An International Standard Equation of State for Difluoromethane (R-32) for Temperatures from the Triple Point at 136.34 K to 435 K and Pressures up to 70 MPa

Reiner Tillner-Roth[a)]

Institut für Thermodynamik, Universität Hannover, Callinstrasse 36, 30167, Hannover, Germany

Akimichi Yokozeki

DuPont Chemicals, Fluorochemicals Laboratory, Chestnut Run Plaza, P.O. Box 80711, Wilmington, Delaware 19880-0711

Received May 27, 1997; revised manuscript received September 3, 1997

A fundamental equation of state for the Helmholtz free energy of R-32 (difluoromethane) is presented which is valid from the triple point at 136.34 K to 435 K and pressures up to 70 MPa. It is based on accurate measurements of pressure-density-temperature (p,ϱ,T), speed of sound, heat capacity, and vapor pressure currently available. New values for the isobaric heat capacity c_p° of the ideal gas calculated from spectroscopic data taking into account also first order anharmonicity corrections are presented. The Helmholtz free energy equation of state has 19 coefficients and represents all selected experimental data within their estimated accuracy with the exception for heat capacities and speed of sound in the region close to the critical point. Typical uncertainties are $\pm 0.05\%$ for density, $\pm 0.02\%$ for the vapor pressure and $\pm 0.5\%-1\%$ for the heat capacity. This equation of state has been compared to equations developed by other research groups by Annex 18 of the International Energy Agency and has been selected as an international standard formulation for the thermodynamic properties of R-32 by this group.
[S0047-2689(97)00306-1]

Key words: difluoromethane, fundamental equation of state, Helmholtz free energy, ideal gas heat capacity, statistical mechanic calculation, R-32.

Contents

List of Tables

a) Corresponding author

List of Figures

List of Symbols

Latin symbols

a	specific Helmholtz free energy, coefficient
A_v, B_v, C_v	rotational constants
c_p	specific isobaric heat capacity
c_v	specific isochoric heat capacity
$\bar{c}_v$	two-phase isochoric heat capacity
c_σ	saturated heat capacity
d	exponent
F_v	rotational energy level
Δh_v	enthalpy of vaporization
J	rotational quantum number
M	molar mass
N	counter
n	vibrational quantum number, coefficient
p	pressure
p_s	vapor pressure
s	entropy, uncertainty
R	individual gas constant
R_m	universal gas constant
t	exponent
T	temperature
w	speed of sound
W_τ	energy function
X	vibrational anharmonicity constant
y	quantity

Greek symbols

$\alpha_i^A, \alpha_i^B, \alpha_i^C$	rotation-vibration constants
β	proportionality constant
δ	reduced density ϱ/ϱ_c
θ	reduced temperature
μ	Joule–Thomson coefficient
ν	vibrational fundamental frequency
ϱ	specific density
τ	inverse reduced temperature T_c/T
Φ	dimensionless Helmholtz free energy

Subscripts

c	critical point parameter
tr	triple point parameter

i,j,k indices

Superscripts

$\circ$	ideal gas
r	residual
0	reference point
$'$	saturated liquid
$''$	saturated vapor

1. Introduction

R-32 (difluoromethane, CF_2H_2) is a non-ozone-depleting and environmentally acceptable refrigerant. It is an important compound in various HFC mixtures which will replace R-22 and R-502 (a mixture of R-22 and R-115) in low-temperature refrigeration, air conditioning, and heat pump applications.

The development of accurate equations of state for binary and ternary HFC blends requires accurate information of the pure components. Thus, a precise formulation of the thermodynamic properties of R-32 is a first important step towards the development of an accurate equation of state for the refrigerant mixtures. In this respect, the establishment of an international standard for the thermodynamic properties of the pure HFC refrigerants is very desirable as it provides an excellent starting point for a reliable formulation for the mixtures.

A group working under the auspices of the Heat Pump Programme of the International Energy Agency (IEA) established in 1978, took over the task, to decide upon standards for environmentally acceptable refrigerants. The program's purpose is to accelerate research, and to accept, and implement this energy saving and environmentally important technology. It is currently supported by 15 countries and offers opportunities of international collaboration in research, development, demonstration, and promotion of heat pumping and related technologies.

The eight member countries: Austria, Canada, Germany, Japan, Norway, Sweden, the United Kingdom, and the United States founded Annex 18 (Thermophysical Properties of the Environmentally Acceptable Refrigerants) in 1990. One of its goals is to provide accurate equations of state as *de facto* international standards for the most important alternative refrigerants.

The main task of phase I (1990–1993) was an evaluation of the thermodynamic properties of R-134a and R-123 including comparisons of existing equations of state. The comparisons were carried out by two groups: the Center for Applied Thermodynamic Studies (CATS) at the University of Idaho, Moscow, Idaho, and the International Union of Pure and Applied Chemistry (IUPAC) Thermodynamic Tables Project Center, Imperial College, London, UK. The two groups prepared independent reports which formed the basis for a recommendation of equations of state for R-134a and R-123 as *de facto* international standards for their thermodynamic properties.

In June 1994, at a meeting in Boulder, Colorado, it was decided that similar comparisons for R-32 and R-125 should be one of the tasks of phase II of Annex 18. Groups wishing to participate in this process were invited to submit equations of state by June 30, 1995. It was regarded as vital to make relevant experimental data quickly available to all participants to accelerate the process towards the establishment of standard formulations for these refrigerants. In the course of the following year, extensive published and unpublished data sets were supplied to an electronic data bank at the University of Stuttgart, Germany, which was set up for this purpose.

Four equations of state for R-32 and three equations for R-125 were submitted to Annex 18 by the deadline. Their evaluation was carried out by the IUPAC Thermodynamic Tables Project Center, Imperial College, London, UK. The final report was distributed among all Annex 18 participants in the spring of 1996, and the results were presented at the meeting in Toronto in September 1996. Based on this report the Annex 18 members recommended the equation presented in this paper as an international standard for the thermodynamic properties of R-32.

Since the deadline for submission, extensive new experimental data became available. Moreover, some of the data sets obtained from the database in Stuttgart about two years ago were corrected or adjusted by the respective researchers prior to their final publication. Therefore, it was decided at the Annex 18 meeting in Toronto that the equations chosen as standards for R-32 and R-125 should be checked by the respective authors against the updated experimental material and refitted if necessary.

In the case of R-32, a new theoretical study on the ideal gas heat capacity has been made which incorporates anharmonicity corrections of vibrational modes in the R-32 molecule. This leads to much more accurate heat capacity values than those in the prior studies of Chase *et al.*[1] and Rodgers *et al.*[2] which are based only on the simple rigid-rotor-harmonic-oscillator model. With the new results, which are presented in Section 3, a new ideal gas correlation was developed. Subsequently, the coefficients and the structure of the equation of state were reconsidered, taking into account also the updated and new experimental data, available at the end of October 1996.

The higher accuracy of the new data results in an improvement of the equation of state compared to the one originally submitted to Annex 18 in 1995. Its accuracy is higher, and the number of coefficients was reduced from 21 to 19 due to a higher degree of thermodynamic consistency of the updated data and to more reliable ideal gas heat capacities. The new equation of state covers temperatures between the triple point (136.34 K) and 435 K at pressures up to 70 MPa. Property data in all parts of the thermodynamic surface are represented within their experimental uncertainties.

2. Data Survey

Experimental data available in 1995 were summarized by Kilner and Craven[3] in their final report to Annex 18. In this section, a summary of data is given which includes material available at the end of October 1996. References for data

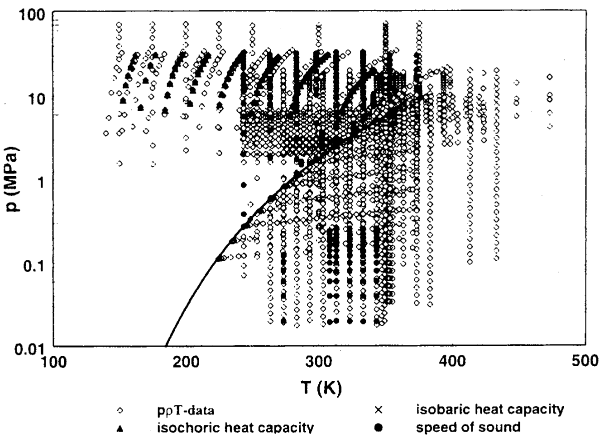

FIG. 1. Distribution of available (p,ϱ,T) and caloric measurements for R-32.

published after October 1996 indicate experimental data which were made available prior to publication. Some of the data listed in Reference 3 have been revised or were supplemented by additional measurements. Only experimental data on the real fluid behavior will be considered here. Ideal gas properties will be discussed in Section 3. All temperatures correspond to the International Temperature Scale of 1990 (ITS-90).

2.1. Critical and Triple Point

A single experimental value for the triple point temperature has been reported by Lüddecke and Magee[4] at $T_{tr}=136.34\pm0.01$ K. For this temperature, a saturation pressure of $p_{tr}=48.00$ Pa is calculated from the present fundamental equation of state. No uncertainty is given for this pressure value, since no measured vapor pressures are available at these low temperatures.

Critical parameters are reported by 10 independent sources. The results for critical temperatures, pressures, and densities are listed in Table 1. This summary has been adopted from the work of Higashi[5] who carried out an assessment of available critical data. The most recent results for T_c, mainly measured in Japanese laboratories, agree remarkably well within ±0.02 K while results measured before 1995 are up to 0.1 K higher. Agreement of critical pressures and densities is very good among all sources except for p_c and ϱ_c measured by Malbrunot *et al.*[12] in 1968. Therefore, the critical temperature and densities recommended by Higashi,[9]

$$T_c=351.255\ \text{K}$$

as measured by Sato *et al.*[15] and

$$\varrho_c=424\ \text{kg m}^{-3}$$

as measured by Kuwabara *et al.*,[11] will be subsequently used for the critical point and also as reducing parameters for the variables $\delta=\varrho/\varrho_c$ and $\tau=T_c/T$ of the equation of state. The critical pressure is not used directly to establish the equation of state, but will serve as a guideline to assess the representation of the region close to the critical point. According to Higashi,[5] the most reliable value is

$$p_c=5784\ \text{kPa}$$

as measured by Sato *et al.*[15]

2.2. Single Phase Properties

A considerable number of measurements in the single phase regions (liquid and vapor) is available. The measurements comprise more than 2500 (p,ϱ,T) data in the liquid and vapor, 217 speed of sound in both phases, 19 isobaric heat capacities in the liquid phase and 74 isochoric heat capacities in the liquid. The data cover temperatures from 140 K to 440 K at pressures up to 70 MPa. A summary is given in Table 2. The distribution of thermal and caloric data is shown in Fig. 1. While (p,ϱ,T) data cover the whole range equally well in all parts of the thermodynamic surface, caloric data are more scarce. There are no caloric properties available above 370 K. In the vapor, only speed of sound values are found at pressures below 0.5 MPa, while the majority of caloric measurements are located in the liquid. Al-

TABLE 1. Critical parameters of R-32

Source	Year	Purity mass %	T_c K	p_c kPa	ϱ_c kg/m³
Defibaugh *et al.*	1994	99.99	351.36[a]	5792.7±2.4	—
Fu *et al.*	1995	99.95	351.295±0.01	5785±2	425±3
Fukushima *et al.*	1995	99.98	351.26±0.03	5778±3	425±5
Higashi	1994	99.98	351.26±0.01	5785±9	428±5
Holcomb *et al.*	1993	99.9	351.52[a]	—	428.5±1.83
Kuwabara *et al.*	1995	99.998	351.25±0.01	—	424±1
Malbrunot *et al.*	1968	99.95	351.52±0.2	5830[a]	430[a]
Nagel & Bier	1995	99.9	351.23±0.06	5783±6	420±8
Nishimura *et al.*	1992	99.98	351.255[a]	5780±2	—
Sato *et al.*	1994	99.998	351.255	5784±2.5	—
Schmidt & Moldover	1994	99.9	351.36±0.02	—	419±7
Weber & Silva	1994	99.99	351.36[a]	5793.1[a]	—
Zhelezny *et al.*	1995	99.9	351.26±0.08	5784±11	424±2

[a] Uncertainty not reported.

TABLE 2. Summary of measurements in the single-phase region

Source	Year		N	Purity (%)	Range of data T/K	Range of data p/MPa	Uncertainties s_T	Uncertainties s_p	Uncertainties s_y
					(p,ϱ,T) measurements $(y=\varrho)$				
Bouchot & Richon[19]	1994	v	15	99.3	253–333	0.12–9.45	20 mK	3 kPa	0.5 kg m^{-3}
Bouchot & Richon[19]	1994	l	21	99.3	253–333	1.03–9.44	20 mK	3 kPa	0.5 kg m^{-3}
Defibaugh *et al.*[6,a]	1994	v	146	99.99	268–373	0.30–9.77	2 mK	0.01 kPa	0.03%
Defibaugh *et al.*[6,b]	1994	v	21	99.99	373	0.24–9.77	2 mK	0.01 kPa	0.03%
Defibaugh *et al.*[6,c]	1994	l	219	99.99	243–349	2.00–6.50	10 mK	0.5 kPa	0.05%
de Vries[20,a]	1997	v	94	99.99	223–334	0.11–1.40	5 mK	0.01%	0.05%
de Vries[20,b]	1997	v	565	99.99	263–433	0.02–20.6	5 mK	0.01%	0.05%
de Vries[20,c]	1997	l	490	99.99	243–393	1.50–18.1	10 mK	0.02%	0.03%
Fu *et al.*[7]	1995	v	121	99.95	243–373	0.07–5.70	10 mK	0.5 kPa	0.2%
Fukushima *et al.*[8]	1995	v	158	99.98	314–424	1.86–10.1	10 mK	3 kPa	0.2%
Holste *et al.*[21]	1993	l	126	99.99	150–375	1.53–71.7	20 mK	0.02 kPa	0.1%
Lüddecke & Magee[4]	1996	l	74	99.9	153–311	5.21–31.8	10 mK	1 kPa	0.1%
Magee[22]	1996	l	137	99.9	152–396	3.82–35.1	10 mK	0.02 kPa	0.05%
Malbrunot *et al.*[12]	1968	v	86	99.95	298–473	0.89–20.1	30 mK	0.2 kPa	0.3%
Malbrunot *et al.*[12]	1968	l	64	99.95	248–343	0.33–20.1	30 mK	0.2 kPa	0.3%
Quian *et al.*[23]	1993	v	95	99.9	290–370	0.13–6.54	10 mK	0.8 kPa	0.2%
Sato *et al.*[15]	1994	v	69	99.998	330–410	4.2–9.4	7 mK	0.4 kPa	0.2%
					Speed of sound $(y=w)$				
Grebenkov *et al.*[24]	1994	l	30[d]	—	286–341	1.49–10.4	10 mK	50 kPa	0.2 m s^{-1}
Hozumi *et al.*[25]	1994	v	67	99.99	273–343	0.02–0.26	9 mK	0.3 kPa	0.01%
Takagi[26]	1993	l	120	—	243–373	0.27–33	10 mK	0.1%	0.2%
					Isobaric heat capacity $(y=c_p)$				
Yomo *et al.*[27]	1994	l	19	99.9	275–315	2.1–3	12 mK	1.8 kPa	0.4%
					Isochoric heat capacity $(y=c_v)$				
Lüddecke & Magee[4]	1996	l	74	99.9	153–341	—	10 mK	—	0.6%

[a]Isochoric cell.
[b]Burnett measurement.
[c]Vibrating tube densimeter.
[d]Same data as of Belyaeva *et al.*[28]

though much data are available. more measurements of thermal and caloric properties would be desirable for $T>T_c$ to support the equation of state in the supercritical region.

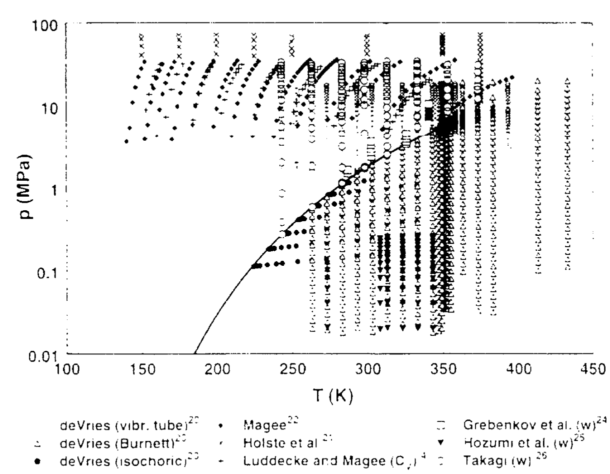

FIG. 2. Selected (p,ϱ,T) and caloric data of R-32 in a (p,T) plane

2.3. Saturation Properties

Measurements of saturation properties are available along the entire two-phase boundary. A summary is given in Table 3. 585 vapor-pressure data exist between the triple-point temperature up to the critical temperature. However, the values below 200 K have mostly been extrapolated from vapor pressures at higher temperatures. Since these extrapolations are based on older data, the reliability of most low-temperature vapor pressure measurements may be questionable.

