A Modified Benedict–Webb–Rubin Equation of State for the Thermodynamic Properties of R152a (1,1-difluoroethane)

Stephanie L. Outcalt and Mark O. McLinden
Thermophysics Division, National Institute of Standards and Technology, Boulder, Colorado 80303-3328

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A modified Benedict–Webb–Rubin (MBWR) equation of state has been developed for R152a (1,1-difluoroethane). The correlation is based on a selection of available experimental thermodynamic property data. Single-phase pressure–volume–temperature (*PVT*), heat capacity, and sound speed data, as well as second virial coefficient, vapor pressure, and saturated liquid and saturated vapor density data, were used with multi-property linear least-squares fitting to determine the 32 adjustable coefficients of the MBWR equation. Ancillary equations representing the vapor pressure, saturated liquid and saturated vapor densities, and the ideal gas heat capacity were determined. Coefficients for the equation of state and the ancillary equations are given. Experimental data used in this work covered temperatures from 162 K to 453 K and pressures to 35 MPa. The MBWR equation established in this work may be used to predict thermodynamic properties of R152a from the triple-point temperature of 154.56 K to 500 K and for pressures up to 60 MPa except in the immediate vicinity of the critical point. © *1996 American Institute of Physics and American Chemical Society.*

Key words: correlation, density, 1,1-difluoroethane, equation of state, heat capacity, pressure-volume-temperature, R152a, thermodynamic properties, vapor pressure.

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1. Introduction

Mixtures containing R152a (1,1-difluoroethane) are being considered as possible replacements for R12 (dichlorodifluoromethane) for use in small and medium-sized air conditioners and heat pumps. Mixtures of R152a with R22 (chlorodifluoromethane) and/or other HCFCs (hydrochlorofluorocarbons) are of the greatest interest. In order to design energy efficient heating and cooling systems that will incorporate these refrigerants, knowledge of their thermodynamic properties is essential. In this work, experimental thermodynamic data for pure R152a has been collected from the literature and other sources, evaluated, and used to determine a 32-term modified Benedict–Webb–Rubin (MBWR) equation of state. The intent of this work is to develop a high-accuracy equation of state to be included in the NIST REFPROP database, and to be used in mixture models. Results are presented comparing predicted values to experimental data.

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2. Experimental Data

The MBWR equation determined for R152a was based upon an extensive set of experimental data. Table 1 lists the

TABLE 1. Reported critical point parameters and triple point temperature for R152a.

Source and year	Temperature (K)	Pressure (MPa)	Density (mol/L)
Critical point			
Baehr[2] (1991)		4.51675	
Bier[26] (1990)	386.53		
Chae[27] (1990)	386.35±0.10		5.587±0.136
Higashi[1] (1987)	386.411±0.01[a]	4.5198±0.001	5.571±0.030
Holcomb[9] (1993)			5.584±0.015
Mears[28] (1955)	386.65±0.5[b]	4.495	5.526±0.151
Wang[29] (1992)	386.46±0.01		
Triple point			
Blanke[5] (1992)	154.560±0.005	65±5[c]	
Magee[7] (1995)	154.56±0.01		

[a]The temperature reported in the source paper was on the IPTS-68; the value listed here has been converted to the ITS-90.
[b]The temperature in the source paper was on an unspecified scale.
[c]The triple point pressure of Blanke has units of Pa.

TABLE 2. Summary of saturation and ideal gas heat capacity data for R152a.

Source and year	No. of points used total	Temperature range (K)	Dev. from anc. eq. (%) bias	AAD
Vapor pressure				
Baehr[2] (1991)	21/55	373–386	0.000	0.003
Blanke[5] (1992)	32/36	154–260	0.011	0.020
Calc. from C_σ of Magee[7] (1995)[a]	9/9	170–250	−0.003	0.012
Geller[30] (1980)	0/13	311–383	[−0.184]	[0.185]
Higashi[1] (1987)	30/44	273–386	0.003	0.036
Holcomb[9] (1993)	0/33	312–384	[0.111]	[0.145]
Iso[31] (1989)	0/7	320–385	[−0.010]	[0.129]
Mears[28] (1955)	0/23	204–377	[4.830]	[5.178]
Silva[6] (1993)	38/38	220–273	−0.011	0.019
Soll[32] (1938)	0/3	194-247	[10.694]	[10.694]
Tamatsu[33] (1992)	0/46	320–386	[−0.069]	[0.081]
Türk[34] (1994)	0/43	207–386	[0.001]	[0.076]
Yada[35] (1988)	0/13	305–385	[0.050]	[0.129]
Zhao[36] (1992)	0/167	237–381	[−0.036]	[0.236]
Overall	130/530	154–386	0.000	0.020
Saturated liquid density				
Blanke[5] (1992)	12/12	252–308	−0.015	0.021
Geller[30] (1980)	0/19	160–340	[0.019]	[0.085]
Higashi[1] (1987)	4/6	370–382	−0.019	0.055
Holcomb[9] (1993)	33/33	311–384	0.002	0.002
Iso[31] (1989)	0/2	353–360	[0.276]	[0.276]
Magee[10] (1995)[b]	8/11	157–370	−0.014	0.022
Masui[37] (1984)	0/1	296	[−0.049]	[−0.049]
Mears[28] (1955)	0/8	232–353	[−0.151]	[0.244]
Sato[38] (1987)	0/25	223–363	[−0.091]	[0.162]
Tamatsu[33] (1992)	0/1	329.55	[0.034]	[0.034]
Tillner-Roth[21] (1993)[c]	0/13	243–353	[−0.015]	[0.024]
Valtz[39] (1987)	0/4	298–372	[−1.119]	[1.153]
Wang[29] (1992)	0/6	376–386	[−0.340]	[0.856]
Zhao[36] (1992)	0/33	308–376	[−2.113]	[2.357]
Overall	57/174	157–384	−0.001	0.025
Saturated vapor density				
Calc. from virials of Gillis[12] (1995)[d]	11/11	160–260	0.011	0.024
Higashi[1] (1987)	8/9	374–386	0.051	0.555
Holcomb[9] (1993)	23/33	338–384	−0.048	0.176
Iso[29] (1989)	0/1	385	[1.435]	[1.435]
Tamatsu[33] (1992)	0/4	336–362	[−1.309]	[1.309]
Wang[29] (1992)	0/7	377–386	[−0.670]	[1.379]
Zhao[36] (1992)	0/69	263–381	[45.951]	[48.807]
Overall	42/134	160–386	−0.003	0.208
Ideal gas heat capacity				
Chen[12] (1975)	3/19	150–1500	0.053	0.230
Gillis[11] (1995)	9/9	242–400	−0.018	0.104
Hozumi[40] (1993)	0/7	273–348	[0.324]	[0.324]
Mears[28] (1955)	0/9	248–1000	[8.348]	[8.469]
Overall	13/45	150–1000	0.000	0.135

[a]Vapor pressures calculated from C_σ data (see text).
[b]Isochoric PVT data extrapolated to saturation.
[c]Isothermal PVT data extrapolated to saturation.
[d]Calculated by intersection of virial surface with vapor pressure equation.
[ ]≡data not used in formulation of ancillary equation.

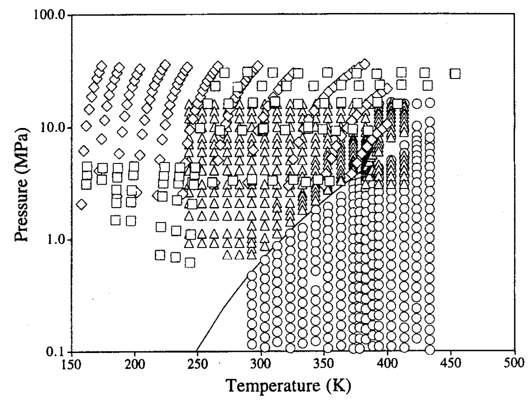

FIG. 1. Experimental *PVT* data used in the MBWR correlation. Blanke[5] (□), Magee[10] (◇), Tillner-Roth[11] (○), Tillner-Roth[21] (△), and the saturation line (—).

eported triple-point and critical parameters for R152a; the critical constants used in this correlation were: T_c=386.411 K, Higashi *et al.*,[1] P_c=4.51675 MPa, Baehr and Tillner-Roth,[2] and ρ_c=5.57145 mol/L (368 kg/m^3), Higashi *et al.*[1] (The critical pressure of Baehr and Tillner-Roth[2] was chosen over that of Higashi *et al.*[1] because upon extrapolation the majority of the experimental vapor pressure data exhibited a trend towards the Tillner-Roth[2] value at the critical point.) Table 2 lists the reported saturation data and the ideal gas heat capacity data. Table 3 summarizes the available pressure–volume–temperature (*PVT*), specific heat, and speed of sound data. The data sets used in the correlation included both liquid and vapor phase data that covered large ranges in temperature and pressure. (All temperatures in this work are on ITS-90; data that were measured on the IPTS-68 were converted to ITS-90 before being fitted to the MBWR equation.) Figure 1 shows the temperature and pressure ranges of the *PVT* data used in the correlation. Figure 2 is a similar plot for the heat capacity and speed of sound data. These data are discussed below in more detail in conjunction with the fits of the respective properties.

3. Ancillary Equations

Equations that accurately represent the vapor pressure, saturated-liquid density, saturated-vapor density and the ideal gas heat capacity are needed. These ancillary equations (and their derivatives) are used by the MBWR fitting routine to define the saturation boundary and calculate values for other thermodynamic properties. The ancillary equation for the ideal gas heat capacity must be used with the MBWR equation for a complete description of the thermodynamic properties, but the ancillary equations for the saturation boundary are used only in the fitting process; they are not part of the final equation of state.

The equation used to represent the vapor pressure P_σ of R152a is

$$\ln\left[\frac{P_\sigma}{P_c}\right]=\frac{\alpha_0\tau+\alpha_1\tau^{1.5}+\alpha_2\tau^2+\alpha_3\tau^4+\alpha_4\tau^{6.5}}{1-\tau}, \quad (1)$$

TABLE 3. Summary of *PVT*, specific heat, and sound speed data for R152a.

Source	No. of points used/total	Range of data: *T* (K)	*P* (MPa)	ρ (mol/L)	Dev. from MBWR (%): bias	*AAD*
PVT						
Blanke[5] (1992)	200/209	190–453	0.6–30.5	10.3–17.9	−0.001	0.007
Dressner[25] (1991)	0/149	333–423	0.2–57.6	0.7–13.2	[−0.053]	[0.143]
Geller[30] (1980)	0/97	159–470	0.7–57.9	9.8–18.0	[4.320]	[4.410]
Iso[31] (1989)	0/221	320–400	1.5–10.0	3.5–13.4	[1.287]	[1.637]
Magee[10] (1995)	134/134	158–400	2–35	9.7–18.0	0.016	0.023
Majima[41] (1987)[a]	0/55	340–390	0.1–5			
Mears[28] (1955)	0/22	345–397	1.8–4.6	0.89–2.5	[−0.715]	[1.571]
Takahashi[42] (1987)	0/113	273–448	0.1–9.8	0.10–8.7	[0.489]	[3.743]
Tamatsu[33] (1992)	0/60	330–440	1.5–9.3	0.8–12.2	[0.173]	[0.346]
Tillner-Roth[20] (1992)	314/335	293–433	0.09–15.8	0.04–11.2	−0.006	0.030
Tillner-Roth[21] (1993)	342/398	243–413	0.07–16.0	1.15–15.9	0.002	0.013
Zhao[36] (1992)	0/257	253–404	0.06–6.1	0.05–12.7	[−0.561]	[1.160]
Overall	990/2061	159–470	0.06–57.9	0.04–18.0	0.001	0.018
Isobaric heat capacity						
Kubota[43] (1987)	0/20	313–353	0.5–1.4		[6.838]	[6.838]
Nakagawa[23] (1993)	0/36	276–360	1.0–3.2		[−1.201]	[1.201]
Porichanski[22] (1982)	0/304	220–425	2–20		[0.056]	[2.313]
Isochoric heat capacity						
Magee[7] (1995)-C_v	85/85	164–342	3.0–33.4	12.5–17.9	0.764	0.793
Magee[7] (1995)-C_σ	70/70	162–315	sat'n	12.9–17.8	1.238	1.238
Overall	155/155	162–342	3.0–33.4	12.5–17.9		
Speed of sound						
Ahn[24] (1995)	234/364	158–398	0.5–35.3		0.010	0.110
Gillis[11] (1995)	161/161	243–400	0.04–1.0		−0.010	0.020
Hozumi[40] (1993)	0/92	273–348	0.01–0.26		[−0.07]	[0.08]
Beckermann[44] (1989)	0/266	255–420	0.01–0.4		[−0.05]	[0.07]
Overall	395/883	158–400	0.04–35.3		0.000	0.070
Second virial coefficient						
Bignell[45] (1993)	0/3	290–310			[−2.945]	[2.945]
Gillis[11] (1995)	8/9	242–400			0.203	0.545
Beckermann[44] (1989)	0/26	233–420			[1.630]	[2.473]
Schramm[46] (1991)	0/4	233–296			[4.355]	[4.355]
Schramm[47] (1992)	4/4	296–473			1.831	2.098
Tillner-Roth[20] (1992)	0/17	293–433			[−1.091]	[1.091]
Overall	12/63	242–473			0.745	1.062

[a]Data presented graphically only. [ ]≡data not used in formulation of MBWR equation.

where $\tau = 1 - T/T_c$, T_c is the critical temperature, P_c is the critical pressure, and the fitted coefficients α_i are given in Table 4. Equations (2) and (3) were used to represent the saturated liquid density ρ_L and the saturated vapor density ρ_V:

$$\rho_L = \rho_c[1 + d_0\tau^{\beta} + d_1\tau + d_2\tau^{4/3} + d_3\tau^2], \tag{2}$$

$$\rho_v = \frac{P_\sigma}{RT}\left[\left[\left[1 + \frac{f_0\tau^{\beta} + f_1\tau^{2\beta} + f_2\tau + f_3\tau^2 + f_4\tau^4}{1 + f_5\tau}\right] \times \frac{P_\sigma(Z_c - 1)}{P_c T_r^8}\right] + 1\right]^{-1}, \tag{3}$$

where $T_r = T/T_c$, $\beta = 0.325$, and $Z_c = P_c/(\rho_c R T_c)$. Equation (2) for the saturated liquid density is an extension of a commonly used form. The equation for the saturated vapor den-

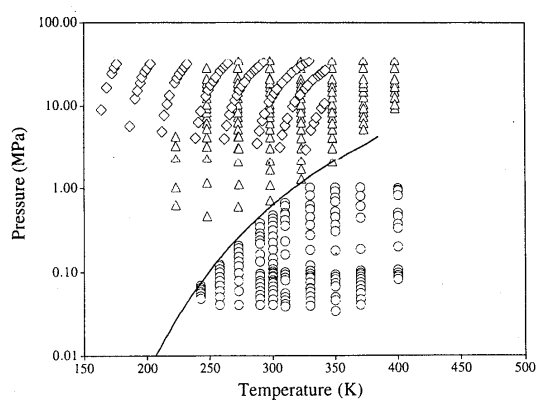

FIG. 2. Experimental isochoric heat capacity and speed of sound data used in MBWR correlation. Speed of sound data of Ahn[24] (△), and Gillis[12] (○), and heat capacity data of Magee[7] (◇).

TABLE 4. Coefficients for ancillary equations (1)–(4); all coefficients are dimensionless.

	0	1	2	3	4	5
α_i	−7.436573	+2.080645	−1.597027	−2.778709	−0.960486	
d_i	+1.838620	+2.803290	−2.856623	+1.243699		
f_i	−0.563910	−1.411520	−0.656730	+1.101725	−0.305923	+0.920950
c_i	+3.354951	+4.245301	+3.735248	−1.608254		

sity is a form suggested by Friend *et al.*[3] It approaches the ideal gas limit at low temperatures and pressures and has the correct shape near the critical temperature. The coefficient f_0 is fixed by the d_0 term in the saturated-liquid density equation by $f_0 = d_0/(1-(1/Z_c))$ ensuring that the saturated-liquid and vapor density curves join smoothly at the critical point. The ideal gas heat capacity is given by a simple polynomial in reduced temperature

$$\frac{C_p^\circ}{R} = c_0 + c_1 T_r + c_2 T_r^2 + c_3 T_r^3, \tag{4}$$

where R is the gas constant, 8.314 471 J/(mol K) (Moldover).[4] The coefficients for the ancillary equations are given in Table 4.

