	875.4	2.002	0.002 627	781.6	873.6	1.975	0.002 507	773.3	873.5	1.952
580	0.002 849	822.8	908.3	2.059	0.002 676	812.5	906.1	2.031	0.002 549	804.0	905.9	2.008
590	0.002 910	854.1	941.4	2.115	0.002 727	843.5	939.0	2.087	0.002 592	834.9	938.5	2.064
600	0.002 973	885.5	974.7	2.171	0.002 777	874.8	972.1	2.143	0.002 635	866.1	971.4	2.120

[a] The symbol υ denotes the specific volume, *U* the internal energy, *H* the enthalpy, and *S* the entropy. [b] The reference states for the derived enthalpy and entropy properties from the surface are adjusted to be those of the liquid at the normal boiling temperature defined by the surface (T = 261.395 K for P = 0.101325 MPa). [c] Use with caution in the critical region.

quality of the data. For the precise liquid densities of Haynes (*12*), the average density deviation is 0.12% for temperatures from 250 to 300 K. For the data of Sage (*13*) and of Morris (*14*), which are self-consistent to 0.3% along isotherms, the deviations are within 0.6% for temperatures from 310 to 394 K. The data of the gas phase for $T < T_c$, with the exception of the saturated vapor pressures and two isotherms measured by Waxman et al. (this paper), are not sufficiently accurate to merit a comparison. The saturated vapor pressures defined by the surface agree with our measurements to within 0.0006 MPa for $245 \leq T \leq 373$ K and 0.0026 MPa for $373 < T \leq 398$ K.

We modeled the function for the Helmholtz energy of isobutane after that used successfully in a recent correlation of the thermodynamic properties of water by Haar, Gallagher, and Kell (*15*). Unknown quantities were evaluated according to the least-squares criterion or, if highly nonlinear, to other less exact criteria. The data used in the evaluation consisted of $P-\rho-T$ data selected from literature sources and our recent measurements. The model was not constrained to fit the actual critical point and a small surrounding region; instead this critical region was allowed to float (unconstrained) in the development of the surface so that the critical anomalies would not distort the analytic surface. Further, the Gibbs energies of the coexisting phases expressed in terms of the Helmholtz function and the product of the saturation pressure and specific volume for each phase were constrained to conform with selected saturation data (*16*, *17*) and to be approximately equal. The critical region of isobutane will be treated separately in a forthcoming report.

In Tables I and II, we have tabulated thermodynamic properties generated from our analytical representation of the Helmoltz energy for isobutane. In Table I, saturated thermodynamic properties of isobutane are given: specific volume (v), internal energy (U), enthalpy (H), and entropy (S), with either temperature or pressure as the parameter. In Table II, similar properties are given along isobars with the temperature as the parameter; a solid line is used to separate the properties of the liquid phase and the gas phase. The intervals between isobars correspond to slowly varying first differences in the specific volume and enthalpy. Within the computer program, the properties are calculated first relative to the reference state of 0 K and then adjusted relative to another reference state within our range of temperatures, liquid at its normal boiling point.

In the Appendix, we have outlined the development of a Helmholtz energy function for defining the thermodynamic properties of isobutane. Further we present our saturated va-

Table III. Constants[a]

P^*		ρ^*		T^*	
MPa	1	kg/m³	1	K	1
bar	10	mol/dm³	1.72045×10^{-2}	K	1
psi	145.0377	lb/ft³	6.24280×10^{-2}	°F	1.8

R		M(isobutane)	
kJ/(kg K)	0.1430452	g/mol	58.1243
J/(mol K)	8.31440	lb/mol	0.1281422
BTU/(lb °F)	0.0341658		

P_c		ρ_c		T_c		t_c	
MPa	3.6306	kg/m³	227.0	K	407.851		
bar	36.306	mol/dm³	3.905	K	407.851		
psi	526.57	lb/ft³	14.17			°F	274.462

[a] Critical point is designated by the subscript c; values were evaluated by Levelt Sengers (*26* (from ref *27*)).

Table IV. Units and Conversion Factors

units	press.	density	temp	energy
SI	MPa	kg/m³	K	kJ/kg
"chemical"	bar	mol/dm³	K	J/mol
"engineering"	psi(abs)	lb/ft³	°F	BTU/lb

	press. conversion factors		
	MPa	bar	psi
1 MPa		10	145.0377
1 bar	0.1		14.50377
1 psi	6.894757×10^{-3}	6.894757×10^{-2}	
1 atm	0.101325	1.01325	14.69595

	density conversion factors		
	kg/m³	mol/dm³	lb/ft³
kg/m³		1.72045×10^{-2}	6.24280×10^{-2}
mol/dm³	58.1243		3.62858
lb/ft³	16.0185	0.275590	

	energy conversion factors		
	kJ/kg	J/mol	BTU/lb
kJ/kg		58.1243	0.429923
J/mol	1.72045×10^{-2}		7.39661×10^{-3}
BTU/lb	2.32600	135.197	

por pressure measurements and Burnett P–ρ–T results for the gas phase and compare them with literature data and values derived from the surface. We also compare enthalpies of vaporization and isobaric heat capacities for the saturated liquid and the vapor phase as derived from the surface with experimental data from the literature. Finally, we compare caloric and speed of sound properties predicted by the recent isochoric (nonanalytic) correlation of Goodwin and Haynes (*9*) for isobutane with corresponding results of this correlation. *Both correlations use the same data base*.