Apart from the vapor-pressure measurements, 166 experimental data for the saturated liquid density are reported along the whole saturation boundary. Limited data are available for the saturated vapor density between 219 K and the critical temperature. However, saturated liquid and vapor densities are regarded to be of secondary importance in this work (with the exception of data close to the critical point), since the adjacent single-phase regions are well defined by (p,ϱ,T) data.

A valuable set of isochoric heat capacities $\bar{c}_v$ in the two-phase region has been measured by Lüddecke and Magee[4]

TABLE 3. Summary of measurements of saturation properties in the two-phase region

Source	Year	N	Purity (%)	Range (T/K)	Uncertainties s_T	Uncertainties s_y
Vapor pressure ($y=p_s$)						
Adams & Stein[29]	1971	4	99.8	222–283	20 mK	0.7 kPa
Bouchot & Richon[19]	1994	8	99.3	253–333	10 mK	1 kPa
Defibaugh *et al.*[6]	1994	18	99.99	268–348	2 mK	0.5 kPa
de Vries (low T)[20]	1997	33	99.99	223–295	5 mK	0.02%
de Vries (high T)[20]	1997	106	99.99	298–351	5 mK	0.015%
Fu *et al.*[7]	1995	60	99.95	233–351	10 mK	0.5 kPa
Fukushima *et al.*[8]	1995	57	99.98	278–351	10 mK	3 kPa
Holcomb *et al.*[10]	1993	25	99.9	295–349	0.1 K	3.5 kPa
Kanungo *et al.*[30,a]	1987	11	—	149–245	—	—
Lüddecke and Magee[4,a]	1987	9	—	140–180	—	—
Magee[22]	1996	7	99.9	270–330	5 mK	0.1%
Malbrunot *et al.*[12]	1968	30	99.95	191–351	30 mK	0.1%
Omata *et al.*[31]	1994	10	99.99	223–346	—	2.5 kPa
Quian *et al.*[23]	1993	9	99.98	280–350	10 mK	0.8 kPa
Sato *et al.*[15]	1994	23	99.998	320–351	—	2 kPa
Tillner-Roth[32,a]	1996	49	—	136–232	—	—
Türk *et al.*[33]	1994	26[b]	99.9	204–351	30 mK	0.1–1 kPa
Weber & Goodwin[34]	1993	27	99.98	208–237	5 mK	0.02–0.05%
Weber & Silva[17]	1994	17	99.99	236–266	5 mK	0.02%
Widiatmo *et al.*[35]	1994	25	99.99	220–325	15 mK	2 kPa
Zhu *et al.*[36]	1993	31	99.95	273–347	10 mK	0.5 kPa
Saturated liquid density ($y=\varrho'$)						
Bouchot & Richon[19]	1994	5	99.9	253–333	10 mK	0.2%
Defibaugh *et al.*[6]	1994	21	99.99	243–338	10 mK	0.05%
Fukushima *et al.*[8]	1995	10	99.98	340–351	20 mK	3 kg m^{-3}
Fukushima *et al.*[8]	1995	5	99.98	232–265	20 mK	3 kg m^{-3}
Fukushima *et al.*[8]	1995	6	99.98	329–348	0.5 K	0.4%
Higashi[9]	1994	8	99.98	336–351	15 mK	0.2%
Holcomb *et al.*[10]	1993	25	99.9	295–349	0.1 K	0.05–0.08%
Kuwabara *et al.*[11]	1995	17	99.998	330–351	10 mK	1 kg m^{-3}
Magee[22]	1996	13	99.9	139–305	10 mK	0.1%
Malbrunot *et al.*[12]	1968	15	99.95	248–356	30 mK	0.3%
Shinsaka *et al.*[37]	1985	19	99.0	150–219	50 mK	0.2%
Widiatmo *et al.*[35]	1994	22	99.99	220–330	15 mK	0.2%
Saturated vapor density ($y=\varrho''$)						
Bouchot & Richon[19]	1994	5	99.3	253–333	10 mK	0.5%
Defibaugh *et al.*[6]	1994	28	99.99	219–343	2 mK	0.3%
Fukushima *et al.*[8]	1995	5	99.98	349–351	20 mK	3 kg m^{-3}
Fukushima *et al.*[8]	1995	8	99.98	298–350	0.5 K	0.4%
Higashi[9]	1994	9	99.98	340–351	15 mK	0.2–0.5%
Holcomb *et al.*[10]	1993	25	99.9	295–349	0.1 K	0.2–1%
Kuwabara *et al.*[11]	1995	13	99.998	345–351	10 mK	1 kg m^{-3}
Two-phase isochoric heat capacity ($y=\bar{c}_v$)						
Lüddecke and Magee[4]	1996	101	99.99	141–342	10 mK	0.5%

[a]Calculated from other measurements.
[b]Same data as of Nagel and Bier.[illegible]

from which a set of saturated heat capacities c_σ was derived by the respective authors. These data are useful to establish an equation of state because they contain information on pressure derivatives in the single-phase region and also on the first and second derivatives of the vapor pressure curve. Fortunately, the c_σ and the $\bar{c}_v$ data for R-32 reach down to low temperatures. Therefore, they are suited to supplement available vapor pressure data which are scarce below 200 K.

2.4. Selection of Experimental Data

An accurate fundamental equation of state which should describe all thermodynamic properties within their experimental uncertainties can only be based on precise and thermodynamically consistent data. Therefore, those experimental data which obey the rules of thermodynamics must be determined in order to allow a consistent description of the thermodynamic surface.

The assessment of data was carried out during the optimization of the equation of state. At the start, a set of data comprising almost all available data was used to develop an interim equation of state. Subsequently, this equation was used to examine the experimental results. Deviation plots reveal data showing large scatter or large systematic deviations. Furthermore, consistency of a particular data set was determined by putting a large weight on the data and running a test optimization. From the resulting increase or decrease of deviations of the remaining data, conclusions can be drawn as to whether the data set under investigation is consistent with the other data or not. Data whose overweighting clearly lead to a deterioration of the representation of most remaining data were eliminated from the data set.

After completing the described selection process, an improved fundamental equation of state was developed, and the data selection process was repeated. Only few data were taken out of the data set at the same time in order to avoid errors due to a misinterpretion of results from the above mentioned test procedure. Wherever possible, data sets were not split, i.e., a data set from a single research group was either taken out completely or left in the data base in its entirety.

In addition to this procedure, the comparisons given by Kilner and Craven[3] in the IUPAC report were particularly helpful during the assessment of experimental data. The final set of selected data consisted of the following sets of measurements:

- 490 (p,ϱ,T) values in the liquid, 565 Burnett (p,ϱ,T) values in the vapor and 94 (p,ϱ,T) values in the vapor from isochoric measurements of de Vries.[20]
- 137 (p,ϱ,T) values in the liquid measured by Magee.[22]
- 44 (p,ϱ,T) values in the liquid measured by Holste *et al.*[21] at pressures above 35 MPa and at 150 K. Since all these values are 0.15% lower than selected data of Magee[22] and de Vries[20] Holste's densities were adjusted by −0.15% in order to smoothly extend Magee's and de Vries' densities.
- a selection of 178 vapor pressure data from the sets of de Vries,[20] Weber and Goodwin,[34] and Weber and Silva.[17] Most of de Vries' data were used except his results at 351.15 K. The sets of Weber and Goodwin[34] and of Weber and Silva[17] were used with a lower weight than those of de Vries. Instead of using calculated values of Kanungo *et al.*[30] or Tillner-Roth[32] down to the triple point an alternative method was employed to obtain a consistent representation of the vapor pressures at low temperatures as described in Section 5.1.
- all isochoric heat capacities in the liquid measured by Lüddecke and Magee.[4]
- all two-phase heat capacities $\bar{c}_v$ and all heat capacities c_σ at saturation measured by Lüddecke and Magee.[4]
- all speed of sound values of Hozumi *et al.*[25] in the vapor, Grebenkov *et al.*[24] in the liquid, and all of Takagi's[26] measurements in the liquid with a very low weight, and
- saturated liquid and vapor densities of Fukushima *et al.*,[8] Kuwabara *et al.*[11] and Higashi[9] at temperatures above 340 K.

Reasons for selection of these data sets are given during the discussion of the equation of state in Section 5. The distribution of the selected data sets is shown in Fig. 2.

3. Ideal Gas Properties

In general, the ideal gas behavior of a fluid is defined if an equation for the isochoric or isobaric heat capacity, $c_v^\circ(T)$ or $c_p^\circ(T)=c_v^\circ(T)+R$, as an analytic function of temperature is known. High precision in the ideal gas heat capacity $c_p^\circ(T)$ is essential for an accurate representation of caloric properties on the entire thermodynamic surface by a fundamental equation of state because errors in $c_p^\circ(T)$ directly propagate into the representation of real gas heat capacities and also affect the values of entropy, enthalpy and speed of sound. $c_p^\circ(T)$ can be experimentally obtained, for example, by extrapolating measured speed of sound data to the zero pressure limit. Unfortunately, for R-32 only one analogous experiment exists by Hozumi *et al.*[25] Although the authors report a high accuracy of ±0.15% for $c_p^\circ(T)$ (three times the standard deviation), their data only cover the range from 273 K to 343 K. Limited data do not provide sufficient information to correlate a function for $c_p^\circ(T)$ over the wide range of temperatures required for a wide-ranging fundamental equation of state.

Another method for obtaining c_p° is the statistical mechanical calculation using spectroscopic data (e.g., Chase *et al.*[1] and Rodgers *et al.*[2]). This method yields correct and accurate results only if the internal energy levels of substances are exactly known, i.e., the electronic, vibrational, and rotational (or their combined) states including their statistical weights (degeneracies and nuclear spin states). Precise and complete analysis of the spectroscopic data, however, gets prohibitively complicated as the number of atoms in a molecule increases. So far, sufficiently accurate information is limited to a few simple molecules such as diatomic and triatomic molecules. Therefore, it is common to adopt a drastically simplified approximation to calculate c_p° for general polyatomic molecules, the so-called rigid-rotator harmonic-oscillator (RRHO) model. This simple model predicts c_p° with a fair accuracy (with an error of several percent) in the moderate temperature range, within about 100–1000 K, where the harmonic or fundamental vibrational frequencies are correctly known. Previous investigators (Chase *et al.*[1] and Rodgers *et al.*[2]) used the RRHO model to calculate $c_p^\circ(T)$ for R-32.

However, the current Helmholtz formulation, accurately representing the thermodynamic property surface, cannot tolerate error margins in the order of several percent; it requires much higher accuracy for c_p° in a sufficiently wide range of temperatures. Unless temperatures are very low (<50 K), or very high (>1000 K), major correction terms to the RRHO model include vibrational anharmonicities and rotation-

TABLE 4. Fundamental frequencies adopted for R-32 (cm^{-1})

Mode		Present work[39]	Rodgers *et al.*[2]	Chase *et al.*[1]
ν_1	(CH_2 *s*-stretching)	2948.0	2949	2949
ν_2	(CH_2 scissoring)	1113.2	1116	1116
ν_3	(CF_2 *s*-stretching)	1508.0	1508	1508
ν_4	(CF_2 scissoring)	528.5	529	529
ν_5	(CH_2 twisting)	1262.0	1262	1262
ν_6	(CH_2 *a*-stretching)	3014.3	3012	3013
ν_7	(CH_2 rocking)	1179.9	1176	1176
ν_8	(CH_2 wagging)	1090.1	1090	1090
ν_9	(CF_2 *a*-stretching)	1435.0	1435	1435

TABLE 6. Rotational constants and rotation-vibration constants (MHz)[a]

A_0	49 829.651	B_0	10 678.945	C_0	9 334.291
α_1^A	430.0	α_1^B	12.3	α_1^C	8.3
α_2^A	192.643	α_2^B	−3.207	α_2^C	− 94.801
α_3^A	855.74	α_3^B	55.165	α_3^C	−178.534
α_4^A	−337.739	α_4^B	21.868	α_4^C	33.244
α_5^A	226.197	α_5^B	0.650	α_5^C	− 82.604
α_6^A	382.0	α_6^B	5.4	α_6^C	6.6
α_7^A	−750.714	α_7^B	−8.155	α_7^C	96.715
α_8^A	119.545	α_8^B	−3.635	α_8^C	114.288
α_9^A	444.03	α_9^B	73.610	α_9^C	269.311

[a]See Ref. 41.

vibration couplings. Anharmonicity effects can be taken into account with various degrees of complexity which depend largely on the available spectroscopic data and their detailed analysis. Pennington and Kobe[38] have worked out a relatively simple method for certain correction terms applying to the RRHO approximation. These are essentially the first order corrections for the vibrational anharmonicity and the rotation-vibration interaction, neglecting Coriolis splitting and Fermi resonance. Due to the insufficient information of energy levels for R-32, we adopt their method to correct the RRHO model. It requires the vibrational anharmonicity constants X_{ij} and rotation-vibration constants α_i^A, α_i^B, and α_i^C as well as vibrational fundamentals ν_i and rotational constants A_0, B_0, and C_0. The energy levels of vibrations and rotations, measured from the lowest level, are given in Eq. (1), without the term of vibrational angular momenta in the present case, because of the molecular symmetry of C_{2v} (no degenerate frequencies):

$$G=\sum_i (\nu_i - X_{ii})n_i + \sum_i \sum_{j\geq i} X_{ij}n_in_j + F_v, \quad (1)$$

where n_i is a vibrational quantum number. The term F_v stands for the rotational level, and for R-32 (asymmetric top molecule), it is given by:

$$F_v=\tfrac{1}{2}(B_v+C_v)J(J+1)+[A_v-\tfrac{1}{2}(B_v+C_v)]W_\tau, \quad (2)$$

where

$$A_v=A-\sum \alpha_i^A n_i, \quad B_v=B-\sum \alpha_i^B n_i,$$

$$C_v=C-\sum \alpha_i^C n_i. \quad (3)$$

W_τ is a non-analytical function of A, B, C, and J, but does not contribute to c_p in the present approximation. R-32 has nine fundamental frequencies (Suzuki and Shimanouchi[39]), as shown in Table 4, which were used in the present work. Those adopted by Chase *et al.*[1] and Rodgers *et al.*[2] are also shown in Table 4 for comparison. The three sets of data deviate from each other by only small amounts which result in minor discrepancies in c_p^0 of less than 0.02%. The first order anharmonicity constants (X_{ij}) for the nine fundamental frequencies total 45 since $X_{ij}=X_{ji}$. Ten constants are determined from the observed overtone and combination bands of R-32 (Suzuki and Shimanouchi[39]), and the other X_{ij} for $i-j$ are estimated in the following way. Darling and Dennison[40] have related the anharmonicity constants for isotope species to squares of the vibrational frequencies. Here, we assume

TABLE 5. Vibrational anharmonicity constants (cm^{-1})[a]

X[illegible]	-49.1	X[illegible]	[-14.5]	X[illegible]	[-7.4]	X[illegible]	[-4.0]
X[illegible]	[11.0]	X[illegible]	[-50.0]	X[illegible]	[−9.7]	X[illegible]	−16.0
X[illegible]	[8.3]	X[illegible]	18.6	X[illegible]	−32.3	X[illegible]	−3.0
X[illegible]	5.3	X[illegible]	−41.1	X[illegible]	−13.0	X[illegible]	−2.4
X[illegible]	3.0	X[illegible]	16.0	X[illegible]	−13.0		

[a][ ] indicates estimated values; see text.