The fits of the experimental data to the ancillary equations are depicted in Fig. 3. Table 2 indicates the quality of the fits in terms of two statistics; (1) average absolute deviation (AAD) defined as

$$\text{AAD} = \frac{1}{n}\sum_{i=1}^{n} |100(x_{i,\exp} - x_{i,\text{calc}})/x_{i,\text{calc}}| \tag{5}$$

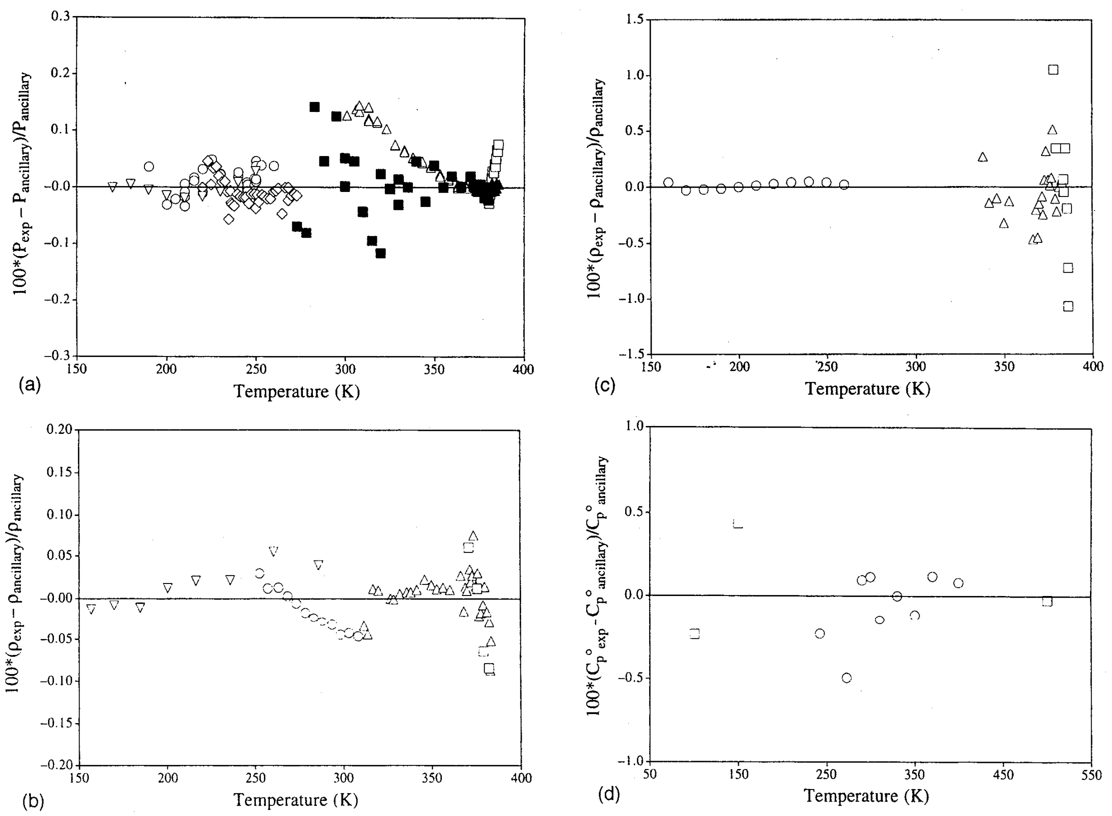

FIG. 3. (a) Deviations of experimental vapor pressures from the ancillary equation. Baehr[2] (▲), Baehr[2] (excluded points) (△), Blanke[5] (○), Higashi[1] (■), Higashi[1] (excluded points) (□), Magee[7] from C_σ (▽), and Silva[6] (◇). (b) Deviations of experimental saturated liquid densities from the ancillary equation. Data of Blanke[5] (○), Higashi[1] (□), Holcomb[9] (△), and calculated from isochoric *PVT* data of Magee[10] (▽). (c) Deviations of experimental and derived saturated vapor densities from the ancillary equation. Data of Gillis[12] (○), Higashi[1] (□), and Holcomb[9] (△). (d) Deviations of experimental ideal gas heat capacities from the ancillary equation. Data of Gillis[12] (○), and Chen[13] (□).

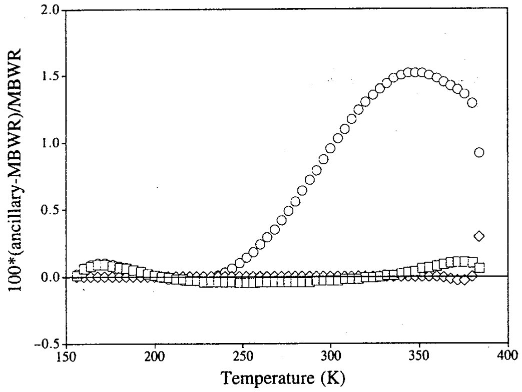

FIG. 4. Deviations of saturation properties calculated with the ancillary equations from saturation properties calculated with the MBWR equation. Saturated vapor densities (○), vapor pressures (□), and saturated liquid densities (◇).

and (2) bias, defined as

$$\text{bias}=\frac{1}{n}\sum_{i=1}^{n} 100(x_{i,\text{exp}}-x_{i,\text{calc}})/x_{i,\text{calc}}. \qquad (6)$$

The average absolute deviation (AAD) is a measure of the overall quality of the fit, and the bias is a measure of systematic differences between the data and the equation. The vapor pressure equation (Eq. (1)) was fitted to a selection of the data of Baehr and Tillner-Roth,[2] Blanke and Weiss,[5] Higashi *et al.*,[1] and Silva and Weber.[6] Blanke and Weiss[5] measured vapor pressures down to the triple point, but at temperatures below about 190 K, the pressures are so low (less than 3 kPa) that the stated uncertainty of the pressure measurement (0.005 kPa) produces a large relative error. In this low temperature region, we used vapor pressures derived from the saturated heat capacities C_σ of Magee.[7] These were calculated using a variation of the method described by Weber.[8] (Weber[8] uses standard thermodynamic relationships to calculate liquid-phase heat capacities from experimental vapor pressures.) At temperatures above 300 K, there was a small (<0.15%) but systematic difference between the values of Baehr and Tillner-Roth[2] and of Higashi *et al.*[1] The Baehr and Tillner-Roth[2] data were consistently above the Higashi *et al.*[1] data (except near the critical point), and the differences increased as the temperature decreased; such deviations could have been caused by a volatile impurity in the sample. The data of Higashi *et al.*[1] show a sharp departure from the Baehr and Tillner-Roth[2] data about 6 K below the critical temperature; this deviation of the Higashi data may possibly be the result of the measuring cell being filled completely with liquid. Between 280 and 360 K the Higashi *et al.*[1] data match best the lower temperature data of Silva and Weber[6] and Blanke and Weiss,[5] and below 280 K the Blanke and Weiss[5] and Silva and Weber[6] data show excellent agreement with each other. Although the possible experimental difficulties of the Baehr and Tillner-Roth[2] and Higashi *et al.*[1] data are purely speculative on our part, we chose to use the Baehr and Tillner-Roth[2] data only above 373 K and the Higashi *et al.*[1] data up to 380 K. Figure 3a shows deviations of experimental vapor pressure data from the ancillary equation and includes the points of Baehr and Tillner-Roth[2] and Higashi *et al.*[1] that were excluded from the formulation of the ancillary equation. The excluded points are shown as unfilled symbols of the same shape as those points that were used in the fit.

For the saturated liquid density, the data of Blanke and Weiss,[5] Higashi *et al.*,[1] and Holcomb *et al.*[9] are in excellent agreement as seen in Fig. 3b. For temperatures below 250 K, saturated liquid densities were extrapolated from the isochoric PVT data of Magee.[10] This was achieved by correlating each isochore with two simple polynomials: (1) temperature as a function of pressure and (2) density as a function of temperature. Intersection of the vapor pressure function (Eq. (1)) with the T vs P polynomial yields a saturation temperature. That temperature was then used in the density vs temperature polynomial to calculate a saturated liquid density.

There are no direct measurements of saturated vapor density below 338 K. For the lower temperatures, saturated-vapor densities were derived from the intersection of a second virial surface with the vapor pressure ancillary equation. The second virial coefficients of Gillis[11] (derived from speed of sound measurements) were used in this process.

The ancillary equation for ideal gas heat capacity was based primarily on the values of Gillis,[11] which are derived from his vapor phase speed of sound measurements. To ex-

TABLE 5. Coefficients for the MBWR equaton of state for R152a units are in K, bar, and mol/L.

b_1	$-0.101\ 623\ 317\ E-01$	b_2	$+0.215\ 677\ 130\ E+01$	b_3	$-0.648\ 581\ 254\ E+02$
b_4	$+0.122\ 535\ 596\ E+05$	b_5	$-0.206\ 805\ 988\ E+07$	b_6	$-0.379\ 836\ 507\ E-03$
b_7	$-0.441\ 333\ 233\ E+00$	b_8	$+0.158\ 248\ 875\ E+03$	b_9	$+0.564\ 062\ 216\ E+06$
b_{10}	$-0.124\ 115\ 350\ E-03$	b_{11}	$+0.494\ 972\ 179\ E+00$	b_{12}	$-0.208\ 058\ 040\ E+03$
b_{13}	$-0.131\ 403\ 187\ E-01$	b_{14}	$+0.212\ 083\ 849\ E+00$	b_{15}	$-0.151\ 263\ 785\ E+03$
b_{16}	$+0.311\ 108\ 025\ E-01$	b_{17}	$-0.115\ 280\ 980\ E-02$	b_{18}	$+0.437\ 040\ 026\ E+00$
b_{19}	$-0.965\ 596\ 535\ E-02$	b_{20}	$-0.242\ 705\ 525\ E+06$	b_{21}	$-0.518\ 042\ 519\ E+08$
b_{22}	$-0.119\ 070\ 546\ E+05$	b_{23}	$+0.459\ 331\ 195\ E+09$	b_{24}	$-0.719\ 317\ 287\ E+02$
b_{25}	$-0.840\ 102\ 861\ E+04$	b_{26}	$-0.102\ 910\ 957\ E+01$	b_{27}	$-0.325\ 913\ 881\ E+05$
b_{28}	$-0.412\ 362\ 182\ E-02$	b_{29}	$+0.175\ 102\ 808\ E+01$	b_{30}	$-0.198\ 636\ 625\ E-04$
b_{31}	$-0.421\ 363\ 036\ E-02$	b_{32}	$-0.198\ 696\ 761\ E+01$		

[a] $T_c=386.411$ K, $P_c=45.1675$ bar, $\rho_c=5.57145$ mol/L.

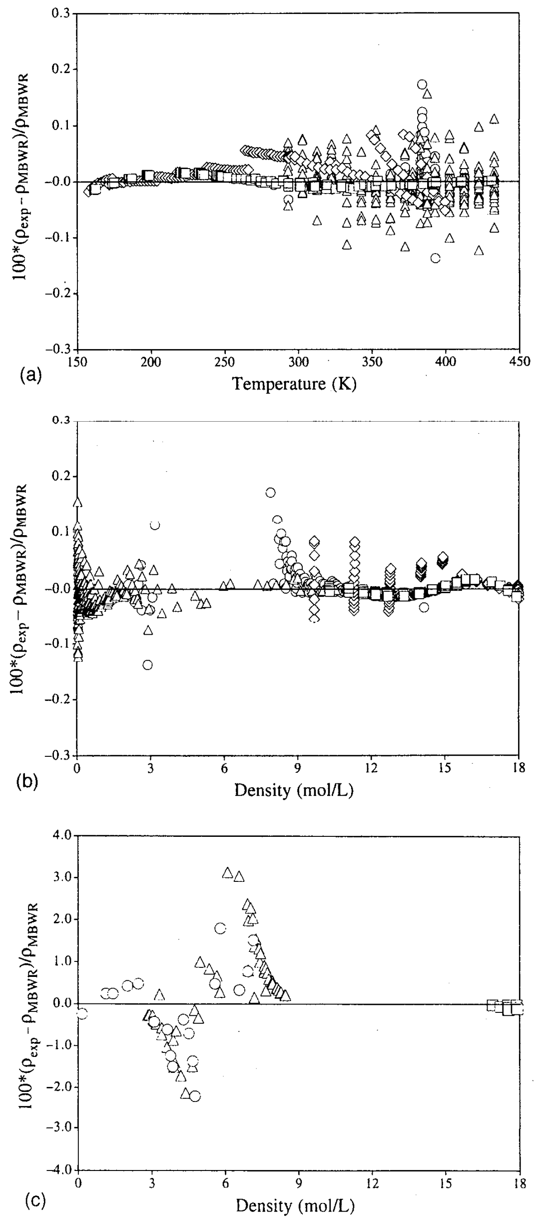

FIG. 5. (a) Deviations (as a function of temperature) of experimental densities (*PVT*) used in the MBWR correlation from densities calculated with the MBWR equation. Blanke[5] (□), Magee[10] (◇), Tillner-Roth[11] (1992) (△), and Tillner-Roth[21] (1993) (○). (b) Deviations (as a function of density) of experimental densities used in the MBWR correlation from densities calculated with the MBWR equation. Data of Blanke[5] (□), Magee[10] (◇), Tillner-Roth[11] (△), and Tillner-Roth[21] (○). (c) Deviations (as a function of density) of experimental densities of Blanke and Tillner-Roth not used in the MBWR correlation from densities calculated with the MBWR equation. Blanke[5] (□), Tillner-Roth[11] (○), and Tillner-Roth[21] (△).

tend the range of the fit, the values of Chen *et al.*[12] at 100, 150, and 500 K were also included in the fit; these points were calculated using spectroscopic data and the methods of statistical mechanics. Deviations are shown in Figure 3d.

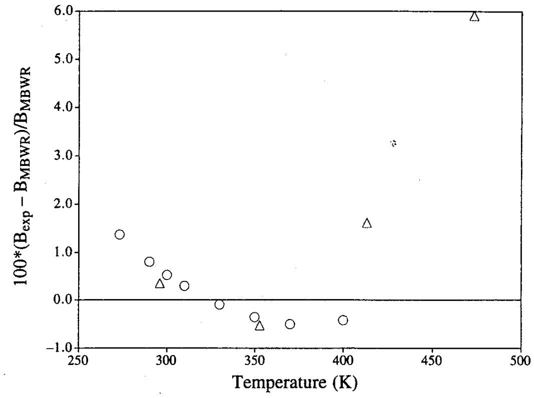

FIG. 6. Deviations of experimental second virial coefficients used in the MBWR correlation from values calculated with the MBWR equation. Data of Gillis[12] (○), and Schramm[36] (△).

4. MBWR Equation of State

The modified Benedict–Webb–Rubin (MBWR) equation used to represent the thermodynamic properties of R152a was that proposed by Jacobsen and Stewart.[13] This equation was selected because of its applicability over wide ranges of temperature and pressure and its proven ability to represent various classes of fluids including hydrocarbons (e.g., Younglove and Ely),[14] cryogenic fluids (e.g., Younglove),[15] and refrigerants (e.g., Huber and McLinden).[16] The MBWR equation is capable of providing highly accurate fits of the liquid, vapor and supercritical regions of a fluid as well as the saturation boundary. The MBWR equation consists of an exponential term (from the original BWR equation, Benedict *et al.*)[17] and what is essentially an expanded virial equation. The equation represents pressure P as a function of molar density ρ and absolute temperature T:

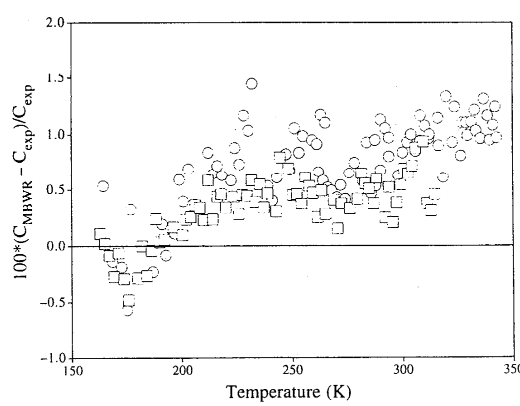

FIG. 7. Deviations of experimental saturated and isochoric heat capacities used in the MBWR correlation from values calculated with the MBWR equation. C_{σ} data of Magee[7] (□), and C_v data of Magee[7] (1995) (○).

$$P=\sum_{i=1}^{9} a_i(T)\rho^i+\exp(-\delta^2)\sum_{i=10}^{15} a_i(T)\rho^{2i-17}, \quad (7)$$

where $\delta=\rho/\rho_c$, and the temperature dependencies of the a_i coefficients are:

$$\begin{aligned}
a_1&=RT,\\
a_2&=b_1T+b_2T^{0.5}+b_3+b_4/T+b_5/T^2,\\
a_3&=b_6T+b_7+b_8/T+b_9/T^2,\\
a_4&=b_{10}T+b_{11}+b_{12}/T,\\
a_5&=b_{13},\\
a_6&=b_{14}/T+b_{15}/T^2,\\
a_7&=b_{16}/T,\\
a_8&=b_{17}/T+b_{18}/T^2,\\
a_9&=b_{19}/T^2,\\
a_{10}&=b_{20}/T^2+b_{21}/T^3,\\
a_{11}&=b_{22}/T^2+b_{23}/T^4,\\
a_{12}&=b_{24}/T^2+b_{25}/T^3,\\
a_{13}&=b_{26}/T^2+b_{27}/T^4,\\
a_{14}&=b_{28}/T^2+b_{29}/T^3,\\
a_{15}&=b_{30}/T^2+b_{31}/T^3+b_{32}/T^4.
\end{aligned}$$

The coefficients of the MBWR equation are given in Table 5. These coefficients are based on pressures in bar, temperatures in K, densities in mol/L, and the value of the gas constant of Moldover,[4] R=0.083 144 71 (bar L)/(mol K). All other thermodynamic properties can be calculated using a pressure-explicit equation of state, as detailed by Younglove and McLinden.[18]

The MBWR fitting process is iterative. It begins with an initial set of 32 coefficients and the saturation boundary as defined by the ancillary equations. Weights are assigned to the data by two different methods: (1) a propagation of uncertainty as described by Hust and McCarty,[19] and (2) manually with respect to data type (e.g., PVT or C_v), individual data sets, or temperature, pressure, or density regions. New coefficients are determined by the linear least-squares method developed by Hust and McCarty.[19] Then, weights are adjusted, the new coefficients used as starting coefficients, and the process repeated. The assignment of weights among the various data sets, data types, etc. is not entirely objective; however the goal is to achieve a set of 32 coefficients that represents well the entire thermodynamic surface, not just a particular data set or type of data. For a more detailed description of the fitting procedure refer to Younglove and McLinden.[18]

4.1. Saturation Boundary

The deviations of the values predicted by the MBWR equation from the ancillary equations for vapor pressure, saturated liquid density, and saturated vapor density are shown in Fig. 4. The vapor pressure and the saturated liquid density values agree well over the entire temperature range (triple point to critical temperature). The average absolute deviation and bias of the ancillary equation for vapor pressure to the MBWR equation were AAD=0.043% and bias =0.009%. The statistics for the saturated liquid and saturated vapor densities were AAD=0.007%, bias=0.004% and AAD =0.623%, bias=0.618% respectively.