Acknowledgment

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Appendix

Preface. To facilitate the reader's use of the equations involved in our representation of a thermodynamic surface for isobutane, we have expressed the equations in a dimensionless form. Some of the equations are inherently dimensionless; i.e., the variables are expressed as reduced quantities. The others are based on quantities initially defined in the SI unit system and then transformed into dimensionless quantities. For example, the reduced temperature variable is expressed as $\boldsymbol{T} = T/T^*$ where T^* is the equivalent of 1 K for the unit system used. Similarly other quantities are expressed relative to either unit equivalents or their inverse values. Transformed quantities are designated by boldface italicized letters and unit equivalents by the asterisk. The boldface italicized equivalent of the density (ρ) is denoted by the symbol ($\boldsymbol{\rho}$). For different unit systems, values of unit equivalents, gas constant (R), isobutane molecular weight (M), and isobutane critical-point constants are listed in Table III. Conversion factors to facilitate the conversion of quantities expressed in one unit system to another are listed in Table IV.

Helmholtz Energy Function. The thermodynamic surface of isobutane is expressed in the form of the Helmholtz energy as a function of temperature and density. This particular function has been adapted from a model developed by Haar, Gallagher, and Kell to represent the thermodynamic surface of water (*15*)

$$A(T,\rho) = A^0(T,\rho_0) + A_{\text{base}}(T,\rho) + A_{\text{res}}(T,\rho) \quad (1)$$

Table V. Coefficients (N_i) and Constant (N_9) of Eq 2 for Ideal-Gas Heat Capacity

i	N_i	N_9
1	$0.113\,634 \times 10^8$	
2	$-0.460\,434 \times 10^6$	
3	$0.622\,522 \times 10^4$	
4	$-0.298\,782 \times 10^2$	
5	0.142 485	
6	$-0.661\,030 \times 10^{-4}$	
7	$-0.115\,812 \times 10^{-7}$	
8	$-0.208\,957 \times 10^2$	
9		0.3250×10^4

Table VI. Coefficients (B_i) of Eq 5 for Second Virial Coefficient

i	$10^3 B_i$	i	$10^3 B_i$
0	3.672 37	5	0.163 192
1	−7.526 73	10	$-0.110\,120 \times 10^{-3}$
3	−1.782 20		

Table VII. Coefficients (b_i) of Eq 6 for Excluded Volume

i	$10^3 b_i$	i	$10^3 b_i$
0	2.729 62	4	$-4.469\,30 \times 10^{-3}$
L	0.694 809	8	$1.752\,19 \times 10^{-5}$

Table VIII. Coefficients (C_{nj}) and Constant (a) of Eq 7 for Residual Helmholtz Energy[a]

n, j	C_{nj}	n, j	C_{nj}
1, 1	$-5.324\,61 \times 10^{-4}$	2, 3	$-4.154\,21 \times 10^{-3}$
2, 1	$2.320\,47 \times 10^{-3}$	4, 3	$3.205\,63 \times 10^{-2}$
4, 1	$-1.740\,15 \times 10^{-2}$	6, 3	$-7.381\,11 \times 10^{-2}$
5, 1	$9.038\,51 \times 10^{-2}$	8, 3	$6.509\,46 \times 10^{-2}$
6, 1	$-9.293\,26 \times 10^{-2}$	1, 4	$-1.270\,11 \times 10^{-3}$
8, 1	$3.522\,14 \times 10^{-2}$	6, 4	$-2.811\,16 \times 10^{-3}$
1, 2	$-6.851\,69 \times 10^{-4}$	1, 5	$-5.631\,15 \times 10^{-4}$
3, 2	$-3.846\,71 \times 10^{-3}$	2, 5	$2.504\,05 \times 10^{-3}$
5, 2	$-9.564\,14 \times 10^{-2}$	5, 5	$-5.574\,20 \times 10^{-3}$
6, 2	$1.031\,33 \times 10^{-1}$	8, 5	$6.355\,84 \times 10^{-3}$
7, 2	$9.193\,27 \times 10^{-2}$	2, 6	$-4.439\,70 \times 10^{-5}$
8, 2	$-1.055\,60 \times 10^{-1}$	8, 6	$9.274\,66 \times 10^{-6}$
1, 3	$3.218\,59 \times 10^{-3}$		

[a] C_{nj} values not listed are equal to zero; the constant $a = 1.72045 \times 10^{-3}$. The value of the term $a\rho_c$ for isobutane was assumed to be the same as for water. This resulted in a reasonable value for the constant.

The Helmholtz function, $A(T,\rho)$, represents the sum of three contributions. The first is of the ideal gas $A^0(T,\rho_0)$ for a reference density (ρ_0) corresponding to a pressure of 0.101 325 MPa and the reference condition $A^0(0\ \mathrm{K},\rho_0) = 0$. The second is of a physically based expression $A_{\mathrm{base}}(T,\rho)$ incorporating the effects of molecular repulsion and attraction (*15*). The remaining contribution is of a sum of residual terms $A_{\mathrm{res}}(T,\rho)$. The residual terms are selected and evaluated from a least-squares analysis of the objective functions $P(\mathrm{exptl}) - \rho^2[\partial A(T,\rho)/\partial\rho]$ and an approximation of the Gibbs equality for the coexisting phases (*18, 19*). Statistical weights are assigned to the experimental data in accordance with our estimate of their precision and accuracy (*3*). Further, we define the reference states for the enthalpy and entropy to be those of the liquid at the normal boiling temperature defined by the surface (T = 261.395 K for P = 0.101325 MPa).