TABLE 7. Ideal gas heat capacity in J mol^{-1} K^{-1} of R-32

T (K)	Corrected c_p^0	RRHO model Present work	RRHO model Chase *et al.*[1]	Correction (%) to RRHO
100	33.498	33.498	33.496	0.0
150	34.690	34.688	34.684	0.005
200	36.709	36.694	36.688	0.039
250	39.532	39.490	39.482	0.105
300	43.100	43.017	43.008	0.195
350	47.143	47.000	46.992	0.303
400	51.347	51.128	51.120	0.428
450	55.480	55.166	55.159	0.568
500	59.409	58.985	58.978	0.720
550	63.074	62.525	62.519	0.878
600	66.459	65.776	65.770	1.039
650	69.574	68.749	68.744	1.200
700	72.436	71.464	71.460	1.360
750	75.068	73.946	73.942	1.517
800	77.491	76.217	76.214	1.671
850	79.725	78.299	78.296	1.821
900	81.789	80.209	80.206	1.969
950	83.697	81.964	81.962	2.113
1000	85.465	83.580	83.578	2.255
1050	87.106	85.068	85.066	2.395
1100	88.630	86.440	86.438	2.533
1150	90.048	87.707	87.705	2.668
1200	91.369	88.878	88.876	2.803
1250	92.602	89.961	89.959	2.935
1300	93.754	90.963	90.962	3.067
1350	94.832	91.893	91.892	3.197
1400	95.842	92.755	92.755	3.327
1450	96.790	93.557	93.556	3.456
1500	97.682	94.302	94.301	3.584

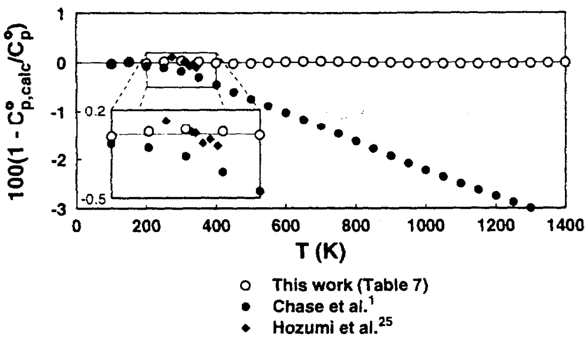

FIG. 3. Deviations of ideal-gas isobaric heat capacities c_p° from the new EOS.

that X_{ii} in general is proportional to the square of the frequency ν_i: $X_{ii}=-\beta\cdot\nu_i^2$. This relation roughly holds for simple molecules (C–F, C–H, CO_2, N_2O, H_2O, OF_2, and O_3) with the proportionality constant, β, of $3-7\times10^{-6}$ cm. X_{22}, X_{33}, X_{44}, X_{55}, X_{66}, X_{77}, and X_{99} are estimated with a β of $6-7\times10^{-6}$ cm. All other cross terms X_{ij} (for $i\neq j$) are assumed to be zero. The non-zero constants are shown in Table 5.

As for the rotation-vibration constants, all required 27 constants for α_i^A, α_i^B, and α_i^C as well as the three rotational constants $A_\circ$, $B_\circ$, and $C_\circ$ have been reported by Hirota.[41] They are listed in Table 6. The ideal gas heat capacity c_p° is finally calculated from a numerical evaluation of the canonical partition function. The results are listed in Table 7, which also includes the result of the RRHO approximation of Chase *et al.*[1] Figure 3 illustrates the magnitude of the correction terms to the RRHO model. Here, deviations of c_p° from Eq. (8) are plotted versus temperature. The observed heat capacity data by Hozumi *et al.*,[25] which were not used in the fit of the ideal-gas part agree with the present calculations within their experimental error limits of ±0.15%, while the RRHO model calculations deviate by more than the experimental errors. The correction to the RRHO model increases as temperatures rise.

Electronically excited states of R-32 are located at 74855 cm^{-1} (continuous) and 80856 cm^{-1} (structured) according to Wagner and Duncan.[42] At temperatures up to 8 000 K they contribute insignificant amounts (less than 0.002%) to c_p°. But at very low temperatures, the symmetry of rotational states and nuclear-spin states becomes important, since R-32 has two identical nuclei (two H's and two F's) with nuclear spins of $\frac{1}{2}$; the statistical weight factors for symmetric and antisymmetric levels are 10:6 (Herzberg[43]). Gordon[44] has examined such effects on water and the contribution to c_p° is 0.06% at 330 K, 0.47% at 99 K, and 13.3% at 50 K, while below 50 K the effect becomes significantly larger. In the present case the effect is much smaller above 100 K (less than 0.001%) due to the heavier molecular mass when using a method similar to that applied by Gordon,[44] thus these contributions were neglected for R-32.

4. The Fundamental Equation of State

The present equation of state for R-32 is a fundamental equation of state for the dimensionless Helmholtz free energy

$$\Phi(\tau,\delta)=\frac{a}{RT}=\Phi^\circ(\tau,\delta)+\Phi^r(\tau,\delta), \tag{4}$$

where a is the specific Helmholtz free energy, $R_m=8.314\,471$ $\text{J/mol}^{-1}\,\text{K}^{-1}$ is the universal gas constant according to Moldover *et al.*,[45] and $R=R_m/M$ is the gas constant of HFC-32 with the molar mass $M=0.052\,024$ kg mol^{-1}. Independent variables are the inverse reduced temperature $\tau=T_c/T$, and the reduced density $\delta=\varrho/\varrho_c$. As mentioned in Section 2.1, the critical parameters $T_c=351.255$ K and $\varrho_c=424.0$ kg m^{-3} were used as reducing parameters.

The dimensionless form Φ of the fundamental equation of state is split into an ideal-gas part Φ° describing ideal gas properties and into a residual part Φ^r taking into account the behavior of the real fluid.

4.1. The Helmholtz Free Energy for the Ideal Gas

Generally, the ideal-gas part of the dimensionless Helmholtz free energy is written as

$$\Phi^\circ(\tau,\delta)=\ln\,\delta+\Phi^*(\tau). \tag{5}$$

While the first term is related to the ideal gas law $p=RT\varrho$, the function Φ^* is related to the isochoric heat capacity c_v° by

$$c_v^\circ=-R\tau^2\frac{d^2\Phi^*}{d\tau^2}. \tag{6}$$

For $c_v^\circ=c_p^\circ-R$ the new results presented in Table 7 were taken as a basis to develop the expression for the ideal-gas part of the Helmholtz free energy equation of state. For simple molecules the most appropriate form is a series of Planck–Einstein functions,

$$a_i\ln[1-\exp(-n_i\tau)]. \tag{7}$$

The general form of mathematical expression can be derived directly from the vibrational contribution to the heat capacity $c_p^\circ(T)$.

Using the regression analysis of Wagner,[46] an equation was developed containing four Planck–Einstein terms. The selection was based on a bank of terms containing 160 Planck–Einstein terms with θ_i being chosen in steps of 0.25 from 0.25 to 40. In addition, polynomial terms τ^n were included with n ranging between −0.25 and −5 in steps of 0.25. No polynomial terms were selected during the regression analysis indicating the superiority of Planck–Einstein terms for the formulation of the ideal-gas part of the equation.

After the structure of the equation was determined using Wagner's method, the coefficients a_i and the constants θ_i were nonlinearly refitted to the new c_p° values from Table 7. In addition, minor adjustments were carried out simultaneously with the optimization of the residual part in order to be able to incorporate property information of real fluid caloric properties like c_v or speed of sound. The final equation for the ideal-gas part Φ° is given in Appendix A, from which the following equation for the ideal-gas heat capacity can be derived:

$$\frac{c_p^\circ}{R} = a_2^\circ + \tau^2 \sum_{i=3}^{6} a_i^\circ n_i^2 \frac{\exp(-n_i\tau)}{[1-\exp(-n_i\tau)]^2}. \tag{8}$$

The coefficients correspond to those valid for the ideal-gas part Φ°. They are listed in Appendix A.

4.2. The Residual Part Φ^r of the Dimensionless Helmholtz Free Energy

The general optimization procedure of the residual part Φ^r was carried out analogously to the process described in Tillner–Roth and Baehr[47] for the establishment of the equation of state for R-134a. Therefore, only a short outline of the process is given here. As for R-134a, the residual part is a linear combination of terms of the form

$$\Phi^r = \sum_{i=1}^{N_0} a_i \delta^{d_i} \tau^{t_i} + \sum_{k=1}^{5} \left\{ \exp(-\delta^k) \cdot \sum_{i=N_{k-1}+1}^{N_k} a_i \delta^{d_i} \tau^{t_i} \right\}. \tag{9}$$

To obtain the most accurate equation for Φ^r, two methods were employed. An implementation of Wagner's regression analysis[46] programmed at the Institute of Thermodynamics, University of Hannover[48] was applied to determine the structure of the residual part. This algorithm operates on a large bank of terms (up to 600) given by Eq. (9) from which a linear combination of the most useful terms is selected. The previously chosen experimental data served as input for this optimization method. Since only linear relationships can be used in the search for the function, a nonlinear fitting procedure was subsequently employed to adjust the equation of state also to experimental property data which are nonlinearly related to the Helmholtz free energy. During the development of the fundamental equation of state, numerous structures were tested and nonlinearly adjusted in an iterative procedure in which Wagner's method and the nonlinear fitting alternated. After each cycle the data base and uncertainties were reassessed, and the weights of experimental data were adjusted which, in turn, had an impact on the structure of the equation of state.

As mentioned in Section 1, a preliminary equation of state had been submitted to Annex 18 based on the limited amount of experimental data available by January, 1995. It contained a Φ^r function with 21 terms. Due to the improvement of the data situation since then, particularly regarding the ideal-gas properties, two of the terms turned out to be insignificant in the new equation during the nonlinear refit leading to a 19-term equation for the residual part Φ^r. Astonishingly, the exponents of the remaining terms resulting from a new search did not change very much compared to the older 21-term equation. Additionally, the new 19-term equation of state has a higher accuracy indicating a higher degree of thermodynamic consistency among the current set of experimental data.

The structure of the residual part Φ^r is given in Appendix A together with the coefficients and exponents. Relations between the dimensionless Helmholtz free energy Φ and thermodynamic properties are listed in Table 9. Furthermore, expressions for first and second derivatives as well as ancillary equations for vapor pressure, saturated liquid and saturated vapor density are given in Appendix A.2.

5. Discussion of the New Equation of State

In this section the new fundamental equation of state is compared to experimental data. For a quick assessment of the data representation the reader may refer to Appendix B where deviation statistics are listed for each data set. These statistics are listed in separate Tables 10 and 11 for single-phase and saturation properties. Graphical comparisons are depicted only for selected experimental data.

5.1. Vapor Pressure and Enthalpy of Vaporization

Figures 4 and 5 show comparisons of the new equation with some vapor pressure data. Statistics for the remaining measurements are listed in Table 11. For temperatures above 240 K, the vapor pressures of de Vries,[20] to which the equation of state has been fitted, are particularly well represented within $\pm 0.02\%$ corresponding to about ± 5 mK in saturation temperature. The results of Defibaugh *et al.*,[6] Fu *et al.*,[7] Quian *et al.*,[23] Türk *et al.*,[33] and Weber and Silva[17] agree well with the data of de Vries,[20] but their scatter is considerably larger, showing deviations larger than $\pm 0.05\%$ in many cases. Below 240 K, relative deviations of de Vries' data increase up to $+0.05\%$ at 223 K, but in terms of temperature, this corresponds to 10 mK which is only slightly larger than the reported uncertainty of temperature measurements and only a little larger than at higher temperatures. Generally, the scatter of data below 230 K becomes much larger compared to higher temperatures. Below 200 K experimental data become scarce. In this temperature range only values which were extrapolated from vapor pressures at higher temperatures are available. Unfortunately, the majority of those proved to be inconsistent with isochoric heat capacities and speed of sound values in the liquid phase during the data assessment. Therefore, an alternative approach was developed to support the vapor pressure curve at low temperatures.

The general idea was taken from the work of Tillner-Roth[32] who used a simple relation for the enthalpy of vaporization, namely the equation reported by Watson,[49]

$$\Delta h_v(T) = \Delta h_0 (1 - T/T_c)^n \tag{10}$$

to approximate the first derivative of the vapor pressure in the Clausius–Clapeyron equation

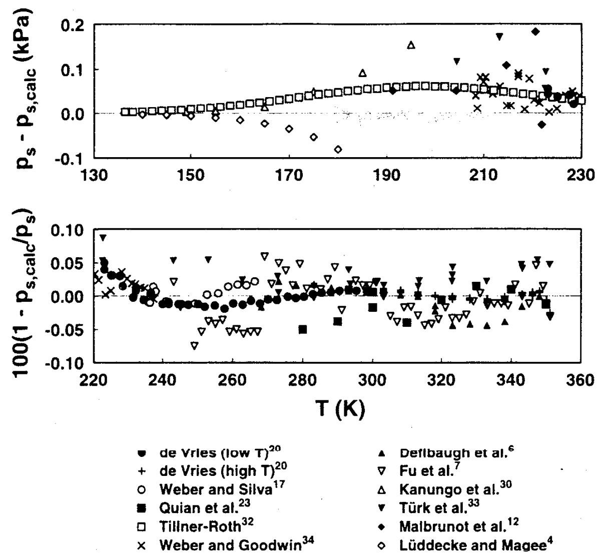

FIG. 4. Deviations between measured vapor pressures and values calculated from the new EOS.

$$\frac{dp_s}{dT} = \frac{\Delta h_v(T)/T}{v'' - v'}. \tag{11}$$

As shown by Svoboda and Basarova,[50] Eq. (10) can describe the enthalpy of vaporization very accurately (within 0.1% or better) for low temperatures. Thus, combined with accurate values for the saturation volumes v' and v'' the enthalpy of vaporization determines the slope of the vapor pressure curve.

In the present case, accurate liquid densities of Magee[22] are included during the optimization method. Given that at

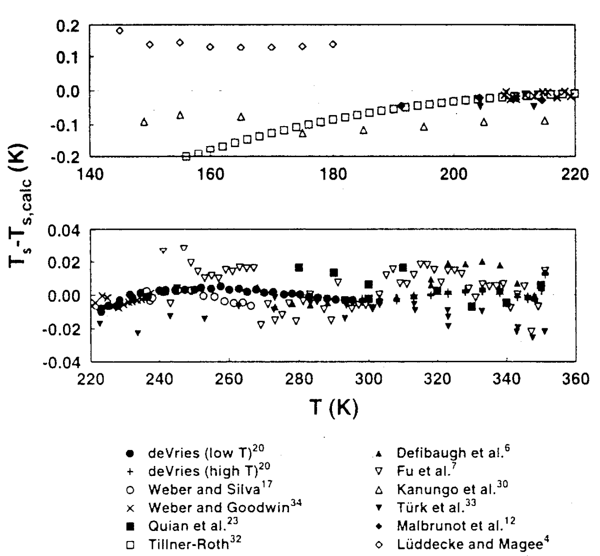

FIG. 5. Deviations between saturation temperatures and values calculated from the new EOS for given pressure.

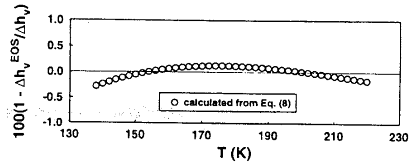

FIG. 6. Deviationes between the enthalpy of vaporization calculated from Watson's equation and the new EOS.

low temperatures density is not very sensitive to pressure it is supposed that the saturated liquid density $\varrho' = 1/v'$ is accurately determined from any interim equation of state which represents Magee's densities well. The saturated vapor volume v'' at low temperatures is essentially determined by the proximity of the ideal gas law. Since real gas corrections are also incorporated into the optimization by the use of low temperature (p,ϱ,T) data, v'' should also be calculated accurately during the optimization. This leaves the enthalpy of vaporization as the major factor influencing dp_s/dT and, thus, the shape of the vapor pressure curve at low temperatures. Therefore, a reasonable vapor pressure behavior of the equation is obtained when the enthalpy of vaporization is constrained to a meaningful model, for example the Watson relation according to Eq. (10).

From these considerations, the parameters of Eq. (10) were optimized simultaneously with the equation of state. The additional conditions which were included during the nonlinear process are essentially differences

$$(\Delta h_v^{\mathrm{WATSON}} - \Delta h_v^{\mathrm{EOS}})$$

between $\Delta h_v^{\mathrm{WATSON}}$ calculated from Eq. (10) and $\Delta h_v^{\mathrm{EOS}}$ from the equation of state currently under optimization. These differences were included for temperatures from the triple point (136.34 K) up to 230 K in steps of 2 K. It slightly overlaps the range of available experimental data in order to connect smoothly to existing vapor pressure data. The upper temperature limit is still far below the critical temperature and, therefore, the Watson relation, Eq. (10), is assumed to be still valid. Initial values for the parameters Δh_s and n were supplied to the optimization beforehand. These were subsequently optimized together with the parameters of the equation of state. The final parameter values for Eq. (10) are

$$\Delta h_s = 556.846\ \mathrm{kJ\,kg^{-1}} \quad \text{and} \quad n = 0.380\,595.$$

The value of n almost exactly matches the value of 0.38 originally recommended for Eq. (10) by Svoboda and Basarova.[50]

Comparisons between enthalpies of vaporization are shown in Fig. 6. Results from Watson's relation agree with results from the fundamental equation of state within 0.2%. The comparisons for the vapor pressure in Fig. 4 show that the vapor pressure calculated from the fundamental equation of state lies almost in between the predicted results of Tillner-Roth,[32] which exceed them by up to 50 Pa, and the calculated values of Lüddecke and Magee[4] which stay below them by about 100 Pa. It is worth mentioning, that the equation agrees well with the vapor pressures estimated by Kanungo *et al.*[30] at temperatures below 170 K. Temperature deviations (Fig. 5) show a different pattern. Data of Lüddecke and Magee[4] possess almost a constant temperature offset of +0.17 K, those of Kanungo *et al.*[30] of −0.1 K. Predicted results of Tillner-Roth[32] below 160 K show negative deviations which monotonously increase at lower temperatures.