4.2. Single-Phase *PVT* Data

Figure 5a shows deviations in density predicted by the MBWR equation from experimental values as a function of temperature. Figure 5b shows those same deviations as a function of density. The MBWR equation predicts values for density with a maximum deviation of 0.2% from experimental values. The AAD of the densities was 0.018% with a bias of 0.001%. Figure 5c shows deviations in density values predicted by the MBWR equation from experimental values of Blanke and Weiss[5] and Tillner-Roth[20,21] that were not used in the correlation. The majority of the excluded points have density values close to the critical density of 5.571 45 mol/L. The MBWR equation typically does not fit the region close to the critical region as well as it fits the rest of the thermodynamic surface. This is a defect of most analytical equa-

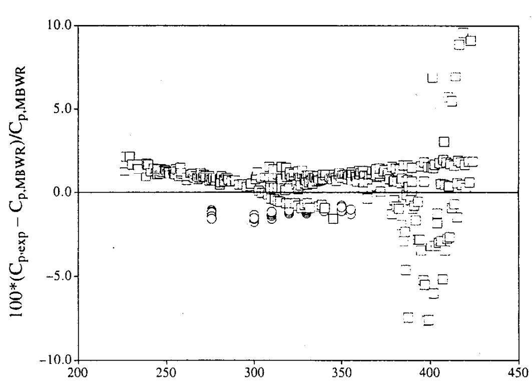

FIG. 8. Deviations of experimental isobaric heat capacities from values calculated with the MBWR equation. Data of Porichanski[22] (□), and Nakagawa[23] (○).

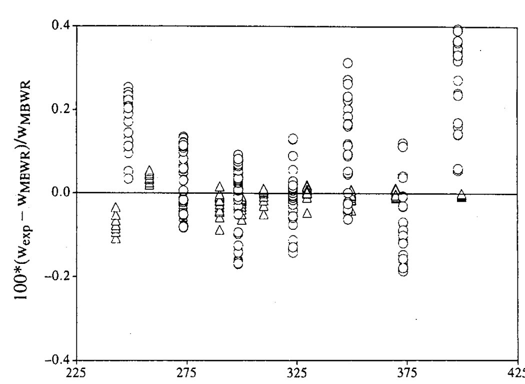

FIG. 9. Deviations of experimental speed of sound used in the MBWR correlation from values calculated with the MBWR equation. Data of Gillis[12] (△), and Ahn[24] (○).

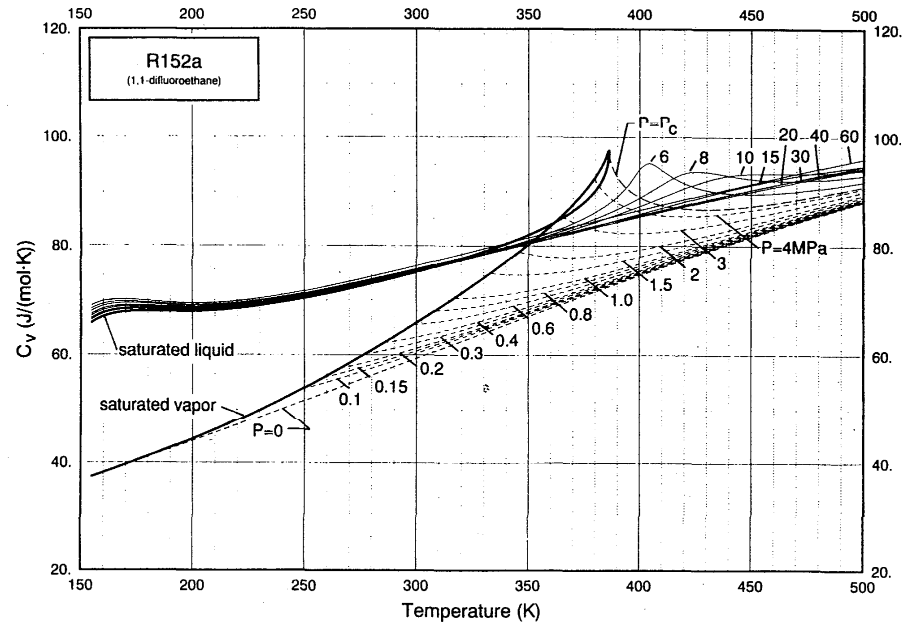

FIG. 10. Isochoric heat capacity calculated with the MBWR equation of state on isobars to 60 MPa.

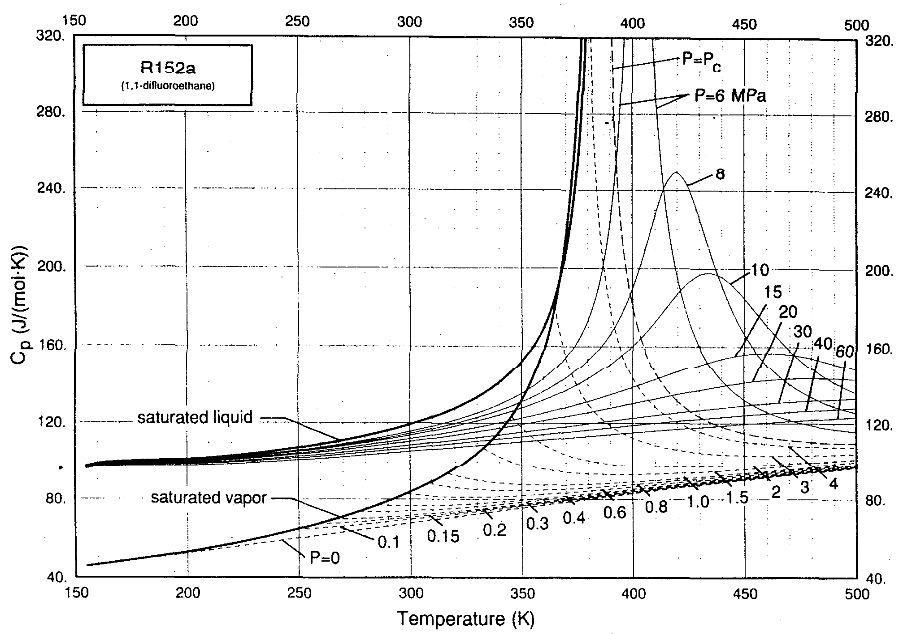

FIG. 11. Isobaric heat capacity calculated with the MBWR equation of state on isobars to 60 MPa.

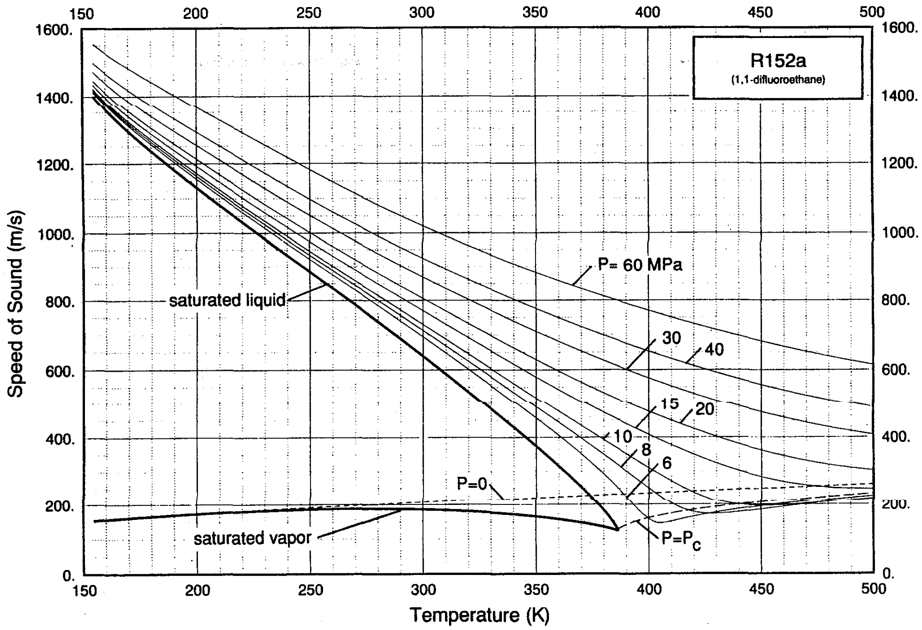

FIG. 12. Speed of sound calculated with the MBWR equation of state on isobars to 60 MPa.

tions of state. It is not, however, our primary intent to fit the critical region, because it is not of significant interest for refrigeration calculations. Therefore, points in the critical region are often excluded (or given very low weight) so as not to decrease the accuracy of the fit in other regions. Figure 6 shows deviations of second virial coefficients predicted by the MBWR equation from experimental values. The maximum percent deviation is 5.90%.

4.3. Heat Capacity and Speed of Sound Data

Figure 7 shows deviations of values predicted by the MBWR equation from experimental values for saturated and isochoric heat capacities of Magee.[7] Saturated heat capacities C_σ had an absolute average deviation of 1.238% and isochoric heat capacities C_v 0.794%. Deviations of both C_σ and C_v increase systematically with increasing temperature. No experimental isobaric heat capacity data were used in the MBWR correlation of R152a. However, the isobaric heat capacities of Porichanski *et al.*[22] and Nakagawa *et al.*[23] are represented by the MBWR very well, as shown in Fig. 8. Except near the critical point and at high temperatures, most of the data are predicted within ±2%. Fourteen points of Porichanski[22] were omitted from the plot because their deviations were in excess of ±10%. (This was done to keep the scale of the plot such that small deviations are distinguishable.) Those points are, however, included in the statistics shown for that data set. The MBWR equation gives values consistently lower than the data of Porichanski *et al.*[22] (bias =0.056%) and consistently higher than the data of Nakagawa *et al.*[23] (bias= 1.202%). The overall statistics are AAD=2.195%, and bias=−0.077%.

Figure 9 shows deviations of sound speed values predicted by the MBWR equation from experimental values. The Gillis[11] data set represents low pressure vapor. The Ahn *et al.*[24] data represent compressed liquid. The average absolute deviation of the speed of sound data was 0.07% and the bias, 0.00%.

4.4. Pressure-Temperature Behavior of Heat Capacity and Speed of Sound

Comparisons of thermodynamic properties calculated by the MBWR equation of state with experimental data indicate a very good fit overall. But a good fit of the data, while necessary, is not sufficient to conclude that the equation of state represents a good thermodynamic surface. The equation should also show correct qualitative behavior over the full temperature and pressure ranges of interest, including regions and/or properties for which no data are available. Plots of the type shown in Figures 10–12 are produced in order to test the MBWR equation's ability to accurately represent the thermodynamic surface of R152a over wide ranges in temperature and pressure. These figures show the behavior of isochoric and isobaric heat capacities and the speed of sound along lines of constant pressure up to 60 MPa at temperatures from the triple point of 154.56 K (measured by Blanke)[5] to 500 K. Plotting these properties is most informative as they are computed using first and second derivatives of the MBWR equation and are thus powerful consistency checks.

The plots of the derived properties (Figs. 10–12) display correct qualitative behavior (based on experience with a wide variety of other fluids) over the entire temperature and pres-

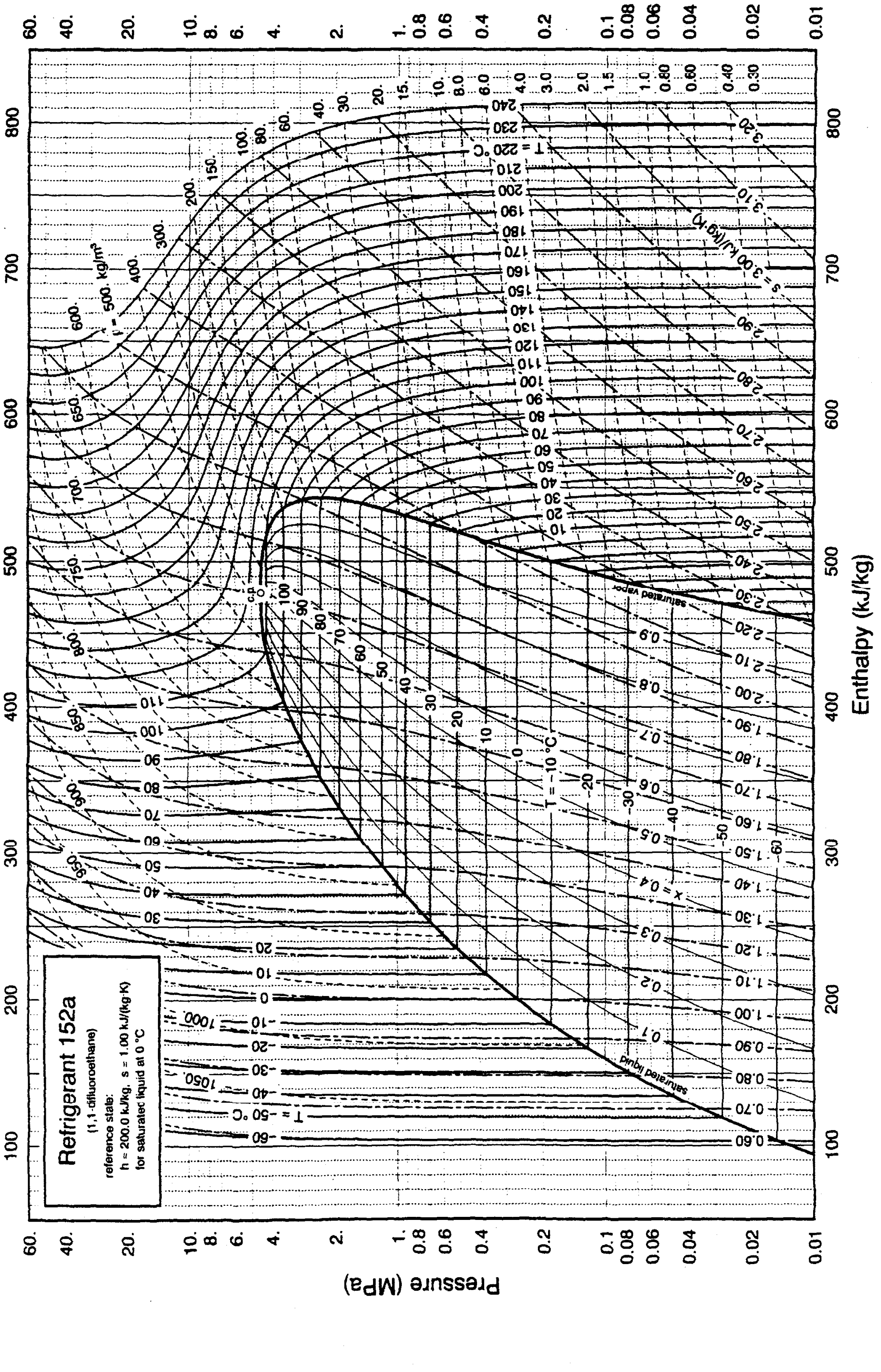

FIG. 13. Pressure-enthalpy diagram for R152a.

sure range with one small exception. The speed of sound does not go to zero at the critical point as it should. This is a common defect of analytical equations of state.

5. Summary and Conclusions

Experimental thermodynamic property data covering temperatures from 162 K to 453 K and pressures up to 35 MPa have been used to fit the thermodynamic surface of R152a with a 32-term modified Benedict-Webb-Rubin (MBWR) equation of state. Results of values predicted by the equation have been compared to experimental data. These comparisons show that the overall representation of the data is excellent. In addition, examination of derived properties has shown that the fit should be valid upon extrapolation to temperatures of 500 K and to pressures of 60 MPa. The upper limit of 500 K is somewhat of academic interest as thermal decomposition has been reported at 450 K and above (Dressner).[25] In practical terms, we can say that the equation of state accurately represents the properties of R152a over the entire range of interest.

6. Acknowledgments

We thank our colleagues whose data we used prior to publication: K. A. Gillis and J. W. Magee. We thank J. A. Zollweg for providing the sound speed data of Ahn *et al.* prior to publication. This research project was supported by a grant from the U.S. Department of Energy, Office of Building Technology through the Air Conditioning and Refrigeration Institute. (Grant No. DE-FG02-91CE23810: Materials Compatibilities and Lubricants Research on CFC-Refrigerant Substitutes).