The evaluation of $A^0(T,\rho_0)$ is based on an analytic representation of the ideal-gas values for the isobaric heat capacity $C_p{}^0$ calculated by Chen et al. (*20*) for temperatures from 0 to 1500 K. The function is of the form initially suggested by Barieau (*21*) for nitrogen

$$C_p{}^0/R = \sum_{i=1}^{7} \boldsymbol{N}_i T^{i-4} + \boldsymbol{N}_8 u^2 e^u/(e^u - 1)^2 \qquad (2)$$

where $\boldsymbol{u} = \boldsymbol{N}_9/\boldsymbol{T}$. In terms of eq 2 and appropriate thermodynamic relations, the ideal-gas contribution becomes

$$\frac{A^0(T,\rho_0)}{RT} = \sum_{i=1,\neq 3}^{7} \frac{\boldsymbol{N}_i T^{i-4}}{i-3} - \sum_{i=1,\neq 4}^{7} \frac{\boldsymbol{N}_i T^{i-4}}{i-4} + (\boldsymbol{N}_3 \boldsymbol{T}^{-1} - \boldsymbol{N}_4 + 1)\ln(\boldsymbol{T}) + \boldsymbol{N}_8[\ln(e^u - 1) - \boldsymbol{u}] - 1 \qquad (3)$$

for which constants of integration are defined as zero. Values of the dimensionless coefficients ($\boldsymbol{N}_1$, ..., $\boldsymbol{N}_8$) and of the dimensionless constant ($\boldsymbol{N}_9$) are listed in Table V. Herein, coefficients and constants refer to quantities evaluated according to the least-squares criterion and to less exact criteria, respectively. The percentage deviations of values calculated with eq 2 as compared to Chen's values are within ±0.1% for temperatures from 250 to 1500 K and ±0.4% for lower temperatures (*3*).

For isobutane, an approximately spherical molecule, the specific model chosen for the physically based function $A_{\mathrm{base}}(T,\rho)$ is

$$A_{\mathrm{base}}(T,\rho)/RT = -\ln(1 - \boldsymbol{y}) + 1.5(1 - \boldsymbol{y})^{-2} + 4\boldsymbol{y}(\boldsymbol{B}/\boldsymbol{b} - 1) - 1.5 + \ln(\rho/\rho_0) \qquad (4)$$

where $\boldsymbol{B}$ and $\boldsymbol{b}$ are the dimensionless equivalents of the second virial (B) and excluded volume (b), both temperature dependent, and $\boldsymbol{y}$ is defined as $\boldsymbol{y} = \boldsymbol{\rho b}/4$ (*3* (from ref *15*)). The function $A_{\mathrm{base}}(T,\rho)$ is most effective in the highly compressed liquid region and in the gas-phase region for densities sufficiently small to only require the second virial for the characterization of its nonideality. For many substances, the second virials calculated with the use of the generalized model, not given herein, compare favorably to literature experimental values (*22*). From eq 4, the quantities B and b were evaluated simultaneously for each isotherm T from $P-\rho-T$ data with a density greater than 1.8 times the critical density. This included mainly liquid-phase data for temperatures from 120 to 394 K. Selected terms of a power series in the ratio of the critical temperature to the temperature were fitted to these B values and calculated values from $P-\rho-T$ data (ref *11* and *23* and this work). The second virial function expressed in terms of dimensionless quantities is given by

$$\boldsymbol{B} = B\rho^* = \boldsymbol{B}_0 + \boldsymbol{B}_1(T_c/T) + \boldsymbol{B}_3(T_c/T)^3 + \boldsymbol{B}_5(T_c/T)^5 + \boldsymbol{B}_{10}(T_c/T)^{10} \qquad (5)$$

The subscript c is used to designate critical-point properties. In the evaluation of the series unknowns, $\boldsymbol{B}_i$, the statistical weights assigned to the gas-phase values were sufficiently large to limit the corresponding residuals to a maximum of 34 × 10^{-5} m^3/kg; the residual average for the data at lower temperatures was a factor of 10 larger. Similarly, the excluded volume quantity is represented in dimensionless form by a finite power series in T_c/T plus a limiting temperature term, ln (T_c/T)

$$\boldsymbol{b} = b\rho^* = \boldsymbol{b}_0 + \boldsymbol{b}_L \ln(T_c/T) + \boldsymbol{b}_4(T_c/T)^4 + \boldsymbol{b}_8(T_c/T)^8 \qquad (6)$$

Values of the two sets of dimensionless coefficients, $\boldsymbol{B}_i$ and $\boldsymbol{b}_j$, are listed in Tables VI and VII, respectively.

The evaluation of the coefficients, $\boldsymbol{B}_i$ and $\boldsymbol{b}_j$, is optimized with respect to the $P-\rho-T$ data; however, caloric properties calculated from eq 4 exhibit an increasing anamolous behavior for decreasing temperatures below 180 K. This is a consequence of the behavior of the pressure derivatives, $\mathrm{d}P/\mathrm{d}T$ and $\mathrm{d}P/\mathrm{d}\rho$, calculated from eq 4 for corresponding decreasing temperatures. For increasing temperatures above 180 K, the derivative behavior is nearly monotonic. Since isobutane geothermal processes do not involve these lower temperatures, we have limited the applicable temperature range of the correlation to higher temperatures, 250–600 K.

The remaining contribution $A_{\mathrm{res}}(T,\rho)$ consists of a sum of residual terms that compensate for the difference between the pressure defined by $A_{\mathrm{base}}(T,\rho)$ and the experimental pressure. The residual function in dimensionless form is expressed as

$$\frac{A_{\mathrm{res}}(T,\rho)}{P^*/\rho^*} = \sum_{n,j} \boldsymbol{C}_{nj} \left(\frac{T_c}{T}\right)^j \frac{(1 - e^{-\boldsymbol{a}\rho})^{n+1}}{\boldsymbol{a}(n+1)} \qquad (7)$$

for which the values of the dimensionless coefficients ($\boldsymbol{C}_{nj}$) and constant ($\boldsymbol{a}$) are listed in Table VIII. The term $1 - e^{-a\rho}$ yields finite limits for zero and infinite density values. The function, which was developed for the thermodynamic correlation of water, is most effective for $T > T_c$. In the liquid phase, the contributions of the function are greater than required for the correlation of isobutane since the term $(T_c/T)^j$ increases with decreasing temperature. For temperatures from 250 to 600 K, the terms are selected and the corresponding coefficients evaluated according to the least-squares optimization of two objective functions. One concerns the residual error in the pressure and the other an approximation of the Gibbs equality for the coexisting phases.