An attempt to fit the equation of state to calculated vapor pressures either of Tillner-Roth[32] or of Lüddecke and Magee[4] led to increasing deviations for isochoric heat capacities, speed of sound, and (p,ϱ,T) data in the liquid. Thus, the available extrapolated values are not consistent with other measurements. The present method, however, achieves a reasonable vapor pressure behavior which is consistent with existing caloric and thermal properties and also follows a simple but proven function for the enthalpy of vaporization.

5.2. Densities at Saturation

Numerous sets for saturated liquid and vapor densities are reported in the literature, some of them extending nearly to the critical point. Deviations are shown in Fig. 7. In the liquid, deviation patterns often correspond to those observed for single-phase densities since some of them are the result of single-phase measurements extrapolated to the saturation boundary. Measurements of Magee,[22] Holcomb *et al.*,[10] and Defibaugh *et al.*[6] are represented within ±0.1% below 330 K. Other data agree with the present equation mostly within ±0.5%.

The saturated vapor densities of Defibaugh *et al.*[6] extend to low temperatures. They are represented within their uncertainty with a maximum deviation of 0.3% below 330 K. Large systematic deviations of up to several percent are observed for most other data, especially at low and high temperatures. Since (p,ϱ,T) data in the vapor phase are represented well, most of the reported saturated vapor densities seem to be inconsistent with the selected single-phase data.

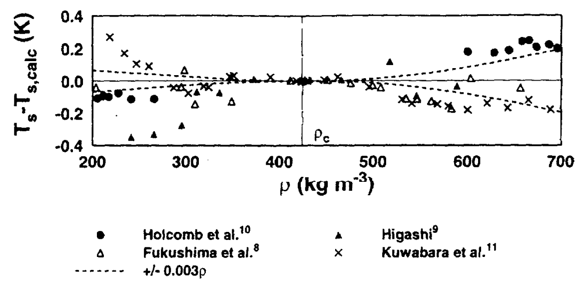

FIG. 8. Deviations between temperatures of measured saturation densities and saturation temperatures calculated from the new EOS at the given density.

Close to the critical point, the saturation densities change rapidly with temperature. Therefore, it is more convenient to compare saturation temperatures calculated at a given density. Such deviations are shown in Fig. 8 for the data which are located within 10 K of the critical temperature. Between $350\ \mathrm{kg\ m^{-3}}$ and $500\ \mathrm{kg\ m^{-3}}$, excellent agreement is observed for the results of Kuwabara *et al.*,[11] Fukushima *et al.*[8] and Higashi.[9] Temperature deviations from the equation of state are in the order of only a few mK. Outside this range, the scatter of data increases as well as the deviations of the calculated temperatures. Here, the data of Holcomb *et al.*[10] show temperature deviations of +0.2 K in the liquid and −0.1 K in the vapor. Compared to Fig. 7, this corresponds to a density deviation of a little more than +0.3%.

The excellent agreement of the saturation density data close to the critical point with values from the equation of state (EOS) indicates a reliable prediction of the critical point which can be calculated from the EOS, when solving the equation for the conditions

$$\left(\frac{\partial p}{\partial v}\right)_{T=T_c}=0 \quad \text{and} \quad \left(\frac{\partial^2 p}{\partial v^2}\right)_{T=T_c}=0. \qquad (12)$$

The calculated critical parameters are

$$T_c=351.255\ \mathrm{K}, \quad \varrho_c=424.00\ \mathrm{kg\ m^{-3}}, \quad p_c=5782.65\ \mathrm{kPa}.$$

Critical temperature and density are the same as chosen in Section 2.1, since the EOS has been constrained to these values. The critical pressure agrees within 0.023% with the value of 5784 kPa as recommended by Higashi.[5]

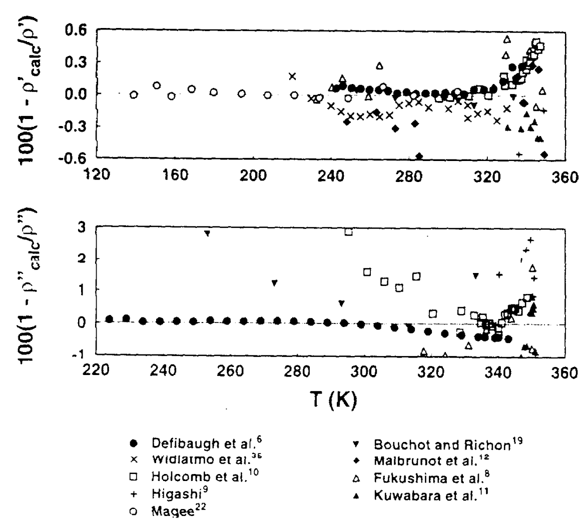

FIG. 7. Deviations between saturated liquid and vapor densities and values calculated from the new EOS.

5.3. Heat Capacities at Saturation

A set of isochoric heat capacities c_v in the two-phase region has been measured by Lüddecke and Magee.[4] From these measurements Lüddecke and Magee derived values for the saturated heat capacity c_σ. Both sets of data are compared with the equation of state in Fig. 9.

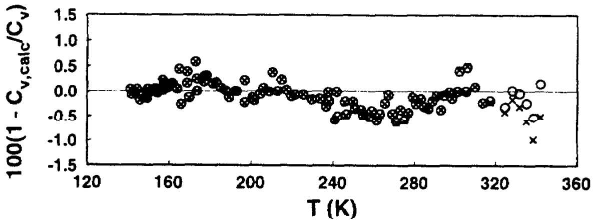

FIG. 9. Deviations between isochoric heat capacities in the two-phase region measured by Lüddecke and Magee (Ref. 4) and values calculated from the new EOS. (○) c_{σ}, (×) $\bar{c}_v$.

The data cover the entire temperature range from 140 K to 341 K. The $\bar{c}_v$ data are represented by the EOS within $\pm 0.6\%$ which corresponds to the experimental uncertainty. The derived c_{σ} values deviate up to 1.2%, especially at high temperatures. These increasing deviations are attributed to higher uncertainties of properties which are required to transform the two-phase heat capacities $\bar{c}_v$ into c_{σ} values. However, the overall excellent agreement shows high consistency with selected experimental data of other thermodynamic properties, such as vapor pressure, (p,ϱ,T) data in the liquid and vapor, or speed of sound values in the liquid which also involves the ideal-gas heat capacity.

5.4. Properties in the Liquid Phase

The liquid phase is well defined by numerous (p,ϱ,T) measurements. Additionally, isochoric heat capacities measured by Lüddecke and Magee,[4] speed of sound data reported by Grebenkov *et al.*[24] and by Takagi,[26] and isobaric heat capacities measured by Yomo *et al.*[27] are available.

Density deviations for selected data sets are shown in Fig. 10. The data of Magee[22] and of de Vries,[20] to which the EOS has been fitted, are represented within $\pm 0.05\%$ by the EOS over the whole range of temperatures and pressures. A slight systematic offset of about 0.04% is observed around 260 K for two isochoric series of Magee.[22] The EOS also agrees very well with the densities of Bouchot and Richon[19] and with most of the data measured by Defibaugh *et al.*[6] although the latter show increasing deviations for temperatures above 320 K and pressures close to the vapor pressure. Experimental data of Holste *et al.*[21] show a negative offset of about 0.15% on average. This systematic offset remains almost constant for pressures up to 70 MPa, where no other experimental data exist. Therefore, it is assumed that the equation of state extrapolates well above 30 MPa (the highest pressures of Magee's data), at least up to 70 MPa.

A sensible test for the accuracy of the derivatives $(\partial p/\partial T)_v$ and $(\partial p/\partial v)_T$ is the representation of speed of sound in the liquid. Two sets of data are available in a limited range of temperature but reaching up to 33 MPa. Deviations are shown in Fig. 11. Results of Grebenkov *et al.*[24] are represented within $\pm 0.3\%$. The data of Takagi[26] are generally represented within $\pm 0.6\%$ except those at 330 K and 375 K which show systematic deviations of $+1\%$ or more. The highest deviations occur around 5 MPa close to the critical pressure. Most of these deviations correspond to the experimental errors of measurements, thus showing good consistency to selected (p,ϱ,T) values.

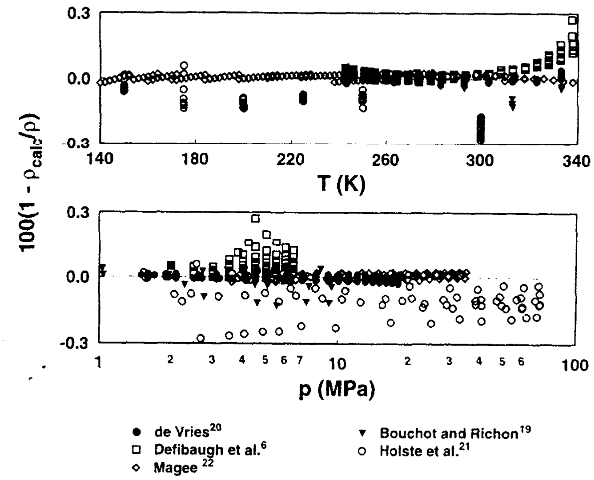

FIG. 10. Deviations between measured liquid densities and values calculated from the new EOS.

Deviations for the liquid isochoric heat capacities of Lüddecke and Magee[4] are shown in Fig. 12. The data are represented with a maximum deviation of $+0.8\%$ similar to the results of Lüddecke and Magee[4] for the heat capacities at saturation. Isobaric heat capacities measured by Yomo *et al.*[27] are also included in this figure. They show a negative offset of about 1%–1.5% as compared to the isochoric heat capacities of Lüddecke and Magee and also from the equation of state. Since densities, isochoric heat capacities and speed of sound are represented well by the current equation,

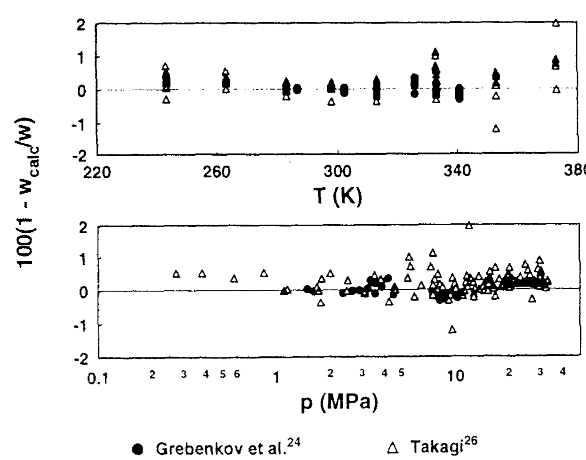

FIG. 11. Deviations between speed of sound data and values calculated from the new EOS.

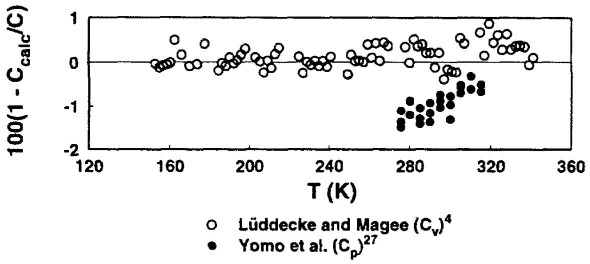

FIG. 12. Deviations between isochoric and isobaric heat capacities and values calculated from the new EOS.

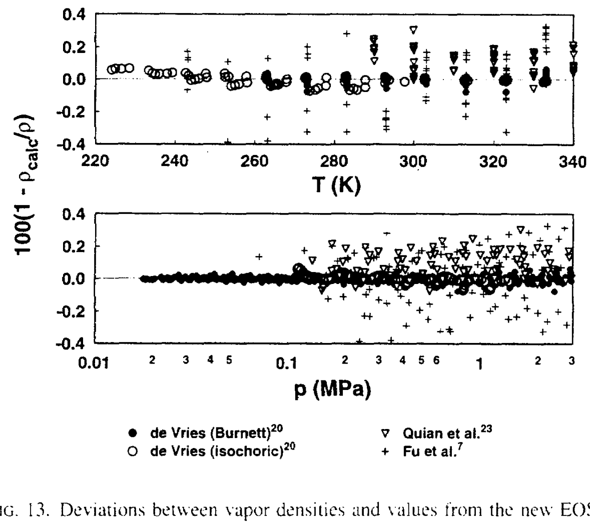

FIG. 13. Deviations between vapor densities and values from the new EOS for temperatures below 340 K and pressures below 3 MPa.

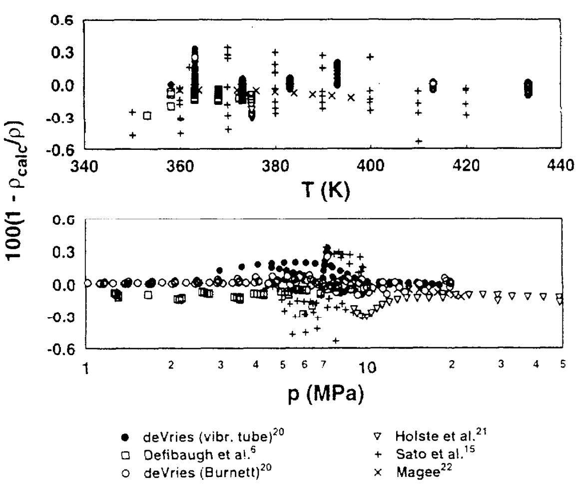

FIG. 14. Deviations between densities in the vapor and supercritical region and values from the new EOS.

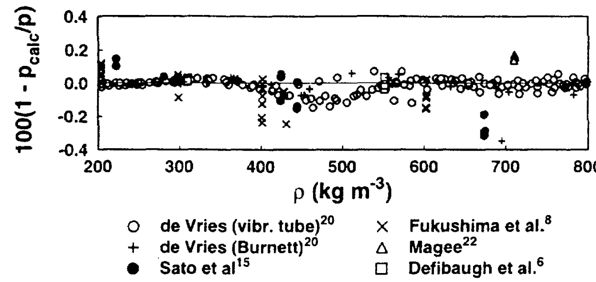

FIG. 15. Pressure deviations between (p,ϱ,T) data between 350 K and 370 K and values from the new EOS.

Yomo's data are most likely not consistent to these data and probably contain some experimental error.

5.5. Properties in the Vapor Phase

The majority of measurements in the vapor and supercritical range are (p,ϱ,T) data. Only a single set of speed of sound data at low pressures is available over a limited temperature range. Density deviations are shown in Fig. 13 for (p,ϱ,T) data below 3 MPa, and in Fig. 14 for temperatures above 350 K. Figure 15 shows pressure deviations for near-critical temperatures at densities between 200 and 800 kg m^{-3}.

In the vapor below the critical density and temperatures above 263 K, the EOS is based on the results of de Vries[20] measured with the Burnett method. De Vries[20] also reports a set of isochoric (p,ϱ,T) measurements which reaches down to 223 K. The data from both series smoothly connect to each other and are represented well within ±0.1% of density. The scatter of other data, such as those of Fu *et al.*[7] or those of Quian *et al.*,[23] for example, is much larger, reaching up to 0.3%. Therefore, these data were not used, although they agree well with the results of de Vries on average.

The same good representation of de Vries's data is observed for temperatures above 350 K, Fig. 14. Deviations

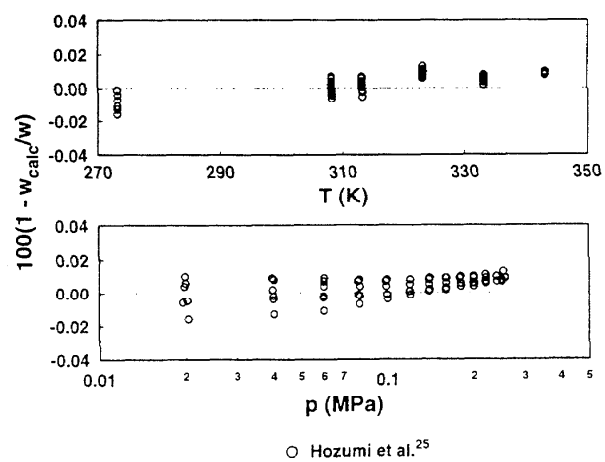

FIG. 16. Deviations between speed of sound data in the vapor and values from the new EOS.

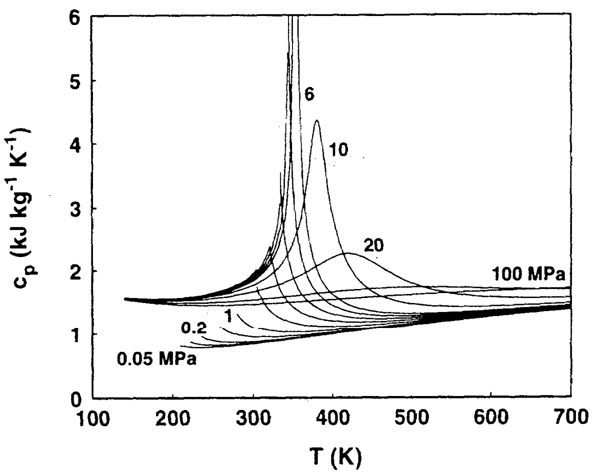

FIG. 17. Isobaric heat capacity c_p as calculated from the new fundamental EOS.