7. Appendix

This appendix presents tables (Tables 6 and 7) for the properties of R152a and also a diagram of the thermodynamic surface on pressure-enthalpy coordinates (Fig. 13). Following usual engineering practice, temperatures are in °C and all properties are on a mass basis. The reference states for enthalpy and entropy follow the convention of the International Institute of Refrigeration, $h=200$ kJ/(kg K) for the saturated liquid at 0° C, and $s=1.00$ kJ/(kg K), also for the saturated liquid at 0° C. Derived properties, such as enthalpy and speed of sound, were calculated with the pressure-volume-temperature MBWR equation of state following the development given by Younglove and McLinden.[18]

TABLE 6. Saturated liquid and saturated vapor properties of R152a calculated with the MBWR equation of state.

Temp. (°C)	Pressure (MPa)	Density (kg/m^3)		Enthalpy (kJ/kg)		Entropy (kJ/(kg·K))		Cv (kJ/(kg·K))		Cp (kJ/(kg·K))		Speed of sound (m/s)		Temp. (°C)
		Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	
−118.59[a]	0.000064	1192.9	0.0033	13.76	419.32	0.1120	2.7357	0.995	0.573	1.477	0.699	1400.8	154.0	−118.59
−118.00	0.000069	1191.8	0.0036	14.67	419.73	0.1176	2.7284	0.998	0.574	1.480	0.700	1396.1	154.3	−118.00
−116.00	0.000090	1188.2	0.0046	17.64	421.13	0.1366	2.7042	1.006	0.578	1.489	0.704	1380.4	155.2	−116.00
−114.00	0.000117	1184.5	0.0058	20.62	422.54	0.1554	2.6809	1.012	0.582	1.495	0.709	1365.4	156.1	−114.00
−112.00	0.000150	1180.8	0.0074	23.62	423.95	0.1742	2.6584	1.017	0.587	1.501	0.713	1351.1	156.9	−112.00
−110.00	0.000191	1177.1	0.0093	26.62	425.38	0.1927	2.6368	1.021	0.591	1.505	0.717	1337.3	157.8	−110.00
−108.00	0.000241	1173.5	0.0116	29.64	426.81	0.2111	2.6160	1.024	0.595	1.509	0.722	1324.1	158.7	−108.00
−106.00	0.000303	1169.8	0.0144	32.66	428.24	0.2292	2.5959	1.026	0.600	1.512	0.726	1311.3	159.5	−106.00
−104.00	0.000378	1166.1	0.0178	35.69	429.69	0.2472	2.5765	1.028	0.604	1.514	0.731	1298.8	160.3	−104.00
−102.00	0.000469	1162.4	0.0218	38.72	431.14	0.2650	2.5579	1.029	0.609	1.516	0.735	1286.7	161.2	−102.00
−100.00	0.000579	1158.7	0.0266	41.75	432.59	0.2827	2.5399	1.030	0.613	1.518	0.740	1274.9	162.0	−100.00
−98.00	0.000710	1155.0	0.0323	44.79	434.06	0.3001	2.5226	1.030	0.618	1.519	0.744	1263.3	162.8	−98.00
−96.00	0.000867	1151.3	0.0389	47.83	435.53	0.3174	2.5059	1.030	0.622	1.520	0.749	1252.0	163.6	−96.00
−94.00	0.001052	1147.5	0.0467	50.87	437.00	0.3344	2.4898	1.031	0.627	1.522	0.754	1240.8	164.4	−94.00
−92.00	0.001271	1143.8	0.0559	53.91	438.48	0.3513	2.4743	1.031	0.631	1.523	0.759	1229.8	165.2	−92.00
−90.00	0.001528	1140.1	0.0664	56.96	439.97	0.3681	2.4593	1.030	0.636	1.524	0.763	1218.9	166.0	−90.00
−88.00	0.001829	1136.4	0.0787	60.01	441.46	0.3846	2.4449	1.030	0.640	1.525	0.768	1208.2	166.8	−88.00
−86.00	0.002179	1132.6	0.0927	63.06	442.96	0.4010	2.4309	1.030	0.645	1.526	0.773	1197.6	167.6	−86.00
−84.00	0.002584	1128.9	0.1089	66.11	444.46	0.4172	2.4175	1.030	0.650	1.527	0.778	1187.1	168.3	−84.00
−82.00	0.003052	1125.1	0.1273	69.17	445.97	0.4333	2.4045	1.030	0.655	1.528	0.783	1176.6	169.1	−82.00
−80.00	0.003591	1121.3	0.1483	72.23	447.48	0.4492	2.3920	1.030	0.660	1.530	0.789	1166.3	169.8	−80.00
−78.00	0.004208	1117.6	0.1721	75.29	448.99	0.4650	2.3799	1.030	0.664	1.531	0.794	1156.0	170.5	−78.00
−76.00	0.004912	1113.8	0.1989	78.35	450.51	0.4806	2.3683	1.031	0.669	1.533	0.799	1145.8	171.3	−76.00
−74.00	0.005713	1110.0	0.2292	81.42	452.03	0.4961	2.3570	1.031	0.674	1.535	0.805	1135.6	172.0	−74.00
−72.00	0.006622	1106.2	0.2632	84.49	453.56	0.5114	2.3462	1.031	0.679	1.537	0.810	1125.5	172.7	−72.00
−70.00	0.007649	1102.4	0.3012	87.57	455.08	0.5266	2.3357	1.032	0.684	1.539	0.816	1115.5	173.4	−70.00
−68.00	0.008807	1098.6	0.3437	90.65	456.61	0.5417	2.3256	1.032	0.689	1.541	0.821	1105.4	174.0	−68.00
−66.00	0.010107	1094.7	0.3909	93.73	458.14	0.5567	2.3158	1.033	0.695	1.543	0.827	1095.4	174.7	−66.00
−64.00	0.011563	1090.9	0.4434	96.82	459.67	0.5715	2.3064	1.034	0.700	1.546	0.833	1085.5	175.4	−64.00
−62.00	0.013190	1087.1	0.5014	99.92	461.20	0.5862	2.2973	1.035	0.705	1.548	0.839	1075.5	176.0	−62.00
−60.00	0.015002	1083.2	0.5656	103.02	462.74	0.6009	2.2885	1.036	0.710	1.551	0.845	1065.6	176.6	−60.00
−58.00	0.017015	1079.3	0.6362	106.13	464.27	0.6154	2.2800	1.037	0.716	1.554	0.851	1055.7	177.2	−58.00
−56.00	0.019246	1075.4	0.7138	109.24	465.80	0.6297	2.2717	1.038	0.721	1.557	0.858	1045.9	177.8	−56.00
−54.00	0.021712	1071.5	0.7989	112.36	467.33	0.6440	2.2638	1.039	0.727	1.561	0.864	1036.0	178.4	−54.00
−52.00	0.024432	1067.6	0.8920	115.49	468.87	0.6582	2.2561	1.041	0.732	1.564	0.871	1026.2	179.0	−52.00
−50.00	0.27425	1063.7	0.9936	118.62	470.40	0.6723	2.2487	1.042	0.738	1.567	0.877	1016.4	179.5	−50.00
−48.00	0.030710	1059.8	1.1044	121.76	471.92	0.6863	2.2416	1.044	0.744	1.571	0.884	1006.5	180.1	−48.00
−46.00	0.034309	1055.8	1.2249	124.91	473.45	0.7002	2.2346	1.045	0.749	1.575	0.891	996.7	180.6	−46.00
−44.00	0.038244	1051.8	1.3556	128.06	474.98	0.7140	2.2279	1.047	0.755	1.579	0.898	987.0	181.1	−44.00
−42.00	0.042537	1047.8	1.4973	131.23	476.50	0.7278	2.2215	1.049	0.761	1.583	0.905	977.2	181.6	−42.00
−40.00	0.047211	1043.8	1.6506	134.40	478.02	0.7414	2.2152	1.051	0.767	1.587	0.913	967.4	182.1	−40.00
−38.00	0.052291	1039.8	1.8161	137.58	479.53	0.7550	2.2091	1.053	0.773	1.591	0.920	957.6	182.5	−38.00
−36.00	0.057802	1035.8	1.9946	140.77	481.04	0.7684	2.2033	1.055	0.779	1.596	0.928	947.9	183.0	−36.00
−34.00	0.063770	1031.7	2.1867	143.97	482.55	0.7819	2.1976	1.057	0.785	1.600	0.936	938.1	183.4	−34.00
−32.00	0.070221	1027.6	2.3933	147.18	484.05	0.7952	2.1921	1.059	0.791	1.605	0.943	928.4	183.8	−32.00
−30.00	0.077184	1023.5	2.6149	150.39	485.55	0.8085	2.1868	1.061	0.797	1.610	0.952	918.6	184.2	−30.00
−28.00	0.084685	1019.4	2.8526	153.62	487.04	0.8216	2.1817	1.063	0.804	1.615	0.960	908.9	184.5	−28.00
26.00	0.092755	1015.3	3.1069	156.86	488.52	0.8348	2.1767	1.066	0.810	1.620	0.968	899.1	184.9	−26.00
−24.02[b]	0.101325	1011.2	3.3758	160.07	489.98	0.8477	2.1719	1.068	0.816	1.625	0.977	889.5	185.2	−24.02
−24.00	0.101424	1011.1	3.3789	160.11	490.00	0.8478	2.1719	1.068	0.816	1.625	0.977	889.4	185.2	−24.00
−22.00	0.110722	1006.9	3.6694	163.37	491.47	0.8608	2.1672	1.071	0.823	1.630	0.985	879.6	185.5	−22.00
−20.00	0.120679	1002.7	3.9791	166.64	492.94	0.8737	2.1627	1.073	0.829	1.635	0.994	869.9	185.8	−20.00
−18.00	0.131330	998.5	4.3092	169.92	494.40	0.8866	2.1583	1.075	0.836	1.641	1.003	860.1	186.1	−18.00
−16.00	0.142706	994.2	4.6605	173.21	495.85	0.8994	2.1541	1.078	0.843	1.647	1.013	850.4	186.3	−16.00
−14.00	0.154841	989.9	5.0339	176.52	497.29	0.9122	2.1500	1.081	0.849	1.653	1.022	840.6	186.5	−14.00
−12.00	0.167768	985.6	5.4306	179.83	498.72	0.9249	2.1460	1.083	0.856	1.658	1.032	830.8	186.7	−12.00
−10.00	0.181524	981.3	5.8515	183.16	500.15	0.9375	2.1421	1.086	0.863	1.665	1.041	821.0	186.9	−10.00
−8.00	0.196144	976.9	6.2978	186.50	501.56	0.9501	2.1383	1.089	0.870	1.671	1.051	811.3	187.0	−8.00
−6.00	0.211663	972.5	6.7705	189.86	502.96	0.9627	2.1347	1.091	0.877	1.677	1.062	801.5	187.1	−6.00
−4.00	0.228119	968.1	7.2707	193.22	504.36	0.9752	2.1311	1.094	0.884	1.684	1.072	791.7	187.2	−4.00
−2.00	0.245550	963.6	7.7998	196.61	505.74	0.9876	2.1277	1.097	0.891	1.690	1.083	781.9	187.3	−2.00

TABLE 6.—Continued

Temp. (°C)	Pressure (MPa)	Density (kg/m³)		Enthalpy (kJ/kg)		Entropy (kJ/(kg·K))		*Cv* (kJ/(kg·K))		*Cp* (kJ/(kg·K))		Speed of sound (m/s)		Temp. (°C)
		Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	Liq.	Vap.	
0.00	0.263992	959.1	8.3589	200.00	507.11	1.0000	2.1243	1.100	0.898	1.697	1.093	772.0	187.4	0.00
2.00	0.283486	954.6	8.9493	203.41	508.47	1.0124	2.1211	1.103	0.905	1.704	1.105	762.2	187.4	2.00
4.00	0.304070	950.0	9.5723	206.83	509.82	1.0247	2.1179	1.105	0.912	1.711	1.116	752.3	187.4	4.00
6.00	0.325785	945.4	10.2293	210.27	511.16	1.0370	2.1148	1.108	0.919	1.719	1.128	742.5	187.4	6.00
8.00	0.348670	940.8	10.9218	213.72	512.48	1.0492	2.1118	1.111	0.927	1.726	1.139	732.6	187.3	8.00
10.00	0.372767	936.1	11.6513	217.19	513.78	1.0614	2.1089	1.114	0.934	1.734	1.152	722.7	187.2	10.00
12.00	0.398117	931.3	12.4192	220.67	515.08	1.0736	2.1060	1.117	0.941	1.742	1.164	712.8	187.1	12.00
14.00	0.424763	926.6	13.2273	224.17	516.36	1.0857	2.1032	1.120	0.949	1.750	1.177	702.9	187.0	14.00
16.00	0.452748	921.8	14.0772	227.69	517.62	1.0978	2.1005	1.124	0.956	1.759	1.190	692.9	186.8	16.00
18.00	0.482114	916.9	14.9707	231.22	518.86	1.1098	2.0978	1.127	0.964	1.768	1.203	683.0	186.6	18.00
20.00	0.512906	912.0	15.9096	234.77	520.09	1.1219	2.0952	1.130	0.971	1.776	1.217	673.0	186.4	20.00
22.00	0.545167	907.0	16.8959	238.34	521.30	1.1339	2.0926	1.133	0.979	1.786	1.231	663.0	186.1	22.00
24.00	0.578944	902.0	17.9316	241.93	522.50	1.1459	2.0901	1.136	0.987	1.795	1.246	652.9	185.8	24.00
26.00	0.6142280	896.9	19.0189	245.53	523.67	1.1578	2.0876	1.140	0.994	1.805	1.261	642.9	185.5	26.00
28.00	0.651223	891.8	20.1600	249.16	524.83	1.1698	2.0852	1.143	1.002	1.815	1.277	632.8	185.1	28.00
30.00	0.689820	886.6	21.3573	252.80	525.96	1.1817	2.0828	1.146	1.010	1.826	1.293	622.7	184.7	30.00
32.00	0.730116	881.4	22.6133	256.47	527.07	1.1936	2.0804	1.150	1.018	1.837	1.309	612.6	184.3	32.00
34.00	0.772160	876.0	23.9307	260.16	528.16	1.2055	2.0780	1.153	1.026	1.848	1.326	602.4	183.9	34.00
36.00	0.816001	870.7	25.3122	263.86	529.23	1.2174	2.0757	1.157	1.034	1.860	1.344	592.2	183.4	36.00
38.00	0.861687	865.2	26.7609	267.60	530.27	1.2292	2.0734	1.160	1.042	1.872	1.362	582.0	182.9	38.00
40.00	0.909268	859.7	28.2800	271.35	531.28	1.2411	2.0711	1.164	1.050	1.885	1.381	571.7	182.3	40.00
42.00	0.958794	854.1	29.8728	275.13	532.27	1.2529	2.0689	1.167	1.058	1.898	1.401	561.4	181.7	42.00
44.00	1.010317	848.4	31.5429	278.93	533.23	1.2648	2.0666	1.171	1.067	1.912	1.421	551.1	181.1	44.00
46.00	1.063887	842.6	33.2943	282.76	534.16	1.2766	2.0643	1.175	1.075	1.926	1.443	540.7	180.4	46.00
48.00	1.119558	836.7	35.1310	286.62	535.06	1.2884	2.0620	1.178	1.083	1.941	1.465	530.3	179.7	48.00
50.00	1.177382	830.8	37.0576	290.50	535.93	1.3003	2.0598	1.182	1.092	1.957	1.489	519.9	178.9	50.00
52.00	1.237413	824.7	39.0789	294.41	536.77	1.3121	2.0575	1.186	1.100	1.974	1.513	509.4	178.2	52.00
54.00	1.299707	818.6	41.2000	298.35	537.56	1.3240	2.0552	1.190	1.109	1.992	1.539	498.8	177.3	54.00
56.00	1.364319	812.3	43.4268	302.33	538.32	1.3358	2.0528	1.194	1.117	2.010	1.566	488.2	176.4	56.00
58.00	1.431305	805.9	45.7652	306.34	539.04	1.3477	2.0504	1.198	1.126	2.030	1.595	477.6	175.5	58.00
60.00	1.500725	799.4	48.2221	310.38	539.72	1.3596	2.0480	1.203	1.135	2.051	1.626	466.9	174.6	60.00
62.00	1.572636	792.7	50.8048	314.45	540.35	1.3716	2.0456	1.207	1.144	2.073	1.658	456.2	173.6	62.00
64.00	1.647099	785.9	53.5214	318.57	540.94	1.3835	2.0431	1.211	1.153	2.097	1.693	445.4	172.5	64.00
66.00	1.724175	779.0	56.3809	322.72	541.47	1.3955	2.0405	1.216	1.162	2.122	1.730	434.5	171.4	66.00
68.00	1.803928	771.9	59.3931	326.92	541.95	1.4076	2.0379	1.220	1.171	2.150	1.769	423.6	170.2	68.00
70.00	1.886423	764.6	62.5692	331.16	542.37	1.4196	2.0351	1.225	1.181	2.179	1.812	412.6	169.0	70.00
72.00	1.971725	757.2	65.9216	335.45	542.73	1.4318	2.0323	1.230	1.190	2.211	1.859	401.5	167.8	72.00
74.00	2.059903	749.5	69.4641	339.79	543.02	1.4440	2.0294	1.235	1.200	2.245	1.909	390.4	166.5	74.00
76.00	2.151028	741.6	73.2126	344.18	543.24	1.4562	2.0264	1.240	1.209	2.283	1.964	379.2	165.1	76.00
78.00	2.245173	733.5	77.1852	348.63	543.38	1.4686	2.0232	1.245	1.219	2.324	2.025	367.8	163.7	78.00
80.00	2.342414	725.2	81.4026	353.15	543.43	1.4810	2.0198	1.251	1.229	2.370	2.092	356.4	162.2	80.00
82.00	2.442830	716.5	85.8889	357.73	543.39	1.4936	2.0163	1.257	1.240	2.421	2.168	344.9	160.6	82.00
84.00	2.546504	707.6	90.6721	362.38	543.25	1.5062	2.0126	1.262	1.250	2.479	2.252	333.2	159.0	84.00
86.00	2.653524	698.3	95.7858	367.12	542.99	1.5190	2.0087	1.269	1.261	2.543	2.348	321.5	157.3	86.00
88.00	2.763981	688.6	101.2696	371.94	542.60	1.5320	2.0045	1.275	1.272	2.618	2.458	309.5	155.5	88.00
90.00	2.877974	678.5	107.1721	376.87	542.06	1.5451	2.0000	1.282	1.283	2.703	2.586	297.4	153.7	90.00
92.00	2.995608	667.9	113.5531	381.90	541.36	1.5585	1.9952	1.289	1.295	2.804	2.737	285.1	151.8	92.00
94.00	3.116998	656.7	120.4876	387.07	540.47	1.5721	1.9899	1.296	1.307	2.925	2.918	272.6	149.7	94.00
96.00	3.242268	644.8	128.0727	392.39	539.36	1.5860	1.9841	1.304	1.319	3.072	3.139	259.9	147.6	96.00
98.00	3.371558	632.2	136.4364	397.88	537.98	1.6003	1.9778	1.313	1.332	3.257	3.417	246.9	145.4	98.00
100.00	3.505025	618.5	145.7543	403.59	536.28	1.6151	1.9706	1.322	1.346	3.495	3.776	233.5	143.1	100.00
102.00	3.642851	603.7	156.2782	409.57	534.17	1.6304	1.9626	1.333	1.360	3.817	4.261	219.7	140.7	102.00
104.00	3.785255	587.1	168.3905	415.91	531.54	1.6466	1.9532	1.344	1.376	4.279	4.953	205.4	138.1	104.00
106.00	3.932506	568.3	182.7220	422.73	528.17	1.6640	1.9421	1.357	1.392	4.999	6.027	190.5	135.3	106.00
108.00	4.084967	546.0	200.4478	430.31	523.71	1.6832	1.9283	1.372	1.411	6.288	7.925	174.8	132.4	108.00
110.00	4.243169	517.4	224.2562	439.22	517.31	1.7058	1.9096	1.392	1.432	9.261	12.215	157.9	129.1	110.00
112.00	4.408087	473.0	263.7988	451.59	506.12	1.7371	1.8787	1.422	1.458	22.908	31.032	139.1	125.5	112.00
113.26[c]	4.516700	368.0	367.9998	477.55	477.55	1.7989	1.7989	∞	∞	∞	∞	0.00	0.00	113.26