Saturated Vapor and Gas-Phase Measurements (This Work). We determined saturated vapor pressures and representative isotherms above and below the critical temperature in an effort to assess the reliability of literature data sources. We obtained our data with an existing Burnett apparatus (*24*) designed to yield high-quality $P-\rho-T$ data for temperatures from 253 to 500 K and pressures from 0.2 to 30 MPa. The precision and the accuracy of the associated pressure measurements have been 5 and 20 ppm, respectively. However, this type of measurement is not obtained readily. For this program, we measured the pressures with more conveniently operated instrumentation. The precision and the accuracy of the pressure measurements for this work were 0.01% for pressures greater than 0.5 MPa. Both degraded proportionately with decreasing pressure below 0.5 MPa to 0.05% at the lower limit of 0.2 MPa. The temperatures were measured on the IPTS-68 with a capsule platinum resistance thermometer, which had a stability of 0.002 K at the triple point of water. We used a commercial research grade of isobutane for the measurements; its purity was reported to be 99.98%.

Saturated Vapor Pressure. Saturated vapor pressures were measured near the vapor side of the coexistence boundary. For several temperatures, we varied the ratio of the quantity of vapor to liquid and measured the pressure for the corre-

Table IX. Coefficients (E_i) of Eq 9 and Coefficients (A_j and A^-) and Constant (θ) of Eq 10[a]

eq 9		eq 10		
i	E_i	j	A_j	A^-
1	−6.837 96	1	6.818 526	
2	1.252 20	2	−10.738 53	
5	−2.340 60	3	6.843 1	
				22.018 24

[a] Saturated vapor pressure. Equation 9 is applicable for $245 \leqslant T \leqslant T_c$ and eq 10 for $298 \leqslant T \leqslant T_c$. Equation 10 is based on the scaling laws for the critical region (*26* (from ref *27*)); the constant $\theta = 0.11$. θ is a critical-region exponent characterizing the divergence of $d^2P(\text{vapor})/dT^2$; it is a universal constant (*28*).

Table X. Vapor Pressure Data of Isobutane Sample from This Work[a]

temp, K	press., MPa	temp, K	press., MPa
298.15	0.3500	333.15	0.8676
303.15	0.4043	343.15	1.0867
308.15	0.4641	353.15	1.3432
313.15	0.5304	363.15	1.6408
318.15	0.6032	373.15	1.9855
323.15	0.6836	383.15	2.3819
328.15	0.7725	393.15	2.8361
333.15	0.8683	398.15	3.0879

[a] Sample purity, commercial research grade, is reported to be 99.98%.

Table XI. Density Virial Coefficients for Selected Temperatures from This Work[a]

T, K	$10^5\mathcal{B}$, m³/kg	$10^6\mathcal{C}$, (m³/kg)²	$10^9\mathcal{D}$, (m³/kg)³	$10^{11}\mathcal{E}$, (m³/kg)⁴	ρ_{max}, kg/m³
377.594	−647.4 ± 0.7	9.86 ± 0.16			41
394.261	−592.2 ± 0.2	10.66 ± 0.08			81
423.15	−501.5 ± 0.3	8.91 ± 0.07	7.9 ± 0.8	−3.0 ± 0.3	150
448.15	−440.3 ± 0.1	8.62 ± 0.01			100

[a] $\mathcal{B}$, second virial; $\mathcal{C}$, third virial; $\mathcal{D}$, fourth virial; $\mathcal{E}$, fifth virial. Virial coefficients correspond to the coefficients of a finite density series representation of the compressibility factor.

Table XII. Isothermal P-ρ-T Data at 423.15 and 448.15 from This Work

press., MPa	density, kg/m³	press., MPa	density, kg/m³
	$T = 423.15$ K		
20.750	457.9	3.747	110.2
4.754	257.2	5.403	314.1
10.840	406.9	4.352	176.4
4.600	228.5	3.571	99.91
3.977	128.3	15.982	438.4
6.426	349.3	4.690	246.2
4.452	196.2	4.078	138.3
	$T = 448.15$ K		
10.024	349.6	6.757	261.2
5.770	196.3	5.060	146.7
4.377	110.3	3.675	82.39
3.018	61.97	7.480	292.5
10.024	349.6	5.328	164.2
5.770	196.4	3.946	92.24
4.377	110.3		

sponding ratios. In general, for different ratios, the vapor pressure did not vary by more than 100 Pa. However, at 298 K, the variation increased to 300 Pa for a change of liquid volume from 1 to 5 cm³ as measured with a volumetric pump. We have represented our data and selected literature data for $245 \leq T \leq 398$ K with appropriate terms of a general power series in $(1 - T/T_c)^{(1+j)/2}$. The generalized form, proposed by Wagner (*25*), is expressed as

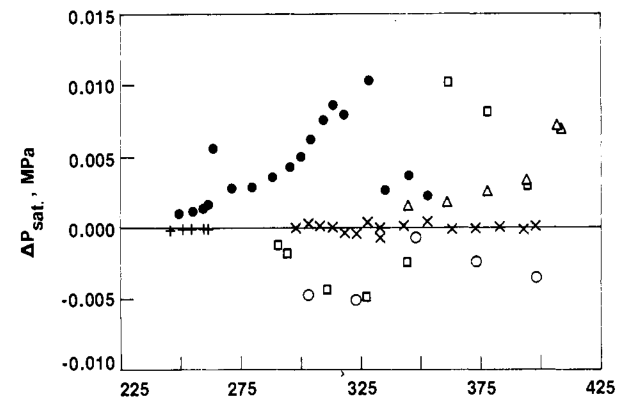

Figure 2. Comparison of saturated vapor pressures, $\Delta_{sat.} = P_{sat.}(\text{exptl}) - P_{sat.}(\text{eq 9})$: (×) this work; (+) Aston (*28*); (○) Beattie (*27*); (△) Connolly (*23*); (●) Dana (*29*); (□) Sage (*13*).