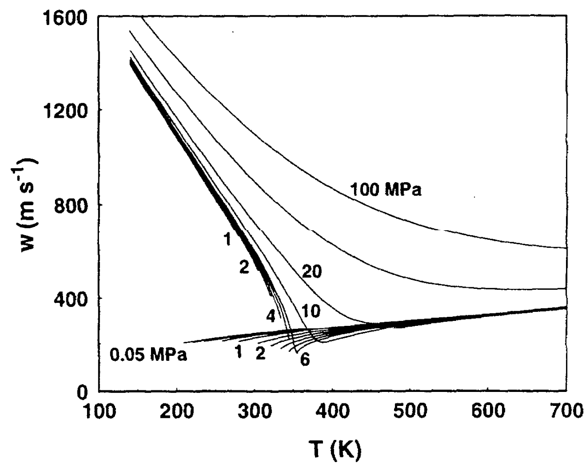

FIG. 19. Speed of sound w as calculated from the new fundamental EOS.

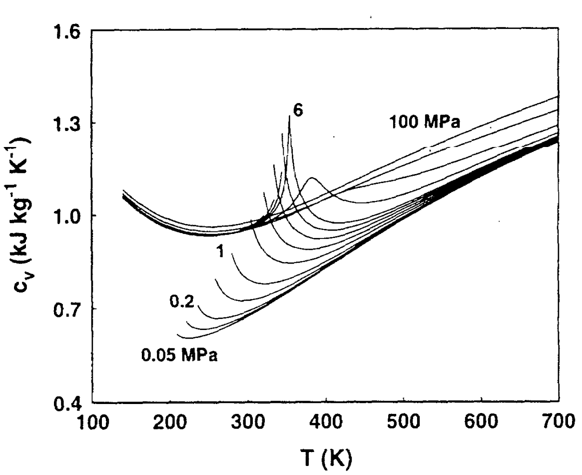

FIG. 18. Isochoric heat capacity c_v as calculated from the new fundamental EOS.

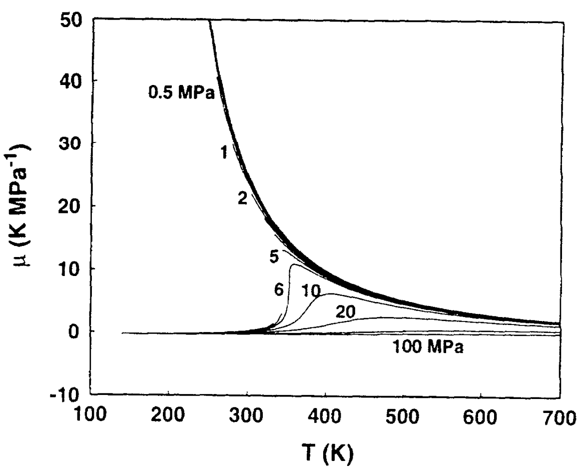

FIG. 20. Joule–Thomson coefficient μ as calculated from the new fundamental EOS.

increase up to 0.4% around the critical pressure. Here the isotherms are very flat and these density deviations correspond to pressure deviations that are 5–10 times smaller. Remarkable agreement between both sets of de Vries' measurements (Burnett and vibrating tube) is observed in the range between 5 and 15 MPa where both sets of data overlap. Densities measured by Holste *et al.*[21] are about 0.2% lower as already observed in the liquid phase. Results of Defibaugh *et al.*[6] are about 0.1% lower than the results of de Vries. The only set of data above 400 K has been measured by Sato *et al.*[15] Their results show a larger scatter of up to 0.4% but generally agree with the data of de Vries.[20] No experimental data are available for temperatures above 440 K.

For temperatures close to the critical temperature (between 350 K and 370 K), pressure deviations are plotted over density in Fig. 15. The results of de Vries[20] are represented within ±0.1% and show small systematic deviations around the critical density, which is at 424 kg m^{-3}. This small deviation may be related to small inconsistencies between (p,ϱ,T) data, vapor pressures and saturated liquid heat capacities, but they may also be due to the fact that this analytical equation of state cannot represent the nonclassical behavior close to the critical point. Most of the data in this region measured by Sato *et al.*,[15] Fukushima *et al.*,[5] Defibaugh *et al.*[6] and Magee[22] generally agree with the results of de Vries within ±0.3% in pressure although some of the data fall far beyond the range of Fig. 15.

Deviations for the speed of sound values measured by Hozumi *et al.*[25] are shown in Fig. 16. Since these data were also used as input data, the representation is within ±0.012% which is only slightly larger than the experimental error.

Although the (p,ϱ,T) behavior of gaseous R-32 is well represented by the EOS, it should be noted that almost no caloric information is available in the vapor. Measurements of speed of sound, heat capacities or other caloric properties in the vapor would be highly desirable to validate the accuracy of the equation of state.

5.6. Behavior of Derived Properties

The general behavior of EOS is often discussed by analyzing plots of properties which are related to higher order derivatives of the EOS. For this purpose, the shapes of the isobaric and isochoric heat capacity c_p and c_v, speed of sound w, and the Joule–Thomson coefficient μ have been calculated along isobars between 0.05 MPa and 100 MPa as functions of temperature. Only a few isobars are labelled in Figs. 17–20. For completeness, the isobars shown are at 0.05, 0.1, 0.2, 0.5, 1, 2, 3, 4, 5, 6, 10, 20, 50, and 100 MPa. Although the EOS is only valid up to 435 K, the property plots extend to 700 K in order to investigate the extrapolation behavior of the EOS.

The isobaric and isochoric heat capacities show a very smooth curvature in the liquid at low temperatures as well as at temperatures above 435 K. In the vapor below p_c, both c_p and c_v show a pronounced upturn towards the saturation boundary. This upturn is typically observed for polar fluids, for example it is also seen for methanol.[51] It should also be noted that the isochoric heat capacity in liquid R-32 exhibits an unusual but experimentally determined (Lüddecke and Magee[4]) minimum.

A smooth behavior is also observed for the speed of sound and for the Joule–Thomson coefficient. In particular, the speed of sound in the liquid at low temperatures shows a smooth behavior without any crossing of isobars although no experimental data were available. Isobars for the Joule–Thomson coefficient also show a very regular pattern. In the vapor, the isobars converge for decreasing pressure towards a limiting boundary. The liquid-phase Joule–Thomson coefficient changes sign around 275 K to 290 K depending slightly on pressure.

6. Conclusion

An equation of state for difluoromethane (R 32) has been developed which is based on measurements between the triple point to 435 K and pressure up to 35 MPa. Comparisons with experimental data show that reliable results are obtained when the equation is extrapolated up to 70 MPa. Furthermore, derived properties such as c_p, c_v, w, and μ show reasonable behavior when extrapolated to higher temperatures. The good extrapolation behavior is mainly due to the improved values for the isobaric heat capacity c_p° of the ideal gas, which have been calculated from spectroscopic data taking into account first order anharmonicity corrections. Uncertainties of properties calculated from the EOS mostly correspond to errors of experimental input data for all kinds of thermodynamic properties.

Although the EOS already well represents all parts of the thermodynamic surface, it should be mentioned that there is still a lack of data. In particular, vapor pressure data at temperatures below 200 K and measurements of caloric properties in the vapor at pressures above 0.5 MPa would be highly desirable to verify the reliability of the EOS.

7. Acknowledgments

The authors thank all participants of the IEA Annex 18 in particular for providing experimental data prior to publication. Further thanks go to E. W. Lemmon and M. O. McLinden, NIST, Boulder for helpful remarks during the preparation of the manuscript.

8. Appendix A: The Helmholtz Free Energy Equation of State of Difluoromethane (R-32)

Reduced Helmholtz free energy:

$$\Phi = \frac{a}{RT} = \Phi^\circ(\tau,\delta) + \Phi^r(\tau,\delta) \tag{A1}$$

Ideal-gas part:

$$\Phi^\circ = \ln\delta + a_0^\circ + a_1^\circ\tau + a_2^\circ \ln\tau + \sum_{i=3}^{6} a_i^\circ \ln[1-\exp(-n_i\tau)] \tag{A2}$$

Residual part:

$$\Phi^r = \sum_{i=1}^{8} a_i\delta^{d_i}\tau^{t_i} + \sum_{i=9}^{19} a_i\delta^{d_i}\tau^{t_i}\exp(-\delta^{l_i}) \tag{A3}$$

Reduced variables:

$$\delta = \frac{\varrho}{\varrho_c}, \quad \tau = \frac{T_c}{T} \tag{A4}$$

Constants:[a]

$M = 0.052\,024$ kg mol^{-1} $R_m = 8.314\,471$ J mol^{-1} K^{-1}
$T_{tr} = 136.34$ K

$\varrho_c = 424$ kg m^{-3} $T_c = 351.255$ K $p_c = 5.782$ MPa

Reference state:

$T_0 = 273.15$ K, $s'(T_0) = 1$ kJ kg^{-1} K^{-1},

$h'(T_0) = 200$ kJ kg^{-1}

Range of validity:

$0 < p < 70$ MPa, $136.34\ \text{K} < T < 435$ K

[a]The chosen value for the gas constant differs slightly from the internationally agreed CODATA[52] value $R_m = 8.31451$ J mol^{-1} K^{-1}. When usage of the international value is needed, the coefficients a_i° and a_i listed in Table 8 should be multiplied with the ratio 8.314471/8.31451. However, the results will be different from values calculated by the original formulation by some ppm.

TABLE 8. Coefficients and exponents for Eqs. (A2) and (A3)

		Ideal-gas part		
i	a_i^0	i	a_i^0	n_i
0	−8.258 096	3	1.160 761	2.271 853 8
1	6.353 098	4	2.645 151	11.914 421 0
2	3.004 486	5	5.794 987	5.141 563 8
		6	1.129 475	32.768 217 0

			Residual part						
i	a_i	e_i	t_i	d_i	i	a_i	e_i	t_i	d_i
1	$0.104\,663\,4\times10^{-1}$	-	1/4	1	11	$0.478\,202\,5\times10^{-3}$	1	−1	8
2	−0.545 116 5	-	1	2	12	$-0.550\,432\,3\times10^{-2}$	4	25	3
3	$-0.244\,859\,5\times10^{-2}$	-	−1/4	5	13	$-0.241\,839\,6\times10^{-1}$	1	7/4	5
4	$-0.487\,700\,2\times10^{-1}$	-	−1	1	14	0.420 903 4	2	4	1
5	$0.352\,015\,8\times10^{-1}$	-	2	1	15	−0.461 653 7	2	5	1
6	$0.162\,275\,0\times10^{-2}$	-	2	3	16	$-0.120\,051\,3\times10^{-1}$	1	1	3
7	$0.237\,722\,5\times10^{-4}$	-	3/4	8	17	$-0.259\,155\,0\times10^{+1}$	1	3/2	1
8	$0.291\,49\times10^{-1}$	-	1/4	4	18	$-0.140\,014\,5\times10^{+1}$	1	1	2
9	$0.338\,620\,3\times10^{-2}$	4	18	4	19	0.826 301 7	1	1/2	3
10	$-0.420\,244\,4\times10^{-2}$	3	26	4					

TABLE 9. Relations between the reduced Helmholtz free energy and thermodynamic properties

Property	Relation
Pressure	$p(\tau,\delta) = RT\varrho(1+\delta\Phi^r_\delta)$
Internal energy	$\frac{u(\tau,\delta)}{RT} = \tau(\Phi^0_\tau+\Phi^r_\tau)$
Enthalpy	$\frac{h(\tau,\delta)}{RT} = 1+\tau(\Phi^0_\tau+\Phi^r_\tau)+\delta\Phi^r_\delta$
Entropy	$\frac{s(\tau,\delta)}{R} = \tau(\Phi^0_\tau+\Phi^r_\tau)-\Phi^0-\Phi^r$
Gibbs energy	$\frac{g(\tau,\delta)}{RT} = 1+\delta\Phi^r_\delta+\Phi^0+\Phi^r$
Isochoric heat capacity	$\frac{c_v(\tau,\delta)}{R} = -\tau^2(\Phi^0_{\tau\tau}+\Phi^r_{\tau\tau})$
Isobaric heat capacity	$\frac{c_p(\tau,\delta)}{R} = (c_v/R)+\frac{(1+\delta\Phi^r_\delta-\delta\tau\Phi^r_{\delta\tau})^2}{1+2\delta\Phi^r_\delta+\delta^2\Phi^r_{\delta\delta}}$
Speed of sound	$\frac{w^2(\tau,\delta)}{RT} = 1+2\delta\Phi^r_\delta+\delta^2\Phi^r_{\delta\delta}-\frac{(1+\delta\Phi^r_\delta-\delta\tau\Phi^r_{\delta\tau})^2}{(c_v/R)}$
Joule–Thomson coefficient	$\mu(\tau,\delta)R\varrho_c = \frac{-(\Phi^r_\delta+\delta\Phi^r_{\delta\delta}+\tau\Phi^r_{\delta\tau})}{(1+\delta\Phi^r_\delta-\delta\tau\Phi^r_{\delta\tau})^2-(c_v/R)(1+2\delta\Phi^r_\delta+\delta^2\Phi^r_{\delta\delta})}$
Second virial coefficient	$B(\tau)\varrho_c = \lim_{\delta\to0}\Phi^r_\delta(\tau,\delta)$
Third virial coefficient	$C(\tau)\varrho_c^2 = \lim_{\delta\to0}\Phi^r_{\delta\delta}(\tau,\delta)$

Abbreviations:

$$\Phi_\delta=\frac{\partial\Phi}{\partial\delta},\quad \Phi_\tau=\frac{\partial\Phi}{\partial\tau},\quad \Phi_{\delta\delta}=\frac{\partial^2\Phi}{\partial\delta^2},\quad \Phi_{\delta\tau}=\frac{\partial^2\Phi}{\partial\delta\,\partial\tau},\quad \Phi_{\tau\tau}=\frac{\partial^2\Phi}{\partial\tau^2}$$

A.1. Derivatives of the Fundamental Equation of State

First order derivatives:

$$\Phi^{\circ}_{\delta}=1/\delta \tag{A5}$$

$$\Phi^{\circ}_{\tau}=a^{\circ}_{1}+\frac{a^{\circ}_{2}}{\tau}+\sum_{i=3}^{6} a^{\circ}_{i}\frac{n_i}{\exp(n_i\tau)-1} \tag{A6}$$

$$\Phi^{r}_{\delta}=\sum_{i=1}^{8} a_i d_i \delta^{d_i-1}\tau^{t_i}+\sum_{i=9}^{19} a_i \exp(-\delta^{e_i})(d_i-e_i\delta^{e_i})\delta^{d_i-1}\tau^{t_i} \tag{A7}$$

$$\Phi^{r}_{\tau}=\sum_{i=1}^{8} a_i t_i \delta^{d_i}\tau^{t_i-1}+\sum_{i=9}^{19} a_i t_i \exp(-\delta^{e_i})\delta^{d_i}\tau^{t_i-1}. \tag{A8}$$

Second order derivatives:

$$\Phi^{\circ}_{\delta\delta}=-1/\delta^2 \tag{A9}$$

$$\Phi^{\circ}_{\tau\tau}=-\frac{a^{\circ}_{2}}{\tau^2}-\sum_{i=3}^{6} a^{\circ}_{i}\frac{n_i^2 \exp(-n_i\tau)}{[1-\exp(-n_i\tau)]^2} \tag{A10}$$

$$\Phi^{\circ}_{\tau\delta}=0 \tag{A11}$$

$$\Phi^{r}_{\delta\delta}=\sum_{i=1}^{8} a_i d_i(d_i-1)\delta^{d_i-2}\tau^{t_i}+\sum_{i=9}^{19} a_i \exp(-\delta^{e_i}) \tag{A12}$$

$$\times[d_i^2-d_i-e_i\delta^{e_i}(2d_i+e_i-1+e_i\delta^{e_i})]\delta^{d_i-2}\tau^{t_i} \tag{A13}$$

$$\Phi^{r}_{\tau\tau}=\sum_{i=1}^{8} a_i t_i(t_i-1)\delta^{d_i}\tau^{t_i-2}+\sum_{i=9}^{19} a_i t_i(t_i-1)\times\exp(-\delta^{e_i})\delta^{d_i}\tau^{t_i-2} \tag{A14}$$

$$\Phi^{r}_{\tau\delta}=\sum_{i=1}^{8} a_i d_i t_i \delta^{d_i-1}\tau^{t_i-1}+\sum_{i=9}^{19} a_i t_i(d_i-e_i\delta^{e_i})\times\exp(-\delta^{e_i})\delta^{d_i-1}\tau^{t_i-1}. \tag{A15}$$

A.2. Ancillary Equations

The following equations may be used to calculate values for the vapor pressure, saturated liquid density and saturated vapor density when required as initial values for the calculation of saturation properties from the fundamental equation of state. The vapor pressure is represented by

$$\vartheta \ln\frac{p_s}{p_c}=-7.448\,92\theta-1.6886\theta^{3/2}-1.908\theta^{5/2}-2.810\theta^{5}, \tag{A16}$$

where $\vartheta=T/T_c$, $T_c=351.255$ K, $\theta=1-\vartheta$ and $p_c=5.781\,16$ MPa. It agrees with vapor pressures calculated from the fundamental equation of state to within ± 5 Pa or 0.04% whichever is greater and is valid from the triple poin to the critical temperature.