[a]Triple point.
[b]Normal boiling point.
[c]Critical point.

TABLE 7. Single phase properties of R152a calculated with the MBWR equation of state.

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.010 MPa							
	−100.00	1158.7	41.76	0.2827	1.030	1.518	1274.9
	−90.00	1140.1	56.96	0.3681	1.030	1.524	1218.9
	−80.00	1121.3	72.23	0.4492	1.030	1.530	1166.3
	−70.00	1102.4	87.57	0.5266	1.032	1.539	1115.5
Sat. Liquid	−66.16	1095.0	93.49	0.5555	1.033	1.543	1096.2
Sat. Vapor	−66.16	0.387	458.02	2.3166	0.694	0.827	174.6
	−60.00	0.376	463.15	2.3410	0.707	0.839	177.1
	−50.00	0.358	471.63	2.3799	0.728	0.859	180.9
	−45.00	0.350	475.95	2.3990	0.739	0.869	182.7
	−40.00	0.343	480.33	2.4180	0.750	0.880	184.6
	−35.00	0.335	484.75	2.4368	0.761	0.890	186.4
	−30.00	0.328	489.23	2.4554	0.772	0.901	188.2
	−25.00	0.321	493.77	2.4738	0.783	0.912	189.9
	−20.00	0.315	798.35	2.4921	0.794	0.923	191.7
	−15.00	0.309	503.00	2.5103	0.806	0.934	193.4
	−10.00	0.303	507.69	2.5283	0.817	0.945	195.1
	−5.00	0.297	512.45	2.5462	0.828	0.956	196.8
	0.00	0.292	517.26	2.5640	0.840	0.968	198.5
	5.00	0.286	522.12	2.5816	0.851	0.979	200.1
	10.00	0.281	527.05	2.5992	0.863	0.990	201.8
	15.00	0.276	532.03	2.6166	0.874	1.002	203.4
	20.00	0.272	537.06	2.6340	0.886	1.013	205.0
	25.00	0.267	542.16	2.6512	0.897	1.024	206.6
	30.00	0.263	547.31	2.6683	0.909	1.036	208.2
	35.00	0.258	552.51	2.6853	0.920	1.047	209.7
	40.00	0.254	557.78	2.7023	0.932	1.059	211.3
	45.00	0.250	563.10	2.7192	0.943	1.070	212.8
	50.00	0.246	568.48	2.7359	0.955	1.082	214.3
	55.00	0.242	573.92	2.7526	0.966	1.093	215.9
	60.00	0.239	579.41	2.7692	0.978	1.105	217.4
	65.00	0.235	584.96	2.7858	0.989	1.116	218.8
	70.00	0.232	590.57	2.8022	1.001	1.127	220.3
	75.00	0.228	596.23	2.8186	1.012	1.139	221.8
	80.00	0.225	601.96	2.8350	1.024	1.150	223.2
	85.00	0.222	607.74	2.8512	1.035	1.162	224.7
	90.00	0.219	613.57	2.8674	1.046	1.173	226.1
	95.00	0.216	619.47	2.8835	1.058	1.184	227.6
	100.00	0.213	625.42	2.8996	1.069	1.196	229.0
	110.00	0.208	637.48	2.9315	1.092	1.218	231.8
	120.00	0.202	649.78	2.9631	1.114	1.240	234.6
	130.00	0.197	662.29	2.9946	1.136	1.263	237.3
	140.00	0.192	675.03	3.0258	1.158	1.284	240.0
	150.00	0.188	687.98	3.0568	1.180	1.306	242.7
	160.00	0.184	701.15	3.0875	1.201	1.328	245.3
	170.00	0.179	714.53	3.1180	1.223	1.349	248.0
	180.00	0.175	728.12	3.1484	1.243	1.370	250.5
	190.00	0.172	741.92	3.1785	1.264	1.390	253.1
	200.00	0.168	755.92	3.2084	1.284	1.410	255.7
	210.00	0.164	770.13	3.2381	1.304	1.430	258.2
	220.00	0.161	784.53	3.2676	1.324	1.450	260.7
	230.00	0.158	799.12	3.2969	1.343	1.469	263.1
	240.00	0.155	813.90	3.3260	1.361	1.487	265.6

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.020 MPa							
	−100.00	1158.7	41.76	0.2826	1.030	1.518	1275.0
	−90.00	1140.1	56.97	0.3680	1.030	1.524	1219.0
	−80.00	1121.4	72.24	0.4492	1.030	1.530	1166.3
	−70.00	1102.4	87.58	0.5266	1.032	1.539	1115.5
	−60.00	1083.2	103.02	0.6008	1.036	1.551	1065.6
Sat. Liquid	−55.37	1074.2	110.23	0.6343	1.038	1.558	1042.7
Sat. Vapor	−55.37	0.740	466.29	2.2692	0.723	0.860	178.0
	−50.00	0.721	470.93	2.2903	0.734	0.869	180.1
	−45.00	0.705	475.30	2.3096	0.744	0.879	182.0
	−40.00	0.689	479.71	2.3288	0.754	0.888	183.9
	−35.00	0.674	484.18	2.3477	0.765	0.898	185.8
	−30.00	0.659	488.70	2.3665	0.776	0.908	187.6
	−25.00	0.646	493.26	2.3851	0.787	0.919	189.4
	−20.00	0.633	497.88	2.4035	0.797	0.929	191.2
	−15.00	0.620	502.55	2.4218	0.808	0.939	192.9
	−10.00	0.608	507.28	2.4399	0.820	0.950	194.7
	−5.00	0.596	512.05	2.4579	0.831	0.961	196.4
	0.00	0.585	516.89	2.4757	0.842	0.972	198.1
	5.00	0.574	521.77	2.4935	0.853	0.983	199.7
	10.00	0.564	526.71	2.5111	0.864	0.994	201.4
	15.00	0.554	531.71	2.5286	0.876	1.005	203.0
	20.00	0.544	536.76	2.5460	0.887	1.016	204.7
	25.00	0.535	541.87	2.5632	0.898	1.027	206.3
	30.00	0.526	547.03	2.5804	0.910	1.038	207.9
	35.00	0.518	552.25	2.5975	0.921	1.050	209.4
	40.00	0.509	557.53	2.6145	0.933	1.061	211.0
	45.00	0.501	562.86	2.6314	0.944	1.072	212.6
	50.00	0.493	568.25	2.6482	0.956	1.084	204.1
	55.00	0.486	573.70	2.6649	0.967	1.095	215.6
	60.00	0.478	579.20	2.6815	0.979	1.106	217.1
	65.00	0.471	584.76	2.6981	0.990	1.118	218.6
	70.00	0.464	590.38	2.7146	1.001	1.129	220.1
	75.00	0.457	596.05	2.7310	1.013	1.140	221.6
	80.00	0.451	601.78	2.7473	1.024	1.152	223.1
	85.00	0.445	607.56	2.7636	1.036	1.163	224.5
	90.00	0.438	613.41	2.7798	1.047	1.174	226.0
	95.00	0.432	619.31	2.7959	1.058	1.185	227.4
	100.00	0.427	625.26	2.8120	1.070	1.197	228.8
	110.00	0.415	637.34	2.8439	1.092	1.219	231.6
	120.00	0.405	649.64	2.8756	1.114	1.241	234.4
	130.00	0.395	662.16	2.9071	1.136	1.263	237.2
	140.00	0.385	674.90	2.9383	1.158	1.285	239.9
	150.00	0.376	687.86	2.9693	1.180	1.307	242.6
	160.00	0.367	701.04	3.0001	1.202	1.328	245.2
	170.00	0.359	714.43	3.0306	1.223	1.349	247.9
	180.00	0.351	728.02	3.0610	1.244	1.370	250.5
	190.00	0.343	741.83	3.0911	1.264	1.391	253.0
	200.00	0.336	755.83	3.1210	1.284	1.411	255.6
	210.00	0.329	770.04	3.1507	1.304	1.431	258.1
	220.00	0.322	784.45	3.1802	1.324	1.450	260.6
	230.00	0.316	799.04	3.2095	1.343	1.469	263.1
	240.00	0.310	813.83	3.2386	1.361	1.488	265.5

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.040 MPa							
	−100.00	1158.7	41.77	0.2826	1.030	1.518	1275.0
	−90.00	1140.1	56.98	0.3680	1.030	1.524	1219.1
	−80.00	1121.4	72.25	0.4492	1.030	1.530	1166.4
	−70.00	1102.4	87.59	0.5266	1.032	1.539	1115.6
	−60.00	1083.2	103.03	0.6008	1.036	1.551	1065.7
	−50.00	1063.7	118.63	0.6723	1.042	1.567	1016.4
	−45.00	1053.8	126.49	0.7071	1.046	1.577	991.9
Sat. Liquid	−43.16	1050.2	129.39	0.7198	1.048	1.580	982.9
Sat. Vapor	−43.16	1.414	475.61	2.2252	0.758	0.901	181.3
	−40.00	1.393	478.47	2.2375	0.764	0.906	182.6
	−35.00	1.361	483.02	2.2568	0.773	0.914	184.5
	−30.00	1.331	487.61	2.2759	0.783	0.923	186.4
	−25.00	1.302	492.25	2.2948	0.793	0.932	188.3
	−20.00	1.275	496.93	2.3135	0.804	0.941	190.1
	−15.00	1.249	501.66	2.3320	0.814	0.950	192.0
	−10.00	1.224	506.44	2.3503	0.825	0.960	193.7
	−5.00	1.200	511.26	2.3685	0.835	0.970	195.5
	0.00	1.177	516.14	2.3865	0.846	0.980	197.3
	5.00	1.155	521.06	2.4044	0.857	0.990	199.0
	10.00	1.134	526.04	2.4221	0.868	1.001	200.7
	15.00	1.113	531.07	2.4397	0.879	1.011	202.3
	20.00	1.094	536.16	2.4572	0.890	1.022	204.0
	25.00	1.075	541.29	2.4746	0.901	1.003	205.6
	30.00	1.057	546.48	2.4918	0.912	1.044	207.3
	35.00	1.039	551.73	2.5090	0.924	1.054	208.9
	40.00	1.022	557.03	2.5261	0.935	1.065	210.5
	45.00	1.005	562.38	2.5430	0.946	1.076	212.0
	50.00	0.990	567.79	2.5599	0.957	1.087	213.6
	55.00	0.974	573.26	2.5767	0.969	1.099	215.1
	60.00	0.959	578.78	2.5934	0.980	1.110	216.7
	65.00	0.945	584.36	2.6100	0.991	1.121	218.2
	70.00	0.931	589.99	2.6265	1.003	1.132	219.7
	75.00	0.917	595.67	2.6430	1.014	1.143	221.2
	80.00	0.904	601.42	2.6593	1.025	1.154	222.7
	85.00	0.891	607.22	2.6756	1.037	1.165	224.1
	90.00	0.879	613.07	2.6919	1.048	1.176	225.6
	95.00	0.866	618.98	2.7081	1.059	1.188	227.1
	100.00	0.855	624.95	2.7242	1.070	1.199	228.5
	110.00	0.832	637.05	2.7561	1.093	1.221	231.3
	120.00	0.811	649.36	2.7879	1.115	1.243	234.1
	130.00	0.791	661.90	2.8194	1.137	1.265	236.9
	140.00	0.771	674.66	2.8506	1.159	1.287	239.7
	150.00	0.753	687.63	2.8816	1.181	1.308	242.4
	160.00	0.735	700.82	2.9124	1.202	1.329	245.0
	170.00	0.719	714.22	2.9430	1.223	1.350	247.7
	180.00	0.703	727.83	2.9734	1.244	1.371	250.3
	190.00	0.687	741.64	3.0035	1.264	1.391	252.9
	200.00	0.673	755.65	3.0335	1.285	1.412	255.4
	210.00	0.659	769.87	3.0632	1.304	1.431	258.0
	220.00	0.645	784.28	3.0927	1.324	1.451	260.5
	230.00	0.632	798.88	3.1221	1.343	1.470	263.0
	240.00	0.620	813.67	3.1512	1.362	1.488	265.4

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.060 MPa							
	−100.00	1158.7	41.79	0.2826	1.030	1.518	1275.1
	−90.00	1140.1	57.00	0.3680	1.031	1.524	1219.1
	−80.00	1121.4	72.26	0.4491	1.030	1.530	1166.5
	−70.00	1102.5	87.60	0.5266	1.032	1.539	1115.7
	−60.00	1083.3	103.05	0.6008	1.036	1.551	1065.8
	−50.00	1063.7	118.64	0.6723	1.042	1.567	1016.5
	−45.00	1053.9	126.50	0.7071	1.046	1.577	992.0
	−40.00	1043.9	134.40	0.7414	1.051	1.587	967.5
Sat. Liquid	−35.25	1034.2	141.98	0.7735	1.056	1.597	944.2
Sat. Vapor	−35.25	2.065	481.61	2.2011	0.781	0.931	183.1
	−35.00	2.063	481.84	2.2021	0.782	0.931	183.2
	−30.00	2.016	486.51	2.2215	0.791	0.938	185.2
	−25.00	1.971	491.22	2.2407	0.800	0.945	187.2
	−20.00	1.928	495.97	2.2596	0.810	0.953	189.1
	−15.00	1.887	500.75	2.2783	0.820	0.962	191.0
	−10.00	1.849	505.58	2.2969	0.830	0.970	192.8
	−5.00	1.812	510.46	2.3152	0.840	0.980	194.6
	0.00	1.776	515.38	2.3334	0.850	0.989	196.4
	5.00	1.742	520.35	2.3514	0.861	0.998	198.2
	10.00	1.710	525.36	2.3693	0.872	1.008	199.9
	15.00	1.678	530.43	2.3870	0.882	1.018	201.6
	20.00	1.648	535.55	2.4046	0.893	1.028	203.3
	25.00	1.619	540.71	2.4221	0.904	1.039	205.0
	30.00	1.591	545.93	2.4395	0.915	1.049	206.7
	35.00	1.564	551.20	2.4567	0.926	1.059	208.3
	40.00	1.538	556.53	2.4738	0.937	1.070	209.9
	45.00	1.513	561.90	2.4909	0.948	1.081	211.5
	50.00	1.489	567.33	2.5078	0.959	1.091	213.1
	55.00	1.465	572.82	2.5247	0.971	1.102	214.7
	60.00	1.443	578.36	2.5414	0.982	1.113	216.2
	65.00	1.421	583.95	2.5581	0.993	1.124	217.8
	70.00	1.400	589.60	2.5747	1.004	1.135	219.3
	75.00	1.379	595.30	2.5912	1.015	1.146	220.8
	80.00	1.359	601.06	2.6076	1.027	1.157	222.3
	85.00	1.340	606.87	2.6239	1.038	1.168	223.8
	90.00	1.321	612.74	2.6402	1.049	1.179	225.3
	95.00	1.302	618.66	2.6564	1.060	1.190	226.7
	100.00	1.285	624.63	2.6725	1.071	1.201	228.2
	110.00	1.250	636.75	2.7045	1.094	1.223	231.0
	120.00	1.218	649.09	2.7363	1.116	1.245	233.9
	130.00	1.187	661.64	2.7679	1.138	1.266	236.7
	140.00	1.158	674.42	2.7992	1.159	1.288	239.4
	150.00	1.130	687.40	2.8302	1.181	1.309	242.1
	160.00	1.104	700.60	2.8610	1.202	1.330	244.8
	170.00	1.079	714.01	2.8917	1.223	1.351	247.5
	180.00	1.055	727.63	2.9220	1.244	1.372	250.1
	190.00	1.032	741.45	2.9522	1.265	1.392	252.7
	200.00	1.010	755.47	2.9822	1.285	1.412	255.3
	210.00	0.989	769.70	3.0119	1.305	1.432	257.8
	220.00	0.968	784.12	3.0414	1.324	1.451	260.3
	230.00	0.949	798.72	3.0708	1.343	1.470	262.8
	240.00	0.930	813.52	3.0999	1.362	1.489	265.3