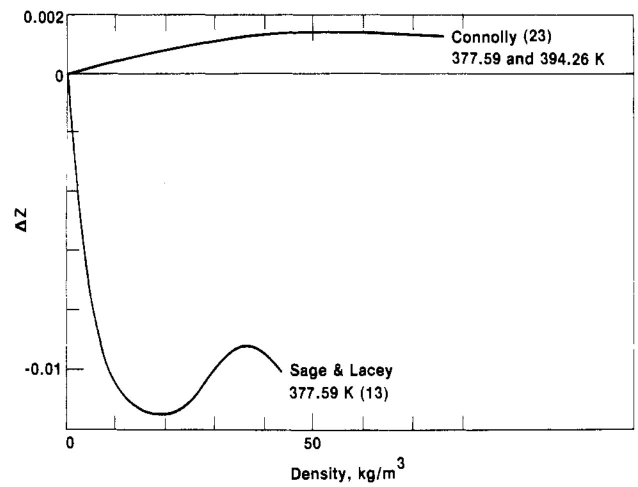

Figure 3. Comparison of compressibility factors ($Z = P\rho/RT$): $\Delta Z = Z(\text{lit.}) - Z(\text{this work})$.

$$\ln (P/P_c) = (T_c/T) \sum_{j=1}^{J} E_j(1 - T/T_c)^{(1+j)/2} \quad (8)$$

We chose the specific form to be

$$\ln (P/P_c) = (T_c/T)[E_1(1 - T/T_c) + E_2(1 - T/T_c)^{3/2} + E_5(1 - T/T_c)^3] \quad (9)$$

for the temperature range $245 \text{ K} \leq T \leq T_c$. We also have as an option the equation

$$P/P_c = 1 + A_1(1 - T/T_c) + A^-(1 - T/T_c)^{2-\theta} + A_2(1 - T/T_c)^2 + A_3(1 - T/T_c)^3 \quad (10)$$

which is based on the scaling laws (*26* (from ref *27*)) and is applicable for the temperature range of $298 \ K \leq T \leq T_c$. Values of the two sets of dimensionless coefficients (E_i) and (A_j) and of the constant θ are listed in Table IX. Our measurements of the saturated vapor pressure are summarized in Table X; details are discussed in ref *26*. Corresponding values from both equations agree to within 1 SD of the residuals, 20 Pa, for the temperature range of $298 \text{ K} \leq T \leq T_c$. This magnitude reflects mainly the variability due to impurities in samples of different liquid-to-vapor ratios (*26*).

Because of the general disagreement between data sources, we deduced the specific terms in eq 9 mainly from our own data. In Figure 2, we compare saturated vapor pressures for different data sources with corresponding values defined by eq 9. The differences between data sources are too large to be

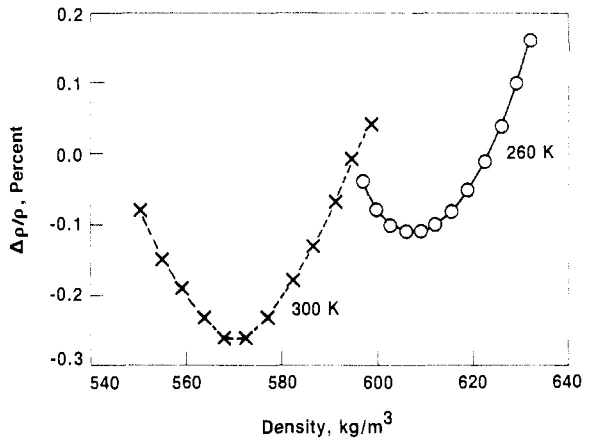

Figure 4. Comparison of surface-derived densities with corresponding experimental values: $\Delta\rho = \rho$(Haynes (*12*)) − ρ(surface).

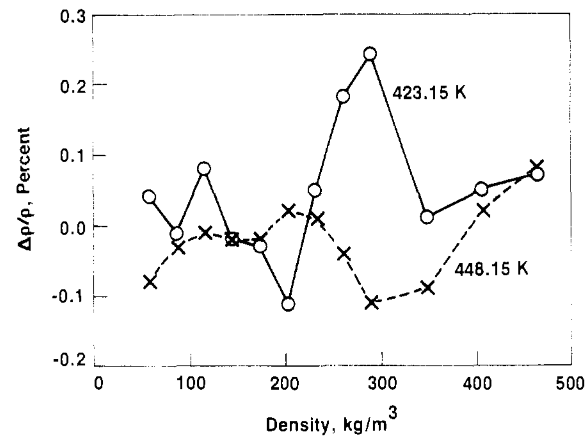

Figure 5. Comparison of surface-derived densities with corresponding experimental values: $\Delta\rho = \rho$(Beattie (*11*)) − ρ(surface).

attributed to variations in sample composition (*26*, *28*, *31*). For the higher temperatures, we estimate the vapor pressure error in our work to be 0.0003 MPa for the pressure variable and the equivalent of 0.0003 MPa for the temperature variable. The latter is based on the reproducibility of the thermometer at the triple point of water.

Gas-Phase Isotherms. Using the Burnett method, we determined isotherms for temperatures of 377.59, 394.26, 423.15, and 448.15 K. For $T > T_c$, the isotherms were represented by a finite polynomial expansion in density for pressures up to 4.2 MPa and by discrete $P-\rho-T$ points for higher pressures (*32*). For $T < T_c$, the isotherms were represented by a finite polynomial expansion in density with the maximum pressure less than that of the saturated vapor. Although the name "virial coefficients" should only be identified with the coefficients of an infinite density series (*33*), we consider the coefficients of these finite series as being equivalent to virial coefficients, particularly for the linear and quadratic terms. The virial coefficients are listed in Table XI and the $P-\rho-T$ data in Table XII. The second virial and compressibility factor results for the higher temperatures, 423 and 448 K, were compared with corresponding results calculated from Beattie's $P-\rho-T$ data (*11*). The second virials agreed favorably to within a maximum difference of 0.3×10^{-5} m^3/kg (0.05%). The differences between compressibility factors were within 0.001 for the 448.15 K isotherm and, in contrast, as much as 0.003 for the near-critical isotherm of 423.15 K. The increase is attributed to the critical enhancement of the effects of sample impurities and of differences in pressure and temperature scales for near-critical densities as the critical temperature is approached. In Figure 3, we compare our values of the compressibility factor with those from Sage (*13*) and Connolly (*23*). Connolly's values and ours follow from the virial representation of the compressibility factor, and Sage's values from $P-\rho-T$ data. The agreement with Connolly's results is acceptable, within 0.002 in the compressibility factor. In contrast, we disagree with Sage's results by as much as 0.01. The $P-\rho-T$ results, reported herein, were evaluated with different models of analysis and found to be the same for any model used. This suggested that sorption, if present, has had a negligible effect and the experimental data are precise.