The equation for the saturated liquid density is given by:

$$\frac{\varrho'}{\text{kg m}^{-3}}=424.0+434.55\theta^{1/4}+1296.53\theta^{2/3}-777.49\theta+366.84\theta^{5/3} \tag{A17}$$

using the same definition for θ as above. It is valid from temperatures from the triple point to 350 K and agrees with values from the fundamental EOS to within $\pm 0.05\%$.

The equation for the saturated vapor density is given by:

$$\ln\frac{\varrho''}{\varrho_c}=-1.969\theta^{1/3}-2.0222\theta^{2/3}-6.7409\theta^{4/3}-27.479\theta^{11/3}, \tag{A18}$$

where $\varrho_c=424$ kg m^{-3} and θ as given above. It is valid from 220 K to 350 K and agrees with values from the fundamental EOS to within $\pm 0.1\%$. For lower temperatures, it is recommended to calculate initial values for ϱ'' from the ideal gas law $\varrho''=RT/p_s$ using P_s as calculated from the vapor pressure equation.

9. Appendix B: Deviation Statistics of Available Experimental Data

For a quick asessment, percentage deviation statistics have been calculated for each available data set. The following statistics are listed in Tables 10 and 11:

- Absolute average deviation:

$$\text{AAD}=\frac{100}{N}\sum_{i=1}^{N}|(y^{\text{meas}}-y^{\text{calc}})/y^{\text{meas}}|_i, \tag{B1}$$

- Bias deviation, which is a measure of systematic offsets:

$$\text{BIAS}=\frac{100}{N}\sum_{i=1}^{N}[(y^{\text{meas}}-y^{\text{calc}})/y^{\text{meas}}]_i, \tag{B2}$$

- Root mean square error:

$$\text{RMS}=100\sqrt{\frac{1}{N}\sum_{i=1}^{N}[(y^{\text{meas}}-y^{\text{calc}})/y^{\text{meas}}]_i^2}, \tag{B3}$$

- the maximum deviation MAXDEV,
- the number of data (NOUT) with a deviation of more than 10%.

TABLE 10. Deviation statistics of measurements in the single-phase region

Source	Year		N	AAD	BIAS	RMS	MAXDEV	NOUT
			(p,ϱ,T) measurements $(y=\varrho)$					
Bouchot & Richon[19]	1994	v	15	2.010	1.659	2.965	6.249	0
Bouchot & Richon[19]	1994	l	21	0.048	−0.029	0.062	−0.129	0
Defibaugh *et al.*[6][a]	1994	v	146	0.089	−0.012	0.110	0.317	0
Defibaugh *et al.*[6][b]	1994	v	21	0.087	−0.087	0.093	−0.139	0
Defibaugh *et al.*[6][c]	1994	l	219	0.146	0.146	0.539	5.911	2
*de Vries[20][b]	1995	v	565	0.032	0.005	0.143	1.752	0
*de Vries[20][c]	1995	v	490	0.071	0.043	0.248	2.871	0
*de Vries[20][a]	1995	v	94	0.020	−0.001	0.028	−0.069	0
Fu *et al.*[7]	1995	v	121	0.186	−0.026	0.236	−0.747	0
Fukushima *et al.*[8]	1995	v	158	1.077	0.235	1.625	7.177	3
*Holste *et al.*[21]	1993	l	126	0.125	−0.118	0.164	−0.910	0
Lüddecke & Magee[4]	1996	l	74	0.056	−0.021	0.071	−0.155	0
*Magee[22]	1996	l	137	0.018	−0.001	0.026	−0.123	0
Malbrunot *et al.*[12]	1968	v	86	1.431	−0.982	1.881	−6.076	1
Malbrunot *et al.*[12]	1968	l	64	0.176	−0.158	0.221	−1.001	0
Quian *et al.*[23]	1993	v	95	0.100	0.078	0.125	−0.386	0
Sato *et al.*[15]	1994	v	69	0.254	−0.095	0.581	−4.232	4
			Speed of sound $(y=w)$					
*Grebenkov[24]	1994	l	30	0.132	−0.080	0.158	0.321	0
*Hozumi *et al.*[25]	1994	v	67	0.006	0.004	0.007	−0.015	0
*Takagi[26]	1993	l	120	0.295	0.228	0.400	1.987	0
			Isobaric heat capacity $(y=c_p)$					
Yomo *et al.*[27]	1994	l	26	0.937	−0.937	0.990	−1.491	0
			Isochoric heat capacity $(y=c_v)$					
*Lüddecke & Magee[4]	1996	l	73	0.223	0.137	0.287	0.858	0

[a]Isochoric cell.
[b]Burnett measurement.
[c]Vibrating tube densimeter.
*Selected in fitting of EOS.

TABLE 11. Deviation statistics of measurements of saturation properties

Source	Year	N	AAD	BIAS	RMS	MAXDEV	N
			Vapor pressure ($y=p_s$)				
Adams & Stein[29]	1971	4	0.379	0.379	0.400	0.522	
Bouchot & Richon[19]	1994	8	0.200	0.158	0.252	0.457	
Defibaugh *et al.*[6]	1994	18	0.018	−0.008	0.023	−0.044	
*de Vries (low T)[20]	1995	33	0.012	0.001	0.016	0.050	
*de Vries (high T)[20]	1995	106	0.006	−0.001	0.008	−0.029	
Fu *et al.*[7]	1995	60	0.043	−0.026	0.066	−0.232	
Fukushima *et al.*[8]	1995	57	0.098	−0.086	0.146	−0.526	
Holcomb *et al.*[10]	1993	25	0.116	0.099	0.183	0.599	
Kanungo *et al.*[30]	1987	11	0.705	0.705	0.748	1.143	
Lüddecke & Magee[4]	1996	9	1.738	−1.738	1.850	−3.130	
Magee[22]	1996	7	0.094	−0.094	0.096	−0.116	
Malbrunot *et al.*[12]	1968	30	0.239	0.029	0.281	0.628	
Omata *et al.*[31]	1994	10	0.147	0.147	0.246	0.727	
Qian *et al.*[23]	1993	9	0.022	−0.015	0.027	−0.050	
Sato *et al.*[15]	1994	23	0.025	0.022	0.044	0.155	
Tillner-Roth[32 a]	1996	49	1.233	1.233	1.915	5.325	
Türk *et al.*[33]	1994	26	0.064	0.064	0.101	0.296	(
*Weber & Goodwin[34]	1993	27	0.051	0.051	0.069	0.155	(
*Weber & Silva[17]	1994	17	0.021	0.015	0.049	0.198	(
Widiatmo *et al.*[35]	1994	25	0.364	−0.249	0.557	−1.253	(
Zhu *et al.*[36]	1993	31	0.239	0.038	0.283	0.575	(
			Saturated liquid density ($y=\varrho'$)				
Bouchot & Richon[19]	1994	5	0.038	−0.015	0.046	−0.087	0
Defibaugh *et al.*[6]	1994	21	0.069	0.069	0.098	0.267	0
*Fukushima *et al.*[8]	1995	10	0.762	−0.355	0.896	2.034	0
Fukushima *et al.*[8]	1995	5	0.112	0.091	0.149	0.282	0
Fukushima *et al.*[8]	1995	6	0.607	0.607	0.731	1.333	0
*Higashi[9]	1994	8	0.950	0.516	1.137	2.001	2
Holcomb *et al.*[10]	1993	25	0.228	0.226	0.290	0.664	0
*Kuwabara *et al.*[11]	1995	17	1.004	0.057	1.628	5.226	2
Magee[22]	1996	13	0.028	0.014	0.038	0.079	0
Malbrunot *et al.*[12]	1968	15	0.251	−0.043	0.309	0.623	0
Shinsaka *et al.*[37]	1985	19	1.023	−1.023	1.024	−1.124	0
Widiatmo *et al.*[35]	1994	22	0.130	−0.115	0.143	−0.230	0
			Saturated vapor density ($y=\varrho''$)				
Bouchot and Richon[19]	1994	5	1.238	1.203	1.544	2.801	0
Defibaugh *et al.*[6]	1994	28	0.145	−0.078	0.197	−0.420	0
*Fukushima *et al.*[8]	1995	5	1.673	1.673	2.001	3.010	2
Fukushima *et al.*[8]	1995	8	0.987	−0.938	1.327	−3.154	0
*Higashi[9]	1994	9	2.372	2.139	2.770	4.983	0
Holcomb *et al.*[10]	1993	25	0.576	0.522	0.863	2.893	0
*Kuwabara *et al.*[11]	1995	13	0.988	−0.062	1.211	2.994	2
			Saturated liquid heat capacity ($y=c_\sigma$)				
Lüddecke and Magee[4]	1996	101	0.222	−0.101	0.295	−0.990	0
			Two-phase isochoric heat capacity ($y=\bar{c}_v$)				
*Lüddecke and Magee[4]	1996	101	0.202	−0.078	0.264	−0.610	0

[a]Calculated.
*Selected in fitting of EOS.

10. Appendix C: Thermodynamic Property Tables of Difluoromethane (R-32)

Tables of thermodynamic properties have been calculated from the new fundamental equation of state. Saturation properties are listed in two sets of tables as functions of temperature and as functions of pressure. Density, enthalpy, and entropy are listed between -80 °C and 160 °C along isobars between 10 kPa and 50 MPa. Separate tables are provided for isobaric and isochoric heat capacities as well as for speed of sound as functions of temperature and pressure between -80 °C and 160 °C and pressure up to 50 MPa.

The intervals between all table entries have been chosen in order to minimize interpolation errors. However, interpolation should be avoided in the critical region, i.e., between 345 K and 355 K and pressures between 5 MPa and 6 MPa because of the extreme shape of the thermodynamic surface and also because of the higher uncertainty of the equation of state in this region.

TABLE 12. Saturation properties as functions of temperature

t, °C	p kPa	ϱ' kg m^{-3}	ϱ'' kg m^{-3}	h' kJ kg^{-1}	Δh_v kJ kg^{-1}	h'' kJ kg^{-1}	s' kJ kg^{-1} K^{-1}	s'' kJ kg^{-1} K^{-1}	c_p' kJ kg^{-1} K^{-1}	c_p'' kJ kg^{-1} K^{-1}
−136.81[a]	0.05	1429.3	0.0022	−19.07	463.38	444.31	−0.104	3.2937	1.593	0.660
−136	0.05	1427.3	0.0025	−17.78	462.62	444.84	−0.095	3.2776	1.591	0.660
−134	0.07	1422.4	0.0033	−14.60	460.75	446.15	−0.072	3.2387	1.589	0.662
−132	0.10	1417.6	0.0044	−11.42	458.89	447.46	−0.049	3.2012	1.586	0.663
−130	0.13	1412.7	0.0057	−8.26	457.03	448.78	−0.027	3.1651	1.584	0.665
−128	0.17	1407.9	0.0075	−5.09	455.18	450.09	−0.005	3.1303	1.581	0.666
−126	0.23	1403.0	0.0096	−1.93	453.33	451.40	0.0160	3.0968	1.579	0.668
−124	0.29	1398.1	0.0123	1.22	451.49	452.71	0.0373	3.0644	1.577	0.670
−122	0.37	1393.2	0.0155	4.38	449.65	454.02	0.0583	3.0332	1.575	0.672
−120	0.48	1388.4	0.0195	7.52	447.81	455.33	0.0790	3.0030	1.573	0.674
−118	0.60	1383.5	0.0244	10.67	445.98	456.64	0.0994	2.9739	1.571	0.676
−116	0.76	1378.6	0.0303	13.81	444.15	457.95	0.1195	2.9458	1.569	0.678
−114	0.95	1373.7	0.0374	16.94	442.32	459.26	0.1393	2.9186	1.567	0.681
−112	1.18	1368.7	0.0458	20.08	440.49	460.56	0.1589	2.8923	1.566	0.683
−110	1.45	1363.8	0.0559	23.21	438.66	461.86	0.1782	2.8669	1.565	0.686
−108	1.78	1358.9	0.0677	26.34	436.82	463.16	0.1973	2.8423	1.563	0.689
−106	2.17	1353.9	0.0816	29.46	434.99	464.45	0.2161	2.8185	1.562	0.692
−104	2.63	1349.0	0.0978	32.59	433.16	465.74	0.2347	2.7954	1.561	0.696
−102	3.18	1344.0	0.1166	35.71	431.32	467.03	0.2530	2.7731	1.561	0.699
−100	3.81	1339.0	0.1385	38.83	429.48	468.31	0.2711	2.7515	1.560	0.703
−98	4.55	1334.0	0.1636	41.95	427.63	469.58	0.2890	2.7306	1.559	0.707
−96	5.42	1329.0	0.1925	45.07	425.78	470.85	0.3067	2.7103	1.559	0.711
−94	6.41	1324.0	0.2255	48.19	423.93	472.11	0.3242	2.6906	1.559	0.716
−92	7.56	1319.0	0.2630	51.30	422.07	473.37	0.3415	2.6715	1.559	0.720
−90	8.87	1313.9	0.3056	54.42	420.20	474.62	0.3587	2.6529	1.559	0.725
−88	10.37	1308.8	0.3538	57.54	418.32	475.86	0.3756	2.6349	1.559	0.731
−86	12.07	1303.8	0.4080	60.66	416.43	477.09	0.3923	2.6174	1.559	0.736
−84	14.01	1298.7	0.4688	63.78	414.53	478.31	0.4089	2.6005	1.559	0.742
−82	16.19	1293.5	0.5369	66.90	412.63	479.52	0.4253	2.5839	1.560	0.748
−80	18.65	1288.4	0.6129	70.02	410.71	480.73	0.4415	2.5679	1.561	0.754
−78	21.42	1283.2	0.6974	73.14	408.78	481.92	0.4576	2.5523	1.561	0.761
−76	24.51	1278.0	0.7912	76.27	406.83	483.10	0.4735	2.5371	1.562	0.768
−74	27.96	1272.8	0.8949	79.40	404.88	484.27	0.4893	2.5223	1.564	0.775
−72	31.80	1267.6	1.0094	82.53	402.90	485.43	0.5049	2.5079	1.565	0.783
−70	36.07	1262.4	1.1354	85.66	400.92	486.58	0.5204	2.4939	1.566	0.790
−68	40.79	1257.1	1.2738	88.80	398.91	487.71	0.5358	2.4803	1.568	0.798
−66	46.00	1251.8	1.4255	91.94	396.90	488.83	0.5510	2.4669	1.570	0.807
−64	51.74	1246.5	1.5912	95.08	394.86	489.94	0.5660	2.4540	1.572	0.815
−62	58.04	1241.1	1.7721	98.23	392.81	491.03	0.5810	2.4413	1.574	0.824
−60	64.96	1235.7	1.9690	101.38	390.73	492.11	0.5958	2.4290	1.576	0.833
−58	72.52	1230.3	2.1831	104.54	388.64	493.18	0.6105	2.4169	1.578	0.843
−56	80.77	1224.9	2.4152	107.70	386.53	494.22	0.6251	2.4051	1.581	0.853
−54	89.76	1219.4	2.6666	110.87	384.39	495.26	0.6396	2.3936	1.583	0.863
−52	99.54	1213.9	2.9384	114.04	382.24	496.28	0.6540	2.3824	1.586	0.873
−50	110.14	1208.4	3.2316	117.22	380.06	497.28	0.6683	2.3714	1.589	0.883
−48	121.63	1202.8	3.5477	120.41	377.85	498.26	0.6825	2.3607	1.593	0.894
−46	134.05	1197.2	3.8877	123.60	375.63	499.23	0.6965	2.3502	1.596	0.905
−44	147.45	1191.5	4.2530	126.80	373.38	500.18	0.7105	2.3399	1.600	0.917
−42	161.88	1185.9	4.6450	130.01	371.10	501.11	0.7244	2.3299	1.604	0.928