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.100 MPa							
	−100.00	1158.8	41.81	0.2825	1.030	1.518	1275.2
	−90.00	1140.2	57.02	0.3679	1.031	1.524	1219.3
	−80.00	1121.4	72.28	0.4491	1.030	1.530	1166.7
	−70.00	1102.5	87.62	0.5265	1.032	1.539	1115.8
	−60.00	1083.3	103.07	0.6007	1.036	1.551	1066.0
	−50.00	1063.8	118.66	0.6722	1.042	1.567	1016.7
	−45.00	1053.9	126.52	0.7070	1.046	1.577	992.2
	−40.00	1043.9	134.43	0.7413	1.051	1.587	967.7
	−35.00	1033.8	142.39	0.7751	1.056	1.598	943.2
	−30.00	1023.6	150.41	0.8084	1.061	1.610	918.8
	−25.00	1013.2	158.48	0.8413	1.067	1.622	894.3
Sat. Liquid	−24.32	1011.8	159.59	0.8457	1.068	1.624	890.9
Sat. Vapor	−24.32	3.334	489.77	2.1727	0.815	0.975	185.2
	−20.00	3.268	493.99	2.1895	0.823	0.980	186.9
	−15.00	3.195	498.90	2.2087	0.831	0.986	189.0
	−10.00	3.125	503.85	2.2277	0.840	0.992	190.9
	−5.00	3.059	508.82	2.2464	0.850	0.999	192.9
	0.00	2.997	513.84	2.2649	0.859	1.007	194.7
	5.00	2.937	518.89	2.2833	0.869	1.015	196.6
	10.00	2.880	523.99	2.3014	0.879	1.023	198.4
	15.00	2.825	529.13	2.3194	0.889	1.032	200.2
	20.00	2.772	534.31	2.3372	0.899	1.041	202.0
	25.00	2.722	539.54	2.3549	0.910	1.050	203.7
	30.00	2.674	544.82	2.3725	0.920	1.060	205.4
	35.00	2.627	550.14	2.3899	0.931	1.070	207.1
	40.00	2.583	555.51	2.4072	0.941	1.079	208.8
	45.00	2.539	560.93	2.4244	0.952	1.089	210.5
	50.00	2.498	566.41	2.4414	0.963	1.100	212.1
	55.00	2.458	571.93	2.4584	0.974	1.110	213.7
	60.00	2.419	577.51	2.4753	0.985	1.120	215.3
	65.00	2.381	583.13	2.4920	0.996	1.131	216.9
	70.00	2.345	588.81	2.5087	1.007	1.141	218.4
	75.00	2.310	594.54	2.5253	1.018	1.152	220.0
	80.00	2.276	600.33	2.5418	1.029	1.162	221.5
	85.00	2.242	606.17	2.5582	1.040	1.173	223.0
	90.00	2.211	612.06	2.5745	1.051	1.184	224.5
	95.00	2.179	618.01	2.5908	1.062	1.194	226.0
	100.00	2.149	624.00	2.6070	1.073	1.205	227.5
	110.00	2.091	636.16	2.6391	1.095	1.227	230.4
	120.00	2.037	648.54	2.6710	1.117	1.248	233.3
	130.00	1.985	661.12	2.7026	1.139	1.269	236.1
	140.00	1.936	673.93	2.7340	1.160	1.291	238.9
	150.00	1.889	686.94	2.7651	1.182	1.312	241.7
	160.00	1.844	700.16	2.7960	1.203	1.333	244.4
	170.00	1.802	713.59	2.8267	1.224	1.353	247.1
	180.00	1.761	727.23	2.8571	1.245	1.374	249.7
	190.00	1.722	741.07	2.8873	1.265	1.394	252.4
	200.00	1.686	755.11	2.9173	1.285	1.414	255.0
	210.00	1.650	769.35	2.9471	1.305	1.434	257.5
	220.00	1.616	783.78	2.9766	1.324	1.453	260.1
	230.00	1.584	798.41	3.0060	1.343	1.472	262.6
	240.00	1.553	813.22	3.0351	1.362	1.490	265.1

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.101325 MPa							
	−100.00	1158.8	41.81	0.2825	1.030	1.518	1275.
	−90.00	1140.2	57.02	0.3679	1.031	1.524	1219.3
	−80.00	1121.4	72.29	0.4491	1.030	1.530	1166.7
	−70.00	1102.5	87.62	0.5265	1.032	1.539	1115.9
	−60.00	1083.3	103.07	0.6007	1.036	1.551	1066.0
	−50.00	1063.8	118.66	0.6722	1.042	1.567	1016.7
	−45.00	1053.9	126.52	0.7070	1.046	1.577	992.2
	−40.00	1043.9	134.43	0.7413	1.051	1.587	967.7
	−35.00	1033.8	142.39	0.7751	1.056	1.598	943.2
	−30.00	1026.3	150.41	0.8084	1.061	1.610	918.8
	−25.00	1013.2	158.49	0.8413	1.067	1.622	894.3
Sat. Liquid	−24.02	1011.2	160.07	0.8477	1.068	1.625	889.5
Sat. Vapor	−24.02	3.376	489.98	2.1719	0.816	0.977	185.2
	−20.00	3.313	493.92	2.1876	0.823	0.981	186.9
	−15.00	3.239	498.84	2.2069	0.832	0.986	188.9
	−10.00	3.168	503.79	2.2258	0.841	0.993	190.9
	−5.00	3.101	508.77	2.2446	0.850	1.000	192.8
	0.00	3.038	513.79	2.2631	0.859	1.008	194.7
	−5.00	2.977	518.84	2.2815	0.869	1.016	196.6
	10.00	2.919	523.94	2.2997	0.879	1.024	198.4
	15.00	2.863	529.08	2.3176	0.889	1.033	200.2
	20.00	2.810	534.27	2.3355	0.899	1.042	201.9
	25.00	2.759	539.50	2.3532	0.910	1.051	203.7
	30.00	2.710	544.78	2.3707	0.920	1.060	205.4
	35.00	2.663	550.10	2.3882	0.931	1.070	207.1
	40.00	2.618	555.48	2.4054	0.942	1.080	208.8
	45.00	2.573	560.90	2.4227	0.952	1.090	210.4
	50.00	2.532	566.38	2.4397	0.963	1.100	212.1
	55.00	2.491	571.90	2.4567	0.974	1.110	213.7
	60.00	2.451	577.48	2.4736	0.985	1.120	215.3
	65.00	2.413	583.11	2.4903	0.996	1.131	216.9
	70.00	2.376	588.79	2.5070	1.007	1.141	218.4
	75.00	2.341	594.52	2.5236	1.018	1.152	220.0
	80.00	2.306	600.31	2.5401	1.029	1.163	221.5
	85.00	2.273	606.15	2.5565	1.040	1.173	223.0
	90.00	2.240	612.04	2.5728	1.051	1.184	224.5
	95.00	2.209	617.98	2.5891	1.062	1.195	226.0
	100.00	2.178	623.98	2.6053	1.073	1.205	227.5
	110.00	2.119	636.14	2.6375	1.095	1.227	230.4
	120.00	2.064	648.52	2.6693	1.117	1.248	233.3
	130.00	2.011	661.11	2.7010	1.139	1.270	236.1
	140.00	1.961	673.91	2.7323	1.161	1.291	238.9
	150.00	1.914	686.92	2.7634	1.182	1.312	241.7
	160.00	1.869	700.15	2.7943	1.203	1.333	244.4
	170.00	1.826	713.58	2.8250	1.224	1.354	247.1
	180.00	1.785	727.22	2.8554	1.245	1.374	249.7
	190.00	1.746	741.06	2.8856	1.265	1.394	252.4
	200.00	1.708	755.10	2.9156	1.285	1.414	255.0
	210.00	1.672	769.34	2.9454	1.305	1.434	257.4
	220.00	1.638	783.77	2.9750	1.324	1.453	260.1
	230.00	1.605	798.40	3.0043	1.343	1.472	262.6
	240.00	1.573	813.21	3.0335	1.362	1.490	265.1

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.200 MPa							
	−100.00	1158.9	41.87	0.2824	1.030	1.518	1275.5
	−90.00	1140.3	57.08	0.3678	1.031	1.523	1219.6
	−80.00	1121.6	72.34	0.4489	1.030	1.530	1167.0
	−70.00	1102.6	87.68	0.5263	1.032	1.538	1116.3
	−60.00	1083.4	103.13	0.6005	1.036	1.551	1066.5
	−50.00	1064.0	118.71	0.6720	1.042	1.567	1017.2
	−45.00	1054.1	126.57	0.7068	1.046	1.576	992.7
	−40.00	1044.1	134.48	0.7411	1.051	1.587	968.3
	−35.00	1034.0	142.44	0.7749	1.056	1.598	943.8
	−30.00	1023.8	150.46	0.8082	1.061	1.609	919.4
	−25.00	1013.4	158.53	0.8411	1.067	1.622	894.9
	−20.00	1002.9	166.67	0.8736	1.073	1.635	870.4
	−15.00	992.2	174.89	0.9057	1.079	1.649	845.8
	−10.00	981.3	183.17	0.9375	1.086	1.664	821.2
Sat. Liquid	−7.49	975.8	187.35	0.9533	1.089	1.672	808.8
Sat. Vapor	−7.49	6.415	501.92	2.1374	0.872	1.054	187.1
	−5.00	6.339	504.54	2.1472	0.875	1.055	188.2
	0.00	6.192	509.82	2.1667	0.882	1.057	190.3
	5.00	6.054	515.12	2.1859	0.890	1.060	192.5
	10.00	5.923	520.43	2.2049	0.898	1.065	194.5
	15.00	5.799	525.76	2.2236	0.906	1.070	196.5
	20.00	5.681	531.13	2.2420	0.915	1.076	198.5
	25.00	5.569	536.52	2.2603	0.924	1.082	200.4
	30.00	5.462	541.95	2.2783	0.934	1.089	202.3
	35.00	5.360	547.42	2.2962	0.943	1.097	204.2
	40.00	5.262	552.92	2.3139	0.953	1.104	206.0
	45.00	5.169	558.46	2.3315	0.963	1.113	207.8
	50.00	5.079	564.04	2.3489	0.973	1.121	209.5
	55.00	4.992	569.67	2.3662	0.983	1.130	211.3
	60.00	4.909	575.34	2.3833	0.993	1.139	213.0
	65.00	4.829	581.06	2.4003	1.004	1.148	214.7
	70.00	4.752	586.82	2.4173	1.014	1.157	216.3
	75.00	4.677	592.63	2.4341	1.024	1.167	218.0
	80.00	4.605	598.49	2.4508	1.035	1.177	219.6
	85.00	4.536	604.40	2.4674	1.046	1.186	221.2
	90.00	4.469	610.35	2.4839	1.056	1.196	222.8
	95.00	4.403	616.36	2.5003	1.067	1.206	224.3
	100.00	4.340	622.42	2.5167	1.078	1.216	225.9
	110.00	4.219	634.68	2.5491	1.099	1.236	228.9
	120.00	4.105	647.15	2.5812	1.120	1.257	231.9
	130.00	3.988	659.82	2.6130	1.142	1.277	234.8
	140.00	3.897	672.69	2.6446	1.163	1.298	237.7
	150.00	3.800	685.77	2.6759	1.184	1.318	240.6
	160.00	3.709	699.06	2.7069	1.205	1.339	243.4
	170.00	3.622	712.55	2.7377	1.226	1.359	246.1
	180.00	3.539	726.23	2.7682	1.246	1.379	248.9
	190.00	3.460	740.12	2.7985	1.267	1.399	251.6
	200.00	3.385	754.21	2.8286	1.287	1.418	254.2
	210.00	3.312	768.49	2.8585	1.306	1.437	256.8
	220.00	3.243	782.96	2.8881	1.325	1.456	259.4
	230.00	3.178	797.61	2.9175	1.344	1.475	262.0
	240.00	3.114	812.45	2.9468	1.363	1.493	264.5

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.400 MPa							
	−100.00	1159.0	42.00	0.2821	1.030	1.517	1276.1
	−90.00	1140.5	57.20	0.3675	1.031	1.523	1220.3
	−80.00	1121.8	72.47	0.4486	1.031	1.529	1167.8
	−70.00	1102.9	87.80	0.5260	1.032	1.538	1117.1
	−60.00	1083.7	103.24	0.6002	1.036	1.551	1067.4
	−50.00	1064.2	118.82	0.6717	1.042	1.567	1018.3
	−45.00	1054.4	126.68	0.7065	1.047	1.576	993.8
	−40.00	1044.4	134.58	0.7407	1.051	1.856	969.4
	−35.00	1034.3	142.54	0.7745	1.056	1.597	945.0
	−30.00	1024.1	150.56	0.8078	1.061	1.609	920.6
	−25.00	1013.8	158.63	0.8407	1.067	1.621	896.2
	−20.00	1003.3	166.77	0.8732	1.073	1.634	871.8
	−15.00	992.6	174.97	0.9053	1.079	1.648	847.3
	−10.00	981.8	183.25	0.9370	1.086	1.663	822.7
	−5.00	970.7	191.61	0.9685	1.093	1.679	798.0
	0.00	959.5	200.05	0.9997	1.100	1.696	773.2
	5.00	947.9	208.58	1.0306	1.107	1.715	748.2
	10.00	936.1	217.20	1.0613	1.114	1.734	723.0
Sat. Liquid	12.14	931.0	220.93	1.0744	1.118	1.743	712.1
Sat. Vapor	12.14	12.476	515.17	2.1058	0.942	1.165	187.1
	15.00	12.293	518.49	2.1174	0.945	1.162	188.5
	20.00	11.990	524.29	2.1374	0.950	1.159	191.0
	25.00	11.707	530.08	2.1569	0.956	1.157	193.4
	30.00	11.441	535.87	2.1762	0.962	1.157	195.7
	35.00	11.192	541.66	2.1951	0.969	1.159	197.9
	40.00	10.956	547.46	2.2138	0.977	1.161	200.0
	45.00	10.733	553.28	2.2322	0.985	1.165	202.1
	50.00	10.521	559.11	2.2504	0.993	1.169	204.2
	55.00	10.320	564.97	2.2684	1.002	1.174	206.2
	60.00	10.128	570.85	2.2862	1.010	1.180	208.1
	65.00	9.944	576.77	2.3038	1.019	1.186	210.1
	70.00	9.769	582.71	2.3213	1.029	1.193	211.9
	75.00	9.602	588.69	2.3386	1.038	1.200	213.8
	80.00	9.440	594.71	2.3557	1.048	1.207	215.6
	85.00	9.285	600.77	2.3728	1.057	1.215	217.3
	90.00	9.137	606.66	2.3897	1.067	1.223	219.1
	95.00	8.992	613.00	2.4065	1.077	1.231	220.8
	100.00	8.854	619.17	2.4231	1.087	1.240	222.5
	110.00	8.592	631.66	2.4561	1.107	1.257	225.8
	120.00	8.346	644.32	2.4888	1.128	1.275	229.1
	130.00	8.115	657.16	2.5210	1.148	1.294	232.2
	140.00	7.899	670.20	2.5529	1.168	1.313	235.3
	150.00	7.696	683.42	2.5845	1.189	1.332	238.3
	160.00	7.502	696.83	2.6159	1.209	1.351	241.3
	170.00	7.319	710.43	2.6469	1.230	1.370	244.2
	180.00	7.145	724.23	2.6777	1.250	1.389	247.1
	190.00	6.981	738.21	2.7082	1.270	1.408	249.9
	200.00	6.824	752.38	2.7385	1.289	1.427	252.7
	210.00	6.674	766.75	2.7686	1.308	1.445	255.4
	220.00	6.532	781.29	2.7983	1.327	1.464	258.1
	230.00	6.394	796.02	2.8279	1.346	1.482	260.8
	240.00	6.264	810.92	2.8572	1.364	1.499	263.4