Comparisons with Derived Properties. P-ρ-T Data. The correlation has been developed solely from $P-\rho-T$ data and reflects the distribution and quality of the data used. In the least-squares selection of significant terms and evaluation of unknowns, we assigned statistical weights to the data points. The weights were varied according to our estimate of the accuracy and precision for each data source and to the magnitude of each variable. Representative comparisons of the more accurate experimental data with values defined by the surface are illustrated in Figure 4 for the 260 and 300 K isotherms in the liquid phase and in Figure 5 for the 423 and 448 K isotherms in the gas phase. In the liquid phase, the average density deviation is 0.12% for temperatures from 260 to 300 K and as much as 0.6% for less accurate data, not shown, for higher temperatures. In the gas phase for $T > T_c$, the density deviations generally do not exceed 0.1%. Some larger deviations of 0.25% occur in a small density and temperature region, near the critical point, as illustrated in Figure 5 by the comparison of the 423 K isotherm. The explanation of the larger deviations lies within the data sources used, Beattie (*11*) and this work. In this region, the experimental data disagree by as much as 0.35%; elsewhere the agreement is with 0.1%. This inconsistency accounts for the larger but localized deviations. Physically, as we have stated previously, the increased difference between these two data sources is attributed to critical enhancement.

The surface $A(T,\rho)$ does not represent the vapor pressures as well as the vapor pressure equation, eq 9, at the higher temperatures, $T > 373$ K. In Figure 6, the experimental data used to obtain eq 9 are compared with corresponding values defined by the surface. The deviations are less than 0.0006 MPa for $245 \leq T_c \leq 373$ K. For higher temperatures, the deviations increase to a maximum of 0.0026 MPa at 398 K. The explanation again lies within the data sources. Above 300 K, the liquid data exhibit limiting values of density with decreasing pressure which are significantly different from the saturated liquid density values defined by an accurate equation (*3*). This degrades the surface near the phase boundry, and therefore phase boundry properties as well.

Caloric Data. Apart from the $P-\rho-T$ data, few thermodynamic properties of isobutane have been measured. These consist mainly of enthalpies of vaporization and isobaric heat capacities of the saturated liquid and of the gas phase at low pressures for moderate temperatures less than T_c. In Figure 7, experimental and surface-derived values for the enthalpy of vaporization are intercompared. The deviations are within 2% for $261 \leq T > 373$ K. For higher temperatures, the deviations are significantly larger, as much as 7.5%. In Table XIII, we have tabulated the experimental and surface-derived values of the isobaric heat capacity. The agreement is within 0.09% in both the liquid and gas phases. The close agreement with the gas-phase (vapor) data confirms the validity of the calculated ideal-gas properties for moderate temperatures.

Comments. The derived surface $A(T,\rho)$ conforms to the $P-\rho-T$ data within the tolerance allowed by the assigned weights (*3*) and agrees favorably with measured caloric data except at 380 and 390 K. The exceptions may be indicative

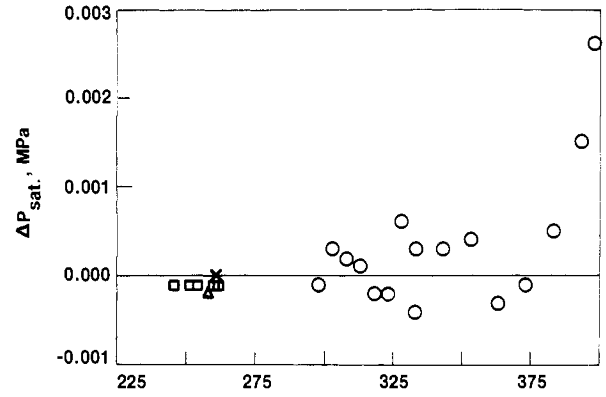

Figure 6. Comparison of surface-derived saturated vapor pressures with experimental values, $\Delta P_{sat.} = P_{sat.}$(exptl) − $P_{sat.}$(surface): (O) this work; (□) Aston (*29*); (X) Gilmour (*34*); (Δ) Wackher (*35*).

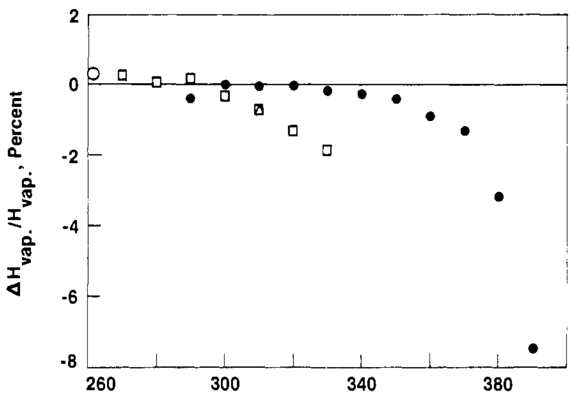

Figure 7. Comparison of surface-derived enthalpies of vaporization with experimental values, $\Delta H_{vap} = H_{vap}$(lit.) − H_{vap}(surface): (O) Aston (exptl (*29*)); (□) Dana (exptl (*30*)); (Δ) Hanson (calcd (*4*)); (●) Sage (exptl (*13*)).

of inaccurate caloric data or of limitations of the surface. The surface has to reflect the quality of the data. In the temperature range of 300 K < T < T_c, our estimate of the data accuracy in the liquid and vapor phases (*13*, *14*) is as small as 1%. Further, most of the isotherms for the liquid phase at higher temperatures exhibit with decreasing pressures limiting density values which are significantly different from those of an accurate phase boundary (*3*). These factors could be the reasons for the larger caloric and vapor pressure differences at the higher temperatures.