TABLE 12. Saturation properties as functions of temperature—Continued

t_s °C	p kPa	ϱ' kg m^{-3}	ϱ''	h'	Δh_v kJ kg^{-1}	h''	s' kJ kg^{-1} K^{-1}	s''	c'_p kJ kg^{-1} K^{-1}	(
−40	177.41	1180.2	5.0651	133.23	368.79	502.02	0.7382	2.3200	1.608	0.
−38	194.09	1174.4	5.5147	136.45	366.46	502.91	0.7519	2.3103	1.612	0.
−36	211.97	1168.6	5.9952	139.69	364.10	503.78	0.7656	2.3009	1.616	0.
−34	231.11	1162.8	6.5084	142.93	361.70	504.64	0.7791	2.2916	1.621	0.
−32	251.59	1156.9	7.0557	146.19	359.28	505.47	0.7926	2.2825	1.626	0.
−30	273.44	1151.0	7.6390	149.45	356.83	506.28	0.8060	2.2735	1.631	1.
−28	296.75	1145.0	8.2598	152.73	354.34	507.06	0.8193	2.2647	1.637	1.
−26	321.57	1138.9	8.9201	156.01	351.82	507.83	0.8326	2.2561	1.642	1.
−24	347.96	1132.9	9.6218	159.31	349.26	508.57	0.8458	2.2476	1.648	1.
−22	376.00	1126.7	10.367	162.62	346.66	509.28	0.8589	2.2392	1.654	1.
−20	405.75	1120.6	11.157	165.94	344.03	509.97	0.8720	2.2310	1.661	1.
−18	437.28	1114.3	11.995	169.28	341.36	510.64	0.8850	2.2229	1.668	1.
−16	470.67	1108.0	12.883	172.63	338.65	511.28	0.8980	2.2149	1.675	1.
−14	505.97	1101.7	13.823	175.99	335.90	511.89	0.9109	2.2070	1.682	1.
−12	543.27	1095.2	14.818	179.37	333.10	512.47	0.9237	2.1992	1.690	1.
−10	582.63	1088.8	15.870	182.77	330.25	513.02	0.9365	2.1916	1.698	1.
−8	624.14	1082.2	16.982	186.18	327.36	513.54	0.9493	2.1840	1.706	1.
−6	667.86	1075.6	18.157	189.61	324.43	514.03	0.9620	2.1764	1.715	1.
−4	713.88	1068.9	19.398	193.05	321.44	514.49	0.9747	2.1690	1.725	1.
−2	762.26	1062.1	20.708	196.52	318.40	514.91	0.9874	2.1616	1.735	1.
0	813.10	1055.3	22.091	200.00	315.30	515.30	1.0000	2.1543	1.745	1.
2	866.47	1048.3	23.550	203.51	312.15	515.65	1.0126	2.1471	1.756	1.
4	922.45	1041.3	25.090	207.03	308.93	515.97	1.0252	2.1399	1.767	1.
6	981.13	1034.2	26.714	210.58	305.66	516.24	1.0377	2.1327	1.779	1.
8	1042.5	1027.0	28.426	214.15	302.32	516.47	1.0503	2.1256	1.792	1.
10	1106.9	1019.7	30.232	217.75	298.92	516.66	1.0628	2.1185	1.806	1.
12	1174.1	1012.2	32.137	221.36	295.44	516.81	1.0753	2.1114	1.820	1.
14	1244.4	1004.7	34.145	225.01	291.89	516.91	1.0878	2.1043	1.835	1.4
16	1317.9	997.05	36.264	228.69	288.27	516.96	1.1003	2.0973	1.851	1.4
18	1394.5	989.28	38.498	232.39	284.57	516.95	1.1128	2.0902	1.868	1.4
20	1474.5	981.38	40.856	236.12	280.78	516.90	1.1253	2.0831	1.886	1.5
22	1557.9	973.34	43.344	239.89	276.90	516.79	1.1378	2.0760	1.905	1.5
24	1644.8	965.16	45.971	243.69	272.93	516.62	1.1503	2.0688	1.926	1.5
26	1735.3	956.82	48.745	247.53	268.86	516.39	1.1629	2.0616	1.948	1.6
28	1829.5	948.31	51.677	251.40	264.69	516.09	1.1755	2.0544	1.972	1.6
30	1927.5	939.62	54.776	255.32	260.41	515.73	1.1881	2.0471	1.997	1.7
32	2029.4	930.75	58.056	259.28	256.01	515.29	1.2008	2.0397	2.025	1.7
34	2135.3	921.67	61.530	263.28	251.49	514.77	1.2135	2.0322	2.055	1.8
36	2245.3	912.37	65.211	267.34	246.83	514.17	1.2262	2.0247	2.088	1.8
38	2359.6	902.83	69.118	271.45	242.04	513.49	1.2391	2.0170	2.124	1.9
40	2478.3	893.04	73.268	275.61	237.09	512.71	1.2520	2.0091	2.163	2.0
42	2601.4	882.96	77.684	279.84	231.98	511.83	1.2650	2.0011	2.206	2.0
44	2729.1	872.58	82.389	284.14	226.70	510.84	1.2781	1.9929	2.255	2.1
46	2861.6	861.86	87.412	288.50	221.22	509.73	1.2914	1.9845	2.309	2.2
48	2998.9	850.76	92.786	292.95	215.54	508.49	1.3048	1.9759	2.369	2.3
50	3141.2	839.26	98.550	297.49	209.62	507.11	1.3183	1.9670	2.439	2.4
52	3288.6	827.28	104.75	302.12	203.45	505.57	1.3321	1.9578	2.518	2.6
54	3441.4	814.78	111.44	306.87	196.99	503.86	1.3461	1.9482	2.609	2.7
56	3599.6	801.68	118.69	311.74	190.21	501.95	1.3603	1.9382	2.717	2.9
58	3763.5	787.90	126.58	316.75	183.07	499.83	1.3749	1.9277	2.845	3.1
60	3933.2	773.31	135.21	321.93	175.51	497.44	1.3898	1.9166	3.001	3.4
62	4108.9	757.78	144.73	327.30	167.46	494.76	1.4052	1.9049	3.193	3.7
64	4290.8	741.10	155.32	332.90	158.83	491.73	1.4211	1.8922	3.438	4.1
66	4479.3	723.02	167.23	338.78	149.48	488.26	1.4378	1.8785	3.761	4.7
68	4674.5	703.16	180.83	345.02	139.23	484.25	1.4553	1.8634	4.207	5.5
70	4876.8	680.93	196.69	351.74	127.78	479.52	1.4741	1.8465	4.865	6.6
72	5086.6	655.38	215.80	359.11	114.66	473.77	1.4946	1.8268	5.941	8.4
74	5304.5	624.57	240.12	367.53	98.88	466.41	1.5179	1.8028	8.051	12.0
76	5531.5	583.33	275.00	378.03	77.83	455.86	1.5470	1.7699		
78	5769.6	484.62	367.24	400.38	28.52	428.90	1.6095	1.6908		
78.105[b]	5782.6	424.00	424.00	414.15	0.00	414.15	1.6487	1.6487		

[a]Triple point.
[b]Critical point.

TABLE 13. Saturation properties as functions of pressure

p kPa	t_s °C	ϱ' kg m^{-3}	ϱ'' kg m^{-3}	h' kJ kg^{-1}	Δh_v kJ kg^{-1}	h'' kJ kg^{-1}	s' kJ kg^{-1} K^{-1}	s'' kJ kg^{-1} K^{-1}	c'_p kJ kg^{-1} K^{-1}	c''_p kJ kg^{-1} K^{-1}
1.0	−113.52	1372.5	0.0392	17.69	441.88	459.57	0.1440	2.9122	1.567	0.681
1.1	−112.64	1370.3	0.0429	19.08	441.07	460.15	0.1527	2.9006	1.566	0.683
1.2	−111.82	1368.3	0.0466	20.35	440.32	460.68	0.1606	2.8900	1.566	0.684
1.3	−111.06	1366.4	0.0503	21.54	439.63	461.17	0.1680	2.8803	1.565	0.685
1.4	−110.36	1364.7	0.0539	22.65	438.98	461.63	0.1748	2.8713	1.565	0.686
1.6	−109.06	1361.5	0.0611	24.68	437.79	462.47	0.1872	2.8552	1.564	0.688
1.8	−107.89	1358.6	0.0683	26.50	436.73	463.23	0.1983	2.8410	1.563	0.689
2.0	−106.84	1356.0	0.0754	28.15	435.76	463.91	0.2082	2.8283	1.563	0.691
2.2	−105.87	1353.6	0.0825	29.67	434.87	464.54	0.2173	2.8169	1.562	0.693
2.4	−104.97	1351.4	0.0896	31.07	434.05	465.12	0.2257	2.8065	1.562	0.694
2.6	−104.13	1349.3	0.0966	32.38	433.28	465.66	0.2334	2.7970	1.562	0.695
2.8	−103.35	1347.4	0.1035	33.60	432.56	466.16	0.2406	2.7881	1.561	0.697
3.0	−102.62	1345.5	0.1105	34.75	431.89	466.63	0.2474	2.7799	1.561	0.698
3.2	−101.92	1343.8	0.1174	35.83	431.25	467.08	0.2537	2.7723	1.561	0.699
3.4	−101.26	1342.2	0.1243	36.86	430.64	467.50	0.2597	2.7651	1.560	0.701
3.6	−100.64	1340.6	0.1311	37.84	430.07	467.90	0.2654	2.7583	1.560	0.702
3.8	−100.04	1339.1	0.1380	38.77	429.51	468.28	0.2708	2.7519	1.560	0.703
4.0	−99.47	1337.7	0.1448	39.66	428.99	468.65	0.2759	2.7459	1.560	0.704
4.5	−98.14	1334.4	0.1617	41.73	427.76	469.50	0.2878	2.7320	1.559	0.707
5.0	−96.93	1331.4	0.1785	43.62	426.65	470.26	0.2985	2.7196	1.559	0.709
5.5	−95.82	1328.6	0.1952	45.35	425.62	470.97	0.3083	2.7085	1.559	0.712
6.0	−94.79	1326.0	0.2118	46.95	424.66	471.62	0.3173	2.6983	1.559	0.714
6.5	−93.83	1323.6	0.2284	48.44	423.77	472.22	0.3257	2.6890	1.559	0.716
7.0	−92.94	1321.3	0.2448	49.84	422.94	472.78	0.3335	2.6803	1.559	0.718
7.5	−92.09	1319.2	0.2611	51.16	422.15	473.31	0.3408	2.6723	1.559	0.720
8.0	−91.29	1317.2	0.2774	52.41	421.41	473.81	0.3476	2.6648	1.559	0.722
9.0	−89.81	1313.4	0.3098	54.71	420.02	474.73	0.3602	2.6512	1.559	0.726
10.0	−88.47	1310.0	0.3419	56.81	418.76	475.57	0.3716	2.6391	1.559	0.729
11.0	−87.23	1306.9	0.3739	58.74	417.59	476.33	0.3821	2.6281	1.559	0.733
12.0	−86.08	1304.0	0.4056	60.53	416.51	477.04	0.3916	2.6181	1.559	0.736
13.0	−85.01	1301.2	0.4371	62.20	415.49	477.69	0.4005	2.6090	1.559	0.739
14.0	−84.01	1298.7	0.4685	63.77	414.54	478.31	0.4088	2.6005	1.559	0.742
16.0	−82.17	1294.0	0.5309	66.64	412.79	479.42	0.4239	2.5853	1.560	0.747
18.0	−80.51	1289.7	0.5927	69.22	411.20	480.42	0.4374	2.5719	1.560	0.753
20.0	−79.00	1285.8	0.6541	71.58	409.74	481.33	0.4496	2.5600	1.561	0.758
22.0	−77.61	1282.2	0.7151	73.76	408.39	482.15	0.4608	2.5493	1.562	0.762
24.0	−76.32	1278.9	0.7757	75.78	407.14	482.91	0.4710	2.5395	1.562	0.767
26.0	−75.11	1275.7	0.8360	77.66	405.96	483.62	0.4806	2.5305	1.563	0.771
28.0	−73.98	1272.8	0.8960	79.43	404.85	484.28	0.4895	2.5222	1.564	0.775
30.0	−72.91	1270.0	0.9557	81.10	403.81	484.90	0.4978	2.5144	1.564	0.779
32.0	−71.90	1267.4	1.0152	82.68	402.81	485.49	0.5057	2.5072	1.565	0.783
34.0	−70.94	1264.8	1.0745	84.18	401.86	486.04	0.5131	2.5005	1.566	0.787
36.0	−70.03	1262.4	1.1335	85.61	400.95	486.56	0.5202	2.4941	1.566	0.790
38.0	−69.16	1260.1	1.1922	86.98	400.07	487.06	0.5269	2.4881	1.567	0.794
40.0	−68.32	1257.9	1.2508	88.29	399.24	487.53	0.5333	2.4824	1.568	0.797
45.0	−66.37	1252.8	1.3965	91.36	397.27	488.63	0.5482	2.4694	1.569	0.805
50.0	−64.59	1248.0	1.5412	94.16	395.46	489.62	0.5616	2.4577	1.571	0.813
55.0	−62.91	1243.6	1.6850	96.71	393.77	490.52	0.5740	2.4472	1.573	0.820
60.0	−61.41	1239.5	1.8280	99.15	392.20	491.35	0.5854	2.4377	1.574	0.827
65.0	−59.99	1235.7	1.9703	101.40	390.72	492.12	0.5959	2.4289	1.576	0.834

TABLE 13. Saturation properties as functions of pressure—Continued

p kPa	t_s °C	ϱ' kg m^{-3}	ϱ'' kg m^{-3}	h' kJ kg^{-1}	Δh_v kJ kg^{-1}	h'' kJ kg^{-1}	s' kJ kg^{-1} K^{-1}	s'' kJ kg^{-1} K^{-1}	c'_p kJ kg^{-1} K^{-1}	c''_p kJ kg^{-1} K^{-1}
70.0	−58.65	1232.1	2.1120	103.52	389.32	492.83	0.6058	2.4208	1.577	0.840
75.0	−57.38	1228.6	2.2530	105.52	387.99	493.50	0.6151	2.4132	1.579	0.846
80.0	−56.18	1225.4	2.3936	107.41	386.72	494.13	0.6238	2.4062	1.581	0.852
90.0	−53.95	1219.3	2.6732	110.95	384.34	495.28	0.6400	2.3934	1.584	0.863
100.0	−51.91	1213.6	2.9512	114.18	382.14	496.32	0.6547	2.3819	1.587	0.873
101.325[a]	−51.65	1212.9	2.9879	114.59	381.86	496.45	0.6565	2.3805	1.587	0.875
110.0	−50.03	1208.4	3.2277	117.18	380.08	497.26	0.6681	2.3716	1.589	0.883
120.0	−48.27	1203.6	3.5029	119.97	378.16	498.13	0.6805	2.3622	1.592	0.893
130.0	−46.63	1199.0	3.7771	122.59	376.34	498.92	0.6921	2.3535	1.595	0.902
140.0	−45.09	1194.6	4.0502	125.05	374.61	499.66	0.7029	2.3455	1.598	0.910
160.0	−42.25	1186.6	4.5940	129.61	371.39	500.99	0.7227	2.3311	1.603	0.927
180.0	−39.68	1179.2	5.1350	133.74	368.42	502.16	0.7404	2.3184	1.608	0.942
200.0	−37.32	1172.4	5.6737	137.55	365.66	503.21	0.7566	2.3071	1.613	0.956
220.0	−35.14	1166.1	6.2106	141.08	363.08	504.15	0.7714	2.2969	1.618	0.970
240.0	−33.12	1160.2	6.7461	144.37	360.64	505.01	0.7851	2.2875	1.623	0.983
260.0	−31.21	1154.6	7.2804	147.47	358.32	505.79	0.7979	2.2789	1.628	0.995
280.0	−29.42	1149.2	7.8138	150.39	356.11	506.51	0.8098	2.2710	1.633	1.007
300.0	−27.73	1144.2	8.3464	153.17	354.00	507.17	0.8211	2.2635	1.637	1.019
320.0	−26.12	1139.3	8.8785	155.81	351.97	507.78	0.8318	2.2566	1.642	1.030
340.0	−24.59	1134.7	9.4102	158.33	350.02	508.35	0.8419	2.2501	1.646	1.041
360.0	23.13	1130.2	9.9417	160.75	348.13	508.88	0.8515	2.2439	1.651	1.052
380.0	−21.72	1125.9	10.473	163.08	346.30	509.38	0.8607	2.2381	1.655	1.062
400.0	−20.38	1121.7	11.004	165.31	344.53	509.85	0.8695	2.2325	1.659	1.072
450.0	−17.22	1111.9	12.333	170.58	340.32	510.89	0.8900	2.2198	1.670	1.096
500.0	−14.33	1102.7	13.664	175.44	336.35	511.79	0.9087	2.2083	1.681	1.119
550.0	−11.65	1094.1	14.997	179.96	332.60	512.57	0.9260	2.1979	1.691	1.142
600.0	−9.15	1086.0	16.335	184.21	329.03	513.25	0.9420	2.1883	1.702	1.163
650.0	−6.80	1078.3	17.676	188.23	325.61	513.84	0.9569	2.1795	1.712	1.185
700.0	−4.59	1070.9	19.023	192.03	322.33	514.36	0.9710	2.1712	1.722	1.205
750.0	−2.50	1063.8	20.375	195.65	319.16	514.81	0.9843	2.1635	1.732	1.226
800.0	−0.51	1057.0	21.734	199.12	316.09	515.21	0.9968	2.1562	1.742	1.246
900.0	3.21	1044.1	24.471	205.64	310.21	515.85	1.0202	2.1427	1.763	1.286
1000.0	6.62	1031.9	27.238	211.69	304.63	516.32	1.0417	2.1305	1.783	1.325
1100.0	9.79	1020.4	30.038	217.37	299.28	516.64	1.0615	2.1192	1.804	1.364
1200.0	12.74	1009.4	32.872	222.72	294.13	516.85	1.0800	2.1088	1.825	1.403
1300.0	15.52	998.90	35.745	227.80	289.15	516.95	1.0973	2.0990	1.847	1.443
1400.0	18.14	988.74	38.657	232.65	284.31	516.95	1.1137	2.0897	1.869	1.483
1600.0	22.98	969.36	44.611	241.74	274.97	516.71	1.1439	2.0725	1.915	1.566
1800.0	27.38	950.96	50.753	250.20	265.99	516.19	1.1716	2.0567	1.964	1.653
2000.0	31.43	933.29	57.104	258.15	257.27	515.42	1.1971	2.0418	2.017	1.746
2200.0	35.18	916.19	63.684	265.68	248.75	514.43	1.2210	2.0278	2.074	1.846
2400.0	38.69	899.49	70.517	272.88	240.36	513.23	1.2435	2.0143	2.137	1.956
2600.0	41.98	883.08	77.631	279.79	232.04	511.84	1.2649	2.0012	2.206	2.076
2800.0	45.08	866.84	85.057	286.48	223.77	510.25	1.2853	1.9884	2.283	2.209
3000.0	48.02	850.68	92.829	292.99	215.49	508.48	1.3049	1.9759	2.370	2.359
3200.0	50.81	834.49	100.99	299.34	207.16	506.51	1.3239	1.9633	2.469	2.530
3400.0	53.46	818.18	109.60	305.59	198.75	504.34	1.3423	1.9508	2.583	2.726
3600.0	56.00	801.66	118.70	311.75	190.20	501.95	1.3603	1.9382	2.717	2.956
3800.0	58.44	784.79	128.39	317.87	181.46	499.33	1.3781	1.9254	2.877	3.229
4000.0	60.77	767.46	138.76	323.97	172.48	496.45	1.3957	1.9122	3.070	3.559
4500.0	66.22	720.98	168.60	339.44	148.42	487.86	1.4396	1.8770	3.802	4.813
5000.0	71.18	666.31	207.51	356.00	120.27	476.27	1.4859	1.8352	5.428	7.607
5500.0	75.73	590.01	269.17	376.39	81.23	457.62	1.5425	1.7753		
5782.6[b]	78.105	424.00	424.00	414.15	0.00	414.15	1.6487	1.6487		