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=0.600 MPa							
	−100.00	1159.2	42.12	0.2818	1.030	1.517	1276.7
	−90.00	1140.7	57.33	0.3672	1.031	1.523	1221.0
	−80.00	1122.0	72.59	0.4483	1.031	1.529	1168.6
	−70.00	1103.1	87.92	0.5257	1.032	1.538	1118.0
	−60.00	1084.0	103.36	0.5999	1.036	1.550	1068.4
	−50.00	1064.5	118.93	0.6713	1.043	1.566	1019.3
	−45.00	1054.7	126.79	0.7061	1.047	1.575	994.9
	−40.00	1044.7	134.69	0.7404	1.051	1.586	970.5
	−35.00	1034.7	142.64	0.7741	1.056	1.596	946.2
	−30.00	1024.5	150.66	0.8074	1.062	1.608	921.8
	−25.00	1014.2	158.73	0.8403	1.067	1.620	897.5
	−20.00	1003.7	166.86	0.8727	1.073	1.634	873.1
	−15.00	993.0	175.06	0.9048	1.080	1.648	848.7
	−10.00	982.2	183.34	0.9366	1.086	1.663	824.2
	−5.00	971.2	191.69	0.9680	1.093	1.678	799.6
	0.00	960.0	200.12	0.9992	1.100	1.695	774.8
	5.00	948.5	208.64	1.0301	1.107	1.713	749.9
	10.00	936.7	217.26	1.0608	1.114	1.732	724.8
	15.00	927.4	225.97	1.0913	1.122	1.753	699.5
	20.00	912.3	234.79	1.1216	1.130	1.776	673.9
	25.00	899.5	243.73	1.1519	1.138	1.800	648.0
Sat. Liquid	25.20	899.0	244.09	1.1531	1.138	1.801	646.9
Sat. Vapor	25.20	18.579	523.21	2.0886	0.991	1.255	185.6
	30.00	18.091	529.20	2.1085	0.994	1.244	188.3
	35.00	17.622	535.40	2.1288	0.998	1.237	191.0
	40.00	17.187	541.57	2.1487	1.003	1.231	193.6
	45.00	16.782	547.72	2.1681	1.009	1.228	196.1
	50.00	16.403	553.85	2.1873	1.015	1.226	198.5
	55.00	16.047	559.98	2.2061	1.022	1.226	200.8
	60.00	15.711	566.11	2.2246	1.029	1.227	203.0
	65.00	15.394	572.25	2.2429	1.036	1.229	205.2
	70.00	15.092	578.41	2.2610	1.044	1.233	207.3
	75.00	14.807	584.58	2.2789	1.052	1.237	209.4
	80.00	14.535	590.78	2.2965	1.061	1.241	211.4
	85.00	14.276	597.00	2.3140	1.069	1.247	213.4
	90.00	14.028	603.24	2.3313	1.078	1.252	215.3
	95.00	13.788	609.52	2.3485	1.087	1.259	217.2
	100.00	13.560	615.83	2.3655	1.097	1.265	219.1
	110.00	13.130	628.55	2.3992	1.115	1.280	222.7
	120.00	12.733	641.43	2.4323	1.135	1.295	226.2
	130.00	12.362	654.46	2.4651	1.154	1.311	229.6
	140.00	12.014	667.66	2.4974	1.174	1.328	232.9
	150.00	11.688	681.03	2.5294	1.194	1.346	236.1
	160.00	11.383	694.57	2.5610	1.213	1.363	239.2
	170.00	11.096	708.30	2.5923	1.233	1.381	242.3
	180.00	10.823	722.20	2.6234	1.253	1.399	245.3
	190.00	10.565	736.28	2.6541	1.272	1.417	248.2
	200.00	10.319	750.55	2.6846	1.292	1.435	251.1
	210.00	10.086	764.99	2.7148	1.311	1.453	254.0
	220.00	9.865	779.62	2.7448	1.329	1.471	256.8
	230.00	9.653	794.42	2.7745	1.348	1.489	259.5
	240.00	9.450	809.39	2.8039	1.366	1.506	262.3

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure = 1.000 MPa							
	−100.00	1159.6	42.37	0.2813	1.031	1.517	1277.9
	−90.00	1141.1	57.57	0.3666	1.031	1.523	1222.4
	−80.00	1122.4	72.83	0.4477	1.031	1.529	1170.2
	−70.00	1103.6	88.15	0.5251	1.032	1.537	1119.7
	−60.00	1084.5	103.58	0.5992	1.036	1.550	1070.3
	−50.00	1065.1	119.16	0.6706	1.043	1.565	1021.3
	−45.00	1055.3	127.01	0.7054	1.047	1.575	997.0
	−40.00	1045.4	134.90	0.7397	1.051	1.584	972.8
	−35.00	1035.3	142.85	0.7734	1.056	1.595	948.5
	−30.00	1025.2	150.86	0.8066	1.062	1.607	924.3
	−25.00	1014.9	158.92	0.8395	1.067	1.619	900.0
	−20.00	1004.5	167.05	0.8719	1.073	1.632	875.8
	−15.00	993.9	175.24	0.9040	1.080	1.646	851.5
	−10.00	983.1	183.51	0.9357	1.086	1.661	827.1
	−5.00	972.2	191.85	0.9671	1.093	1.676	802.7
	0.00	961.0	200.27	0.9982	1.100	1.693	778.1
	5.00	949.6	208.78	1.0291	1.107	1.710	753.4
	10.00	937.9	217.38	1.0597	1.115	1.729	728.5
	15.00	926.0	226.07	1.0901	1.122	1.750	703.4
	20.00	913.6	234.88	1.1204	1.130	1.771	678.0
	25.00	901.0	243.79	1.1506	1.138	1.795	652.4
	30.00	887.9	252.83	1.1806	1.146	1.821	626.4
	35.00	874.3	262.01	1.2107	1.155	1.850	599.9
	40.00	860.1	271.34	1.2407	1.164	1.883	573.0
Sat. Liquid	43.61	849.5	278.18	1.2624	1.170	1.909	553.1
Sat. Vapor	43.61	31.207	533.05	2.0670	1.065	1.417	181.2
	45.00	30.920	535.02	2.0732	1.065	1.409	182.2
	50.00	29.956	542.00	2.0950	1.065	1.385	185.6
	55.00	29.084	548.87	2.1161	1.067	1.366	188.8
	60.00	28.288	555.66	2.1367	1.070	1.352	191.8
	65.00	27.557	562.39	2.1567	1.074	1.341	194.7
	70.00	26.880	569.08	2.1763	1.078	1.333	197.4
	75.00	26.250	575.73	2.1956	1.084	1.328	200.0
	80.00	25.662	582.36	2.2145	1.089	1.324	202.5
	85.00	25.111	588.97	2.2331	1.096	1.322	205.0
	90.00	24.589	595.59	2.2514	1.102	1.322	207.3
	95.00	24.097	602.20	2.2695	1.110	1.323	209.6
	100.00	23.633	608.81	2.2874	1.117	1.324	211.9
	110.00	22.773	622.08	2.3225	1.133	1.331	216.1
	120.00	21.989	635.43	2.3568	1.150	1.339	220.2
	130.00	21.270	648.88	2.3906	1.167	1.350	224.1
	140.00	20.614	662.44	2.4238	1.185	1.363	227.8
	150.00	20.001	676.13	2.4566	1.203	1.376	231.5
	160.00	19.429	689.97	2.4889	1.222	1.391	235.0
	170.00	18.895	703.95	2.5208	1.241	1.406	238.4
	180.00	18.398	718.08	2.5524	1.259	1.422	241.7
	190.00	17.929	732.38	2.5836	1.278	1.438	244.9
	200.00	17.486	746.84	2.6144	1.297	1.454	248.1
	210.00	17.067	761.45	2.6450	1.315	1.470	251.1
	220.00	16.672	776.24	2.6753	1.333	1.487	254.2
	230.00	16.295	791.19	2.7053	1.351	1.503	257.1
	240.00	15.939	806.30	2.7350	1.369	1.519	260.0

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure = 2.000 MPa							
	−100.00	1160.5	43.00	0.2799	1.032	1.516	1281.0
	−90.00	1142.1	58.19	0.3652	1.032	1.522	1225.9
	−80.00	1123.5	73.43	0.4462	1.032	1.527	1174.1
	−70.00	1104.8	88.74	0.5235	1.033	1.536	1124.0
	−60.00	1085.8	104.16	0.5976	1.037	1.548	1074.9
	−50.00	1066.5	119.71	0.6689	1.044	1.563	1026.5
	−45.00	1056.8	127.55	0.7036	1.048	1.572	1002.4
	−40.00	1046.9	135.44	0.7378	1.052	1.582	978.3
	−35.00	1037.0	143.37	0.7715	1.057	1.592	954.3
	−30.00	1026.9	151.36	0.8047	1.062	1.604	930.3
	−25.00	1016.8	159.41	0.8375	1.068	1.616	906.4
	−20.00	1006.4	167.52	0.8698	1.074	1.628	882.4
	−15.00	996.0	175.69	0.9018	1.080	1.642	858.4
	−10.00	985.3	183.94	0.9334	1.087	1.656	834.4
	−5.00	974.5	192.26	0.9648	1.093	1.671	810.3
	0.00	963.5	200.65	0.9958	1.100	1.687	786.2
	5.00	952.3	209.13	1.0265	1.107	1.704	761.9
	10.00	940.8	217.69	1.0570	1.115	1.722	737.5
	15.00	929.1	226.35	1.0873	1.122	1.741	712.9
	20.00	917.0	235.10	1.1175	1.130	1.762	688.2
	25.00	904.6	243.97	1.1475	1.138	1.784	663.2
	30.00	891.8	252.95	1.1773	1.146	1.808	637.9
	35.00	878.6	262.06	1.2071	1.154	1.835	612.3
	40.00	864.9	271.31	1.2369	1.163	1.865	586.3
	45.00	850.6	280.71	1.2667	1.172	1.898	559.8
	50.00	835.7	290.29	1.2966	1.181	1.935	532.7
	55.00	819.9	300.07	1.3266	1.191	1.979	504.9
	60.00	803.2	310.09	1.3569	1.201	2.030	476.3
	65.00	785.3	320.39	1.3876	1.213	2.092	446.5
	70.00	765.8	331.04	1.4188	1.225	2.170	415.3
Sat. Liquid	72.65	754.7	336.85	1.4357	1.232	2.222	397.9
Sat. Vapor	72.65	67.049	542.83	2.0314	1.193	1.874	167.4
	75.00	65.469	547.17	2.0439	1.189	1.820	170.0
	80.00	62.536	556.03	2.0692	1.183	1.730	175.1
	85.00	60.042	564.52	2.0930	1.179	1.666	179.7
	90.00	57.873	572.72	2.1158	1.177	1.618	183.9
	95.00	55.956	580.72	2.1376	1.177	1.582	187.8
	100.00	54.240	588.55	2.1588	1.178	1.553	191.4
	110.00	51.260	603.87	2.1993	1.184	1.514	198.1
	120.00	48.751	618.88	2.2380	1.192	1.490	204.1
	130.00	46.584	633.71	2.2752	1.203	1.477	209.6
	140.00	44.675	648.44	2.3113	1.216	1.470	214.7
	150.00	42.979	663.13	2.3464	1.230	1.469	219.5
	160.00	41.440	677.84	2.3808	1.245	1.472	224.1
	170.00	40.053	692.58	2.4144	1.260	1.477	228.4
	180.00	38.779	707.39	2.4475	1.276	1.485	232.5
	190.00	37.611	722.29	2.4800	1.293	1.494	236.5
	200.00	36.521	737.29	2.5120	1.310	1.505	240.3
	210.00	35.511	752.39	2.5436	1.327	1.517	244.0
	220.00	34.567	767.62	2.5748	1.344	1.529	247.6
	230.00	33.682	782.97	2.6057	1.360	1.542	251.1
	240.00	32.851	798.45	2.6361	1.377	1.555	254.5

TABLE 7.—Continued

	Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=4.000 MPa							
	−100.00	1162.3	44.25	0.2772	1.034	1.514	1287.2
	−90.00	1144.0	59.42	0.3624	1.034	1.520	1232.9
	−80.00	1125.6	74.64	0.4433	1.033	1.525	1181.9
	−70.00	1107.1	89.93	0.5205	1.035	1.533	1132.5
	−60.00	1088.3	105.31	0.5944	1.038	1.544	1084.2
	−50.00	1069.3	120.83	0.6655	1.045	1.559	1036.6
	−45.00	1059.7	128.65	0.7002	1.049	1.568	1012.9
	−40.00	1050.0	136.51	0.7343	1.053	1.577	989.3
	−35.00	1040.3	144.42	0.7678	1.058	1.587	965.7
	−30.00	1030.4	152.38	0.8009	1.063	1.598	942.3
	−25.00	1020.4	160.40	0.8336	1.069	1.609	918.8
	−20.00	1010.3	168.48	0.8658	1.075	1.621	895.4
	−15.00	1000.0	176.62	0.8976	1.081	1.634	872.0
	−10.00	989.6	184.82	0.9291	1.088	1.647	848.6
	−5.00	979.1	193.09	0.9602	1.094	1.662	825.2
	0.00	968.4	201.44	0.9911	1.101	1.676	801.8
	5.00	957.4	209.86	1.0216	1.108	1.692	778.3
	10.00	946.3	218.36	1.0519	1.115	1.709	754.8
	15.00	935.0	226.94	1.0820	1.123	1.726	731.2
	20.00	923.4	235.62	1.1118	1.130	1.745	707.4
	25.00	911.5	244.39	1.1415	1.138	1.765	683.6
	30.00	899.3	253.27	1.1710	1.146	1.786	659.6
	35.00	886.7	262.25	1.2004	1.154	1.809	635.4
	40.00	873.8	271.36	1.2297	1.162	1.834	611.0
	45.00	860.4	280.60	1.2590	1.171	1.861	586.3
	50.00	846.5	289.98	1.2882	1.179	1.891	561.3
	55.00	832.0	299.52	1.3175	1.188	1.925	535.9
	60.00	816.9	309.24	1.3469	1.198	1.963	510.1
	65.00	800.9	319.16	1.3765	1.208	2.007	483.7
	70.00	784.0	329.32	1.4063	1.218	2.059	456.6
	75.00	765.9	339.76	1.4365	1.229	2.120	428.8
	80.00	746.3	350.55	1.4673	1.241	2.196	399.8
	85.00	724.8	361.77	1.4988	1.254	2.295	369.4
	90.00	700.8	373.56	1.5315	1.269	2.430	337.0
	95.00	672.8	386.18	1.5661	1.287	2.636	301.6
	100.00	638.3	400.18	1.6038	1.309	3.008	261.3
Sat. Liquid	106.89	558.9	426.01	1.6723	1.363	5.472	183.6
Sat. Vapor	106.89	190.122	526.34	1.9363	1.400	6.726	134.0
	110.00	167.000	541.74	1.9767	1.366	3.962	143.9
	120.00	136.533	571.67	2.0539	1.319	2.471	162.6
	130.00	121.186	594.15	2.1104	1.301	2.083	175.2
	140.00	110.867	613.98	2.1590	1.293	1.901	185.2
	150.00	103.122	632.43	2.2031	1.293	1.797	193.8
	160.00	96.946	650.05	2.2443	1.297	1.733	201.3
	170.00	91.827	667.16	2.2833	1.304	1.692	208.0
	180.00	87.468	683.94	2.3208	1.314	1.665	214.2
	190.00	83.681	700.49	2.3569	1.325	1.648	219.9
	200.00	80.340	716.92	2.3920	1.337	1.638	225.3
	210.00	77.356	733.28	2.4262	1.350	1.633	230.3
	220.00	74.665	749.60	2.4596	1.364	1.632	235.1
	230.00	72.217	765.93	2.4924	1.378	1.634	239.7
	240.00	69.975	782.29	2.5246	1.393	1.638	244.0