The surface exhibits the characteristic retrograde behavior of hydrocarbons for temperature–entropy behavior of the saturated liquid and vapor. It is applicable for the calculation of thermodynamic properties for temperatures from 250 to 600 K and pressures up to 40 MPa with the exception of the critical region. The excluded critical region is defined by $0.98_5 < T_c/T < 1.01_5$ and $0.7 < \rho_c/\rho < 1.3$. For this region, a separate formulation is in preparation.

Comparison of Correlations. Concurrently with our isobutane correlation program and using a data base similar to ours, Goodwin and Haynes (*9*) have developed an isochoric (nonanalytic) correlation. Its primary purpose is the thermodynamic characterization of isobutane as a component of liquefied natural gas (LNG). The temperature and pressure ranges are 114–700 K and up to 70 MPa, respectively, whereas, for geothermal applications, our ranges are more limited, 250–600 K and up to 40 MPa. As applied to isobutane, each method has its own merits. The analytic method employs

Table XIII. Comparison of Isobaric Heat Capacities (C_p)

Saturated Liquid

temp, K	press., MPa	C_p, kJ/(kg K) this work	Aston (*29*)	Parks (*36*)
230	0.0247	2.078	2.087	2.078
240	0.0404	2.130	2.139	2.121
250	0.7634	2.173	2.187	2.168
260	0.0958	2.212	2.231	2.219

Vapor

temp, K	press., MPa	C_p, kJ/(kg K) this work	Ernst (*37*)	Wacker (*38*)
293.15	0.0490	1.651	1.638	
	0.1471	1.676	1.670	
	0.1961	1.693	1.706	
353.15	0.0490	1.930	1.922	
	0.1471	1.942	1.935	
	0.4903	2.004	2.011	
	0.7845	2.086	2.096	
243.15	0.0121	1.416		1.424
	0.0234	1.420		1.431
	0.0301	1.422		1.435
273.15	0.0249	1.554		1.558
	0.0505	1.560		1.569
313.15	0.0245	1.739		1.740
	0.0512	1.743		1.745
353.15	0.0247	1.927		1.926
	0.0513	1.930		1.929

Table XIV. Comparison of Correlations for Percentage Difference of Enthalpies of Vaporization, H_{vap}(ref *9*) with Respect to H_{vap}(this paper)

temp, K	% difference	temp, K	% difference
255	−0.2	360	0.1
280	0.1	370	0.1
300	0.3	390	1
320	0.3	395	3
340	0.3	400	5

slowly varying functions and closely approximates the data base for $T > T_c$. In the liquid range, its effectiveness is limited by the particular function used for the temperature dependence in eq 7. The isochoric method employs a highly constrained function and closely approximates the accurate P–ρ–T data in the liquid phase for 120 ≤ T ≤ 300 K. For $T > T_c$, it is not as effective. A comparison is given in the following table:

temp range, K	data source	av density difference, % analytic method	isochoric method
$T > T_c$	ref *11* and this paper	0.1	0.8
liquid phase, $120 \leq T \leq 300$	ref *12*		0.04
liquid phase, $250 \leq T \leq 300$	this paper	0.2_-	

The 0.2% difference for the analytic method is also characteristic of an extrapolation to lower temperatures, lower limit of 120 K, in the liquid phase. In the comparison, the 300 K < T < T_c liquid interval is omitted as the corresponding data are not sufficiently accurate to merit a comparison.

A complementary guide for judging the merit of the correlation methods is the comparison of derived properties, caloric and speed of sound. A limited comparison of enthalpies of vaporization is given in Table XIV and of heat capacities and speed of sound values in Table XV. The corresponding enthalpies of vaporization predicted by each correlation agree to within 0.3% for temperatures from 250 to 370 K. For higher

Table XV. Comparison of Correlations for Percentage Difference of Heat Capacities and Speed of Sound (W) Values, C_p (ref *9*) with Respect to C_p (ref *10*), C_v (ref *9*) with Respect to C_v (ref *10*), and W (ref *9*) with Respect to W (ref *10*)[a]

	% difference		
temp, K	C_p	C_v	W
	Pressure = 0.101325 MPa		
250	−2	4	−9
300	0.5	−0.3	0.5
350	0.3	0.2	0.5
400	0.1	0.2	0.4
450	0.3	0.03	0.4
500	−0.3	0.01	0.4
600	−0.2	0.04	0.7
700	−0.3	−0.04	0.3
	Pressure = 0.5 MPa		
250	−2	4	−9
300	−0.8	3	−8
350	0.1	0.04	0
400	0.1	0.2	0.4
450	0.01	−0.2	0.4
500	0.4	0.1	0.4
600	0.04	−0.02	0.7
700	0.1	−0.1	0.3
	Pressure = 1 MPa		
250	−2	4	−10
300	−1	2	−8
350	−0.2	−0.3	−0.5
400	−0.2	0.1	−0.5
450	−0.2	0.1	0
500	0.1	−0.3	0
600	0.2	0.1	0.3
700	−0.2	0.1	0.3
	Pressure = 5 MPa		
250	−2	2	−5
300	1	1	−4
350	1	5	−4
400	−4	−4	−1
450	−0.7	−1	0.6
500	0.6	−1	0
600	0.2	−0.5	0.4
700	0.1	−0.03	0.1
	Pressure = 10 MPa		
250	−2	−1	1
300	−1	−0.2	−1
350	1	3	−1
400	−4	−6	1
450	−2	−3	2
500	0.5	−2	0.4
600	−0.5	−1	2
700	0.02	−0.6	2
	Pressure = 20 MPa		
250	−1	−4	4
300	−1	−3	2
350	2	2	1
400	−5	−7	−2
450	−3	−3	1
500	−2	−2	1
600	−0.4	−2	0.6
700	0.1	−1	2
	Pressure = 40 MPa		
250	−2	−5	9
300	−1	−3	5
350	2	2	2
400	−5	−5	−1
450	−3	−3	−0.1
500	−1	−1	−1
600	−1	−1	0.2
700	−0.5	−1	−2

[a] Temperature range of ref *10* is 250–700 K.

temperatures the percentage difference increases slightly: 1% at 390 K, 3% at 395 K, and 5% at 400 K. At 390 K, the close agreement of 1% in contrast with the much larger disagreement of both correlations (ref *9* and this paper) with Sage (*13*), about 6%, suggests an error in Sage's value. The generally close agreement reflects the use of similar or the same boundary data in both correlations.

The corresponding isobaric and isochoric heat capacities agree to within an average of 2% for pressures up to 10 MPa and temperatures from 250 to 700 K. For higher pressures up to 40 MPa, the average percentage difference increases to 3%. Outliers as large as 6% occur in the liquid region, particularly near the critical temperature. For the same range of conditions, corresponding speed of sound values agree within an average of a few percent. Outliers as large as 10% occur in the vapor region ($T < T_c$).

Although the comparison is characterized as being favorable, its significance may be limited. In regions where experimental caloric and speed of sound properties do not exist, the close comparison suggests only that the results are consistent with the data base and independent of the correlation method. Accurate experimental data for caloric and speed of sound properties over a wide range of conditions are needed for the thorough evaluation of the correlations.

Addendum. Since the completion of this correlation, a question has arisen concerning the appropriate value for the isobutane molecular weight to be associated with Beattie's data (*11*) published in 1950. A value of 58.077 is stated in the publication, whereas the generally accepted value since 1941 is 58.124_+. The latter is the one that we used with Beattie's data in the development of the surface. We cannot give a definitive argument for the use of one or the other value.

The effect of the discrepancy on surface-derived $P-\rho-T$ values is only 0.08% in density. In the following table, a comparison is given in percentage deviations of surface-derived density values with Beattie's data for each molecular weight value:

	deviation, %	
	$M = 58.124_+$	$M = 58.077$
mean	−0.02	−0.09
σ(mean)	0.01	0.007
σ	0.09	0.06

The effect on caloric properties derived from the surface has not been considered.

Glossary

$\mathbf{a}$	constant of eq 7, residual Helmholtz energy
A_i and A^-	coefficients of eq 10, saturated vapor pressure (scaled)
$A(T,\rho)$	total Helmholtz energy, eq 1
$A^0(T,\rho_0)$	ideal-gas contribution to $A(T,\rho)$ for the condition T and ρ_0, eq 3
$A_{base}(T,\rho)$	physically based contribution to $A(T,\rho)$, compensates for the difference between the pressure defined by the sum of $A^0(T,\rho_0)$ and $A_{base}(T,\rho)$ and the $P-\rho-T$ data base, eq 7
b	excluded volume parameter, eq 6
$\mathbf{b}$	reduced excluded volume parameter, eq 6
$\mathbf{b}_i$ and $\mathbf{b}_L$	coefficients of eq 6, excluded volume parameter
B	second virial parameter, eq 5
$\mathbf{B}$	reduced second virial parameter, eq 5
$\mathbf{B}_i$	coefficients of eq 5, second virial
$\mathcal{B}$	second virial for new isothermal data (this paper), Table XI
C_p	isobaric heat capacity
C_p^0	C_p for ideal gas
C_v	isochoric heat capacity

C_{nj}	coefficients of eq 7, residual Helmholtz energy function
$\mathcal{C}$	third virial for new isothermal data (this paper), Table XI
$\mathcal{D}$	fourth virial for new isothermal data (this paper), Table XI
$\mathcal{E}$	fifth virial for new isothermal data (this paper), Table XI
E_j	coefficients of eq 9, saturated vapor pressure
H	enthalpy
H_l	liquid enthalpy
H_ν	vapor enthalpy
H_{vap}	vaporization enthalpy
M	molecular weight
N_i	coefficients of eq 2, isobaric heat capacity for ideal gas
P	pressure
P_c	critical pressure
P^*	designated unit of P equivalent to its SI unit
$\boldsymbol{P}$	reduced pressure, P/P^*
R	gas constant
S	entropy
S_l	liquid entropy
S_ν	vapor entropy
S_{vap}	vaporization entropy
T	temperature
T_c	critical temperature
T^*	designated unit of T equivalent to its SI unit
$\boldsymbol{T}$	reduced temperature
$\boldsymbol{u}$	coefficient of eq 2, $\boldsymbol{N_9/T}$
U	internal energy
U_l	liquid internal energy
U_ν	vapor internal energy
U_{vap}	vaporization internal energy
v	specific volume
v_l	liquid specific volume
v_ν	vapor specific volume
W	speed of sound
$\boldsymbol{y}$	defined as $\boldsymbol{pb}/4$ in eq 4
ρ	density
ρ_c	critical density
ρ_0	density corresponding to a pressure of 0.101325 MPa
ρ^*	designated unit of ρ equivalent to its SI unit
$\boldsymbol{p}$	reduced density, ρ/ρ^*
θ	universal critical region exponent characterizing the divergence at d^2P_ν/dT^2
ν	vapor phase, defined as gas phase for $T < T_c$
σ	standard deviation

Boldface italicized symbols are pseudo reduced quantities.

Registry No. Isobutane, 75-28-5.

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