TABLE 7.—Continued

Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=6.000 MPa						
−100.00	1164.0	45.51	0.2745	1.036	1.513	1293.5
−90.00	1145.9	60.66	0.3596	1.036	1.518	1240.0
−80.00	1127.7	75.86	0.4404	1.035	1.523	1189.7
−70.00	1109.4	91.12	0.5175	1.036	1.530	1141.1
−60.00	1090.8	106.48	0.5912	1.040	1.541	1093.5
−50.00	1072.1	121.96	0.6622	1.046	1.556	1046.5
−45.00	1062.6	129.76	0.6968	1.050	1.564	1023.3
−40.00	1053.1	137.60	0.7308	1.054	1.573	1000.1
−35.00	1043.4	145.48	0.7642	1.059	1.582	977.0
−30.00	1033.7	153.42	0.7972	1.064	1.593	953.9
−25.00	1023.9	161.41	0.8298	1.070	1.603	931.0
−20.00	1014.0	169.46	0.8619	1.076	1.615	908.1
−15.00	1003.9	177.56	0.8936	1.082	1.627	885.2
−10.00	993.8	185.73	0.9249	1.088	1.640	862.4
−5.00	983.5	193.96	0.9559	1.095	1.653	839.6
0.00	973.0	202.26	0.9865	1.102	1.667	816.8
5.00	962.4	210.63	1.0169	1.109	1.681	794.0
10.00	951.6	219.07	1.0470	1.116	1.697	771.2
15.00	940.6	227.60	1.0768	1.123	1.713	748.4
20.00	929.4	236.20	1.1064	1.130	1.730	725.6
25.00	917.9	244.90	1.1358	1.138	1.748	702.7
30.00	906.2	253.68	1.1651	1.146	1.767	679.8
35.00	894.2	262.57	1.1941	1.153	1.787	656.7
40.00	881.9	271.56	1.2231	1.161	1.809	633.6
45.00	869.2	280.66	1.2519	1.170	1.832	610.3
50.00	856.1	289.88	1.2807	1.178	1.858	586.9
55.00	842.6	299.24	1.3094	1.187	1.885	563.3
60.00	828.6	308.74	1.3381	1.195	1.916	539.5
65.00	814.0	318.40	1.3669	1.204	1.949	515.5
70.00	798.8	328.24	1.3958	1.214	1.987	491.1
75.00	782.7	338.28	1.4248	1.224	2.030	466.4
80.00	765.8	348.55	1.4541	1.234	2.080	441.2
85.00	747.8	359.09	1.4838	1.245	2.138	415.5
90.00	728.5	369.95	1.5139	1.256	2.208	389.2
95.00	707.5	381.20	1.5447	1.269	2.295	362.0
100.00	684.4	392.95	1.5763	1.282	2.408	333.8
110.00	628.2	418.68	1.6444	1.316	2.788	272.7
120.00	542.8	450.93	1.7274	1.366	3.918	201.2
130.00	366.0	506.47	1.8667	1.440	6.636	145.6
140.00	248.3	557.97	1.9931	1.408	3.811	154.4
150.00	204.5	589.73	2.0691	1.377	2.735	167.9
160.00	180.2	614.71	2.1274	1.362	2.312	179.2
170.00	163.8	636.64	2.1775	1.356	2.095	188.9
180.00	151.6	656.89	2.2227	1.356	1.966	197.5
190.00	142.0	676.11	2.2647	1.359	1.884	205.1
200.00	134.1	694.66	2.3043	1.366	1.829	212.0
210.00	127.4	712.76	2.3421	1.374	1.792	218.4
220.00	121.6	730.55	2.3786	1.385	1.767	224.4
230.00	116.5	748.13	2.4139	1.396	1.750	230.0
240.00	112.0	765.57	2.4482	1.408	1.739	235.2

TABLE 7.—Continued

Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=10.000 MPa						
−100.00	1167.5	48.03	0.2693	1.040	1.509	1306.2
−90.00	1149.7	63.15	0.3542	1.039	1.514	1254.2
−80.00	1131.8	78.31	0.4347	1.038	1.518	1205.3
−70.00	1113.8	93.52	0.5116	1.038	1.525	1158.0
−60.00	1095.7	108.82	0.5851	1.042	1.535	1111.7
−50.00	1077.4	124.24	0.6558	1.048	1.549	1066.1
−45.00	1068.2	132.00	0.6902	1.052	1.556	1043.6
−40.00	1058.9	139.80	0.7240	1.056	1.565	1021.1
−35.00	1049.5	147.65	0.7573	1.061	1.574	998.8
−30.00	1040.1	155.54	0.7901	1.066	1.583	976.5
−25.00	1030.6	163.48	0.8224	1.072	1.593	954.4
−20.00	1021.0	171.47	0.8543	1.078	1.604	932.4
−15.00	1011.4	179.52	0.8857	1.084	1.615	910.4
−10.00	1001.6	187.62	0.9168	1.090	1.626	888.6
−5.00	991.7	195.78	0.9475	1.096	1.638	866.8
0.00	981.7	204.00	0.9779	1.103	1.650	845.2
5.00	971.6	212.28	1.0080	1.110	1.663	823.6
10.00	961.3	220.63	1.0377	1.117	1.677	802.0
15.00	950.9	229.05	1.0672	1.124	1.691	780.6
20.00	940.4	237.54	1.0964	1.131	1.705	759.2
25.00	929.6	246.10	1.1254	1.138	1.720	737.9
30.00	918.7	254.74	1.1541	1.146	1.736	716.6
35.00	907.6	263.46	1.1826	1.153	1.753	695.4
40.00	896.3	272.27	1.2110	1.161	1.770	674.2
45.00	884.7	281.17	1.2392	1.169	1.788	653.0
50.00	872.9	290.15	1.2672	1.177	1.808	631.9
55.00	860.8	299.24	1.2951	1.184	1.828	610.8
60.00	848.4	308.44	1.3229	1.193	1.850	589.7
65.00	835.6	317.74	1.3506	1.201	1.873	568.7
70.00	822.5	327.17	1.3783	1.209	1.898	547.6
75.00	808.9	336.72	1.4060	1.218	1.924	526.6
80.00	795.0	346.41	1.4336	1.226	1.953	505.6
85.00	780.5	356.26	1.4613	1.235	1.984	484.6
90.00	765.4	366.26	1.4890	1.244	2.018	463.6
95.00	749.7	376.45	1.5169	1.253	2.056	442.7
100.00	733.4	386.83	1.5449	1.263	2.097	421.7
110.00	698.1	408.27	1.6016	1.283	2.196	380.0
120.00	658.8	430.83	1.6597	1.305	2.320	338.6
130.00	614.3	454.80	1.7199	1.328	2.482	298.3
140.00	563.2	480.60	1.7831	1.353	2.683	260.5
150.00	505.4	508.49	1.8498	1.377	2.889	229.0
160.00	444.5	538.03	1.9188	1.397	2.992	207.9
170.00	388.0	567.72	1.9866	1.409	2.920	198.2
180.00	341.3	596.03	2.0497	1.412	2.731	196.5
190.00	305.1	622.28	2.1070	1.412	2.522	199.3
200.00	277.2	646.58	2.1590	1.413	2.346	204.1
210.00	255.3	669.33	2.2065	1.415	2.211	209.9
220.00	237.7	690.92	2.2508	1.420	2.111	215.8
230.00	223.2	711.64	2.2924	1.426	2.037	221.8
240.00	211.0	731.71	2.3319	1.434	1.982	227.6

TABLE 7.—Continued

Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=20.000 MPa						
−100.00	1175.7	54.37	0.2566	1.047	1.502	1338.7
−90.00	1158.6	69.41	0.3411	1.045	1.506	1290.1
−80.00	1141.5	84.48	0.4212	1.043	1.509	1244.1
−70.00	1124.3	99.60	0.4975	1.043	1.515	1199.6
−60.00	1107.1	114.79	0.5705	1.046	1.523	1156.1
−50.00	1089.8	130.07	0.6405	1.052	1.534	1113.3
−45.00	1081.1	137.76	0.6746	1.056	1.541	1092.1
−40.00	1072.3	145.48	0.7081	1.060	1.548	1071.1
−35.00	1063.6	153.24	0.7410	1.065	1.556	1050.2
−30.00	1054.8	161.04	0.7734	1.070	1.564	1029.5
−25.00	1045.9	168.88	0.8053	1.075	1.572	1009.0
−20.00	1037.0	176.76	0.8368	1.081	1.581	988.6
−15.00	1028.1	184.69	0.8678	1.087	1.590	968.4
−10.00	1019.1	192.67	0.8984	1.093	1.600	948.3
−5.00	1010.0	200.69	0.9286	1.100	1.610	928.4
0.00	1000.9	208.76	0.9584	1.106	1.620	908.7
5.00	991.8	216.89	0.9879	1.113	1.630	889.2
10.00	982.5	225.07	1.0171	1.120	1.641	869.9
15.00	973.2	233.30	1.0459	1.127	1.651	850.7
20.00	963.8	241.58	1.0744	1.134	1.662	831.7
25.00	954.4	249.92	1.1026	1.141	1.674	812.9
30.00	944.8	258.32	1.1305	1.148	1.685	794.2
35.00	935.2	266.77	1.1582	1.155	1.697	775.8
40.00	925.4	275.29	1.1856	1.162	1.709	757.5
45.00	915.6	283.87	1.2128	1.170	1.721	739.4
50.00	905.7	292.50	1.2397	1.177	1.734	721.5
55.00	895.6	301.21	1.2664	1.184	1.747	703.9
60.00	885.4	309.98	1.2929	1.192	1.760	686.4
65.00	875.1	318.81	1.3193	1.199	1.774	669.1
70.00	864.7	327.71	1.3454	1.206	1.788	652.0
75.00	854.1	336.69	1.3714	1.214	1.802	635.2
80.00	843.4	345.73	1.3972	1.221	1.816	618.6
85.00	832.5	354.85	1.4228	1.229	1.831	602.2
90.00	821.5	364.04	1.4483	1.236	1.846	586.1
95.00	810.3	373.32	1.4737	1.244	1.862	570.2
100.00	799.0	382.67	1.4989	1.251	1.878	554.6
110.00	775.8	401.61	1.5490	1.267	1.911	524.3
120.00	751.8	420.89	1.5987	1.282	1.945	495.3
130.00	727.2	440.52	1.6479	1.297	1.980	467.7
140.00	701.8	460.50	1.6969	1.312	2.015	441.6
150.00	675.8	480.82	1.7455	1.327	2.050	417.3
160.00	649.2	501.49	1.7938	1.341	2.083	394.9
170.00	622.2	522.47	1.8417	1.356	2.112	374.7
180.00	595.1	543.73	1.8891	1.370	2.137	356.6
190.00	568.1	565.20	1.9360	1.383	2.156	341.0
200.00	541.5	586.81	1.9821	1.396	2.167	327.7
210.00	515.7	608.50	2.0275	1.409	2.170	316.8
220.00	490.9	630.19	2.0719	1.421	2.166	308.2
230.00	467.4	651.81	2.1153	1.433	2.157	301.5
240.00	445.3	673.31	2.1576	1.444	2.142	296.7

TABLE 7.—Continued

Temp. (°C)	Density (kg/m^3)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=40.000 MPa						
−100.00	1190.8	67.20	0.2331	1.056	1.490	1405.7
−90.00	1174.9	82.11	0.3168	1.053	1.493	1362.0
−80.00	1159.0	97.05	0.3963	1.050	1.495	1320.4
−70.00	1143.1	112.02	0.4718	1.049	1.499	1279.8
−60.00	1127.2	127.04	0.5440	1.052	1.505	1239.9
−50.00	1111.4	142.13	0.6132	1.058	1.514	1200.6
−45.00	1103.4	149.72	0.6468	1.061	1.520	1181.2
−40.00	1095.5	157.33	0.6798	1.066	1.526	1162.0
−35.00	1087.6	164.98	0.7122	1.071	1.532	1143.0
−30.00	1079.7	172.65	0.7441	1.076	1.538	1124.1
−25.00	1071.8	180.36	0.7755	1.081	1.545	1105.4
−20.00	1063.8	188.10	0.8064	1.087	1.552	1087.0
−15.00	1055.9	195.88	0.8368	1.093	1.560	1068.7
−10.00	1048.0	203.70	0.8668	1.100	1.567	1050.7
−5.00	1040.0	211.56	0.8964	1.106	1.575	1032.9
0.00	1032.1	219.45	0.9256	1.113	1.583	1015.3
5.00	1024.1	227.39	0.9544	1.120	1.591	998.0
10.00	1016.2	235.36	0.9828	1.127	1.599	980.9
15.00	1008.2	243.38	1.0108	1.134	1.607	964.0
20.00	1000.2	251.43	1.0386	1.141	1.615	947.4
25.00	992.2	259.53	1.0660	1.148	1.624	931.0
30.00	984.2	267.67	1.0930	1.155	1.632	914.9
35.00	976.2	275.85	1.1198	1.162	1.641	899.1
40.00	968.1	284.08	1.1463	1.169	1.649	883.4
45.00	960.0	292.34	1.1725	1.177	1.657	868.1
50.00	952.0	300.65	1.1984	1.184	1.666	852.9
55.00	943.9	309.00	1.2240	1.191	1.675	838.1
60.00	935.8	317.40	1.2494	1.199	1.683	823.5
65.00	927.6	325.83	1.2745	1.206	1.692	809.1
70.00	919.5	334.31	1.2994	1.213	1.700	795.0
75.00	911.3	342.84	1.3241	1.220	1.709	781.2
80.00	903.1	351.40	1.3485	1.228	1.718	767.6
85.00	894.9	360.01	1.3727	1.235	1.726	754.2
90.00	886.7	368.67	1.3967	1.242	1.735	741.2
95.00	878.5	377.36	1.4205	1.250	1.744	728.4
100.00	870.2	386.10	1.4441	1.257	1.752	715.8
110.00	853.6	403.71	1.4907	1.271	1.769	691.5
120.00	837.0	421.49	1.5365	1.286	1.787	668.3
130.00	820.3	439.44	1.5816	1.300	1.803	646.2
140.00	803.6	457.56	1.6259	1.314	1.820	625.1
150.00	786.8	475.84	1.6697	1.328	1.836	605.2
160.00	770.1	494.29	1.7128	1.342	1.852	586.4
170.00	753.4	512.89	1.7552	1.356	1.867	568.7
180.00	736.7	531.63	1.7970	1.370	1.882	552.1
190.00	720.1	550.52	1.8383	1.384	1.895	536.7
200.00	703.7	569.54	1.8789	1.397	1.908	522.3
210.00	687.4	588.68	1.9189	1.410	1.920	509.1
220.00	671.3	607.94	1.9584	1.424	1.931	496.9
230.00	655.5	627.29	1.9972	1.437	1.940	485.8
240.00	640.0	646.74	2.0355	1.449	1.949	475.7

TABLE 7.—Continued

Temp. (°C)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/(kg·K))	C_v (kJ/(kg·K))	C_p (kJ/(kg·K))	Speed of sound (m/s)
Pressure=60 MPa						
−100.00	1204.4	80.16	0.2115	1.061	1.481	1472.8
−90.00	1189.4	94.98	0.2947	1.057	1.483	1432.6
−80.00	1174.4	109.82	0.3736	1.053	1.485	1393.7
−70.00	1159.5	124.68	0.4486	1.053	1.488	1355.5
−60.00	1144.6	139.58	0.5202	1.056	1.493	1317.7
−50.00	1129.9	154.56	0.5889	1.062	1.501	1280.5
−45.00	1122.5	162.07	0.6222	1.066	1.506	1262.0
−40.00	1115.2	169.62	0.6549	1.070	1.511	1243.8
−35.00	1107.9	177.19	0.6870	1.075	1.517	1225.7
−30.00	1100.6	184.78	0.7186	1.081	1.523	1207.7
−25.00	1093.3	192.41	0.7497	1.087	1.529	1190.9
−20.00	1086.0	200.07	0.7802	1.093	1.535	1172.6
−15.00	1078.8	207.76	0.8103	1.099	1.542	1155.3
−10.00	1071.5	215.49	0.8399	1.106	1.548	1138.3
−5.00	1064.3	223.24	0.8691	1.113	1.555	1121.5
0.00	1057.1	231.04	0.8979	1.120	1.562	1104.9
5.00	1050.0	238.86	0.9263	1.127	1.569	1088.6
10.00	1042.8	246.73	0.9543	1.134	1.576	1072.6
15.00	1035.6	254.62	0.9820	1.141	1.583	1056.8
20.00	1028.5	262.56	1.0093	1.149	1.590	1041.3
25.00	1021.4	270.53	1.0362	1.156	1.598	1026.0
30.00	1014.3	278.53	1.0629	1.164	1.605	1011.0
35.00	1007.2	286.58	1.0892	1.171	1.612	996.2
40.00	1000.1	294.65	1.1152	1.179	1.619	981.8
45.00	993.0	302.77	1.1409	1.186	1.626	967.5
50.00	985.9	310.92	1.1663	1.194	1.634	953.6
55.00	978.9	319.11	1.1915	1.202	1.641	939.9
60.00	971.9	327.33	1.2163	1.209	1.648	926.4
65.00	964.8	335.59	1.2409	1.217	1.655	913.2
70.00	957.8	343.88	1.2653	1.224	1.662	900.3
75.00	950.8	352.21	1.2894	1.232	1.670	887.6
80.00	943.9	360.58	1.3132	1.240	1.677	875.2
85.00	936.9	368.98	1.3369	1.247	1.684	863.0
90.00	929.9	377.41	1.3602	1.255	1.691	851.1
95.00	923.0	385.89	1.3834	1.262	1.698	839.4
100.00	916.1	394.39	1.4064	1.270	1.705	827.9
110.00	902.2	411.51	1.4516	1.285	1.719	805.8
120.00	888.5	428.77	1.4961	1.300	1.733	784.6
130.00	874.8	446.17	1.5398	1.315	1.746	764.3
140.00	861.2	463.70	1.5828	1.329	1.760	745.0
150.00	847.6	481.36	1.6250	1.344	1.773	726.6
160.00	834.2	499.16	1.6666	1.359	1.786	709.0
170.00	820.8	517.09	1.7075	1.373	1.799	692.4
180.00	807.6	535.15	1.7478	1.387	1.812	676.6
190.00	794.4	553.33	1.7875	1.402	1.824	661.7
200.00	781.4	571.63	1.8266	1.416	1.836	647.6
210.00	768.5	590.04	1.8651	1.430	1.847	634.4
220.00	755.8	608.57	1.9030	1.443	1.858	621.9
230.00	743.2	627.21	1.9405	1.457	1.869	610.2
240.00	730.8	645.95	1.9773	1.470	1.879	599.3

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