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

TABLE 14. Properties of liquid and vapor

	$p = 10.0$ kPa			$p = 20.0$ kPa			$p = 30.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	0.3354	478.09	2.6526	1301.2	62.22	0.4006	1301.2	62.23	0.4006
−80	0.3263	481.73	2.6717	1288.4	70.02	0.4415	1288.4	70.02	0.4415
−75	0.3178	485.36	2.6902	0.6400	484.34	2.5754	1275.4	77.83	0.4814
−70	0.3098	488.99	2.7084	0.6233	488.09	2.5941	0.9408	487.16	2.5257
−65	0.3021	492.63	2.7261	0.6075	491.83	2.6123	0.9163	491.01	2.5444
−60	0.2949	496.29	2.7434	0.5926	495.57	2.6300	0.8933	494.83	2.5625
−55	0.2880	499.96	2.7604	0.5785	499.31	2.6473	0.8716	498.64	2.5802
−50	0.2814	503.65	2.7772	0.5651	503.05	2.6643	0.8510	502.45	2.5975
−45	0.2752	507.36	2.7936	0.5523	506.81	2.6810	0.8314	506.26	2.6143
−40	0.2692	511.09	2.8098	0.5401	510.59	2.6974	0.8128	510.08	2.6309
−35	0.2635	514.84	2.8257	0.5285	514.38	2.7131	0.7951	513.92	2.6472
−30	0.2580	518.62	2.8414	0.5174	518.19	2.7293	0.7782	517.76	2.6632
−25	0.2527	522.42	2.8569	0.5067	522.02	2.7449	0.7620	521.63	2.6789
−20	0.2477	526.25	2.8721	0.4965	525.88	2.7603	0.7466	525.51	2.6944
−15	0.2428	530.11	2.8872	0.4868	529.77	2.7755	0.7317	529.42	2.7097
−10	0.2382	533.99	2.9022	0.4774	533.68	2.7905	0.7175	533.36	2.7248
−5	0.2337	537.91	2.9169	0.4683	537.61	2.8053	0.7038	537.31	2.7397
0	0.2294	541.86	2.9315	0.4596	541.58	2.8200	0.6907	541.30	2.7544
5	0.2253	545.85	2.9459	0.4513	545.58	2.8345	0.6780	545.32	2.7690
10	0.2213	549.86	2.9603	0.4432	549.61	2.8488	0.6658	549.36	2.7834
15	0.2174	553.91	2.9744	0.4354	553.68	2.8631	0.6541	553.44	2.7977
20	0.2137	558.00	2.9885	0.4279	557.77	2.8772	0.6428	557.55	2.8118
25	0.2101	562.12	3.0024	0.4207	561.90	2.8911	0.6318	561.69	2.8258
30	0.2066	566.27	3.0162	0.4137	566.07	2.9050	0.6213	565.87	2.8397
35	0.2032	570.46	3.0300	0.4069	570.27	2.9187	0.6111	570.08	2.8535
40	0.2000	574.69	3.0436	0.4004	574.51	2.9324	0.6012	574.32	2.8671
45	0.1968	578.96	3.0571	0.3941	578.78	2.9459	0.5917	578.61	2.8807
50	0.1938	583.27	3.0705	0.3879	583.10	2.9594	0.5824	582.93	2.8942
55	0.1908	587.61	3.0839	0.3820	587.45	2.9727	0.5735	587.29	2.9076
60	0.1879	591.99	3.0971	0.3762	591.84	2.9860	0.5648	591.68	2.9209
65	0.1851	596.41	3.1103	0.3706	596.26	2.9992	0.5564	596.11	2.9341
70	0.1824	600.87	3.1234	0.3652	600.73	3.0123	0.5482	600.59	2.9472
75	0.1798	605.38	3.1364	0.3599	605.24	3.0253	0.5402	605.10	2.9603
80	0.1772	609.92	3.1494	0.3548	609.78	3.0383	0.5325	609.65	2.9732
85	0.1748	614.50	3.1622	0.3498	614.37	3.0512	0.5251	614.24	2.9861
90	0.1724	619.12	3.1750	0.3450	618.99	3.0640	0.5178	618.87	2.9990
95	0.1700	623.78	3.1878	0.3403	623.66	3.0768	0.5107	623.54	3.0117
100	0.1677	628.48	3.2005	0.3357	628.36	3.0895	0.5038	628.24	3.0244
105	0.1655	633.22	3.2131	0.3312	633.11	3.1021	0.4971	632.99	3.0371
110	0.1633	638.00	3.2257	0.3269	637.89	3.1147	0.4906	637.78	3.0497
115	0.1612	642.82	3.2382	0.3227	642.72	3.1272	0.4842	642.61	3.0622
120	0.1592	647.69	3.2506	0.3185	647.58	3.1396	0.4781	647.48	3.0746
125	0.1572	652.59	3.2630	0.3145	652.49	3.1520	0.4720	652.39	3.0871
130	0.1552	657.53	3.2753	0.3106	657.44	3.1644	0.4661	657.34	3.0994
135	0.1533	662.52	3.2876	0.3068	662.42	3.1767	0.4604	662.33	3.1117
140	0.1515	667.54	3.2999	0.3031	667.45	3.1889	0.4548	667.36	3.1240
145	0.1496	672.60	3.3120	0.2994	672.51	3.2011	0.4493	672.43	3.1362
150	0.1479	677.71	3.3242	0.2959	677.62	3.2132	0.4440	677.53	3.1483
155	0.1461	682.85	3.3363	0.2924	682.77	3.2253	0.4388	682.68	3.1604
160	0.1445	688.03	3.3483	0.2890	687.95	3.2374	0.4337	687.87	3.1724

TABLE 14. Properties of liquid and vapor—Continued

	$p=40.0$ kPa			$p=50.0$ kPa			$p=60.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.2	62.23	0.4006	1301.3	62.24	0.4006	1301.3	62.24	0.4006
80	1288.4	70.03	0.4415	1288.4	70.03	0.4415	1288.4	70.04	0.4415
−75	1275.5	77.84	0.4814	1275.5	77.84	0.4814	1275.5	77.85	0.4814
−70	1262.4	85.66	0.5204	1262.4	85.67	0.5204	1262.4	85.67	0.5204
−65	1.2287	490.16	2.4952	1249.1	93.51	0.5585	1249.1	93.51	0.5585
−60	1.1970	494.08	2.5138	1.5039	493.31	2.4753	1.8141	492.52	2.4432
−55	1.1673	497.97	2.5318	1.4657	497.29	2.4937	1.7669	496.59	2.4620
−50	1.1392	501.84	2.5494	1.4298	501.23	2.5116	1.7228	500.60	2.4802
−45	1.1126	505.71	2.5665	1.3959	505.15	2.5290	1.6812	504.59	2.4979
−40	1.0874	509.58	2.5833	1.3637	509.07	2.5459	1.6420	508.55	2.5151
−35	1.0634	513.45	2.5997	1.3332	512.98	2.5625	1.6048	512.51	2.5319
−30	1.0405	517.34	2.6158	1.3042	516.90	2.5788	1.5694	516.47	2.5483
−25	1.0187	521.23	2.6317	1.2765	520.83	2.5948	1.5357	520.43	2.5645
−20	0.9977	525.15	2.6473	1.2501	524.78	2.6106	1.5036	524.40	2.5803
−15	0.9777	529.08	2.6627	1.2248	528.73	2.6260	1.4730	528.39	2.5959
−10	0.9586	533.03	2.6779	1.2006	532.71	2.6413	1.4436	532.39	2.6113
−5	0.9402	537.01	2.6929	1.1774	536.71	2.6564	1.4155	536.41	2.6264
0	0.9225	541.02	2.7077	1.1551	540.73	2.6712	1.3886	540.45	2.6413
5	0.9055	545.05	2.7223	1.1337	544.78	2.6859	1.3627	544.51	2.6561
10	0.8891	549.11	2.7368	1.1131	548.86	2.7004	1.3378	548.61	2.6706
15	0.8734	553.20	2.7511	1.0933	552.96	2.7148	1.3138	552.72	2.6851
20	0.8582	557.32	2.7653	1.0742	557.10	2.7290	1.2907	556.87	2.6993
25	0.8435	561.48	2.7793	1.0557	561.26	2.7431	1.2685	561.05	2.7135
30	0.8294	565.66	2.7932	1.0380	565.46	2.7571	1.2470	565.25	2.7274
35	0.8157	569.88	2.8070	1.0208	569.69	2.7709	1.2263	569.50	2.7413
40	0.8025	574.14	2.8207	1.0042	573.95	2.7846	1.2062	573.77	2.7551
45	0.7897	578.43	2.8343	0.9881	578.25	2.7983	1.1869	578.08	2.7687
50	0.7773	582.76	2.8478	0.9725	582.59	2.8118	1.1681	582.42	2.7823
55	0.7653	587.12	2.8612	0.9575	586.96	2.8252	1.1500	586.80	2.7957
60	0.7537	591.53	2.8745	0.9429	591.37	2.8385	1.1324	591.21	2.8091
65	0.7424	595.97	2.8878	0.9287	595.82	2.8518	1.1154	595.67	2.8223
70	0.7315	600.44	2.9009	0.9150	600.30	2.8650	1.0989	600.15	2.8355
75	0.7208	604.96	2.9140	0.9017	604.82	2.8780	1.0829	604.68	2.8486
80	0.7105	609.51	2.9270	0.8888	609.38	2.8910	1.0673	609.25	2.8616
85	0.7005	614.11	2.9399	0.8762	613.98	2.9040	1.0522	613.85	2.8746
90	0.6908	618.74	2.9527	0.8640	618.62	2.9168	1.0375	618.49	2.8874
95	0.6813	623.42	2.9655	0.8522	623.29	2.9296	1.0232	623.17	2.9002
100	0.6721	628.13	2.9782	0.8406	628.01	2.9424	1.0094	627.89	2.9130
105	0.6632	632.88	2.9909	0.8294	632.77	2.9550	0.9958	632.65	2.9257
110	0.6545	637.67	3.0035	0.8185	637.56	2.9676	0.9827	637.45	2.9383
115	0.6460	642.51	3.0160	0.8079	642.40	2.9801	0.9699	642.29	2.9508
120	0.6377	647.38	3.0285	0.7975	647.27	2.9926	0.9574	647.17	2.9633
125	0.6296	652.29	3.0409	0.7874	652.19	3.0051	0.9453	652.09	2.9757
130	0.6218	657.24	3.0533	0.7776	657.14	3.0174	0.9335	657.05	2.9881
135	0.6141	662.23	3.0656	0.7680	662.14	3.0297	0.9219	662.04	3.0004
140	0.6066	667.27	3.0778	0.7586	667.17	3.0420	0.9107	667.08	3.0127
145	0.5994	672.34	3.0900	0.7495	672.25	3.0542	0.8997	672.16	3.0249
150	0.5922	677.45	3.1022	0.7406	677.36	3.0664	0.8890	677.27	3.0371
155	0.5853	682.60	3.1143	0.7319	682.51	3.0785	0.8785	682.43	3.0492
160	0.5785	687.79	3.1263	0.7234	687.71	3.0905	0.8683	687.62	3.0612

TABLE 14. Properties of liquid and vapor—Continued

t	$p=70.0$ kPa			$p=80.0$ kPa			$p=90.0$ kPa		
°C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.3	62.24	0.4005	1301.3	62.25	0.4005	1301.3	62.25	0.4005
−80	1288.5	70.04	0.4415	1288.5	70.05	0.4414	1288.5	70.05	0.4414
−75	1275.5	77.85	0.4814	1275.5	77.86	0.4813	1275.5	77.86	0.4813
−70	1262.4	85.67	0.5204	1262.4	85.68	0.5203	1262.4	85.68	0.5203
−65	1249.2	93.52	0.5585	1249.2	93.52	0.5585	1249.2	93.52	0.5585
−60	1235.7	101.38	0.5958	1235.7	101.39	0.5958	1235.8	101.39	0.5958
−55	2.0711	495.87	2.4348	2.3783	495.13	2.4108	1222.1	109.28	0.6324
−50	2.0183	499.97	2.4534	2.3164	499.32	2.4298	2.6172	498.66	2.4086
−45	1.9688	504.01	2.4713	2.2585	503.43	2.4480	2.5506	502.85	2.4272
−40	1.9221	508.03	2.4887	2.2042	507.51	2.4657	2.4883	506.98	2.4451
−35	1.8780	512.04	2.5057	2.1529	511.56	2.4829	2.4296	511.07	2.4625
−30	1.8361	516.03	2.5223	2.1043	515.59	2.4996	2.3741	515.15	2.4794
−25	1.7963	520.03	2.5386	2.0582	519.62	2.5160	2.3215	519.21	2.4960
−20	1.7584	524.03	2.5546	2.0144	523.65	2.5321	2.2716	523.28	2.5122
−15	1.7222	528.04	2.5703	1.9725	527.69	2.5479	2.2240	527.34	2.5281
−10	1.6876	532.06	2.5857	1.9326	531.74	2.5634	2.1786	531.41	2.5437
−5	1.6545	536.10	2.6009	1.8944	535.80	2.5787	2.1352	535.49	2.5590
0	1.6228	540.16	2.6159	1.8578	539.88	2.5938	2.0937	539.59	2.5742
5	1.5923	544.25	2.6307	1.8228	543.98	2.6087	2.0539	543.71	2.5891
10	1.5631	548.35	2.6453	1.7891	548.10	2.6233	2.0157	547.84	2.6039
15	1.5349	552.48	2.6598	1.7567	552.24	2.6379	1.9791	552.00	2.6184
20	1.5078	556.64	2.6741	1.7255	556.42	2.6522	1.9438	556.19	2.6328
25	1.4817	560.83	2.6883	1.6955	560.62	2.6664	1.9098	560.40	2.6471
30	1.4565	565.05	2.7023	1.6665	564.85	2.6805	1.8770	564.64	2.6612
35	1.4322	569.30	2.7162	1.6386	569.11	2.6944	1.8455	568.91	2.6751
40	1.4087	573.58	2.7300	1.6116	573.40	2.7082	1.8150	573.21	2.6890
45	1.3860	577.90	2.7437	1.5856	577.72	2.7219	1.7855	577.54	2.7027
50	1.3641	582.25	2.7573	1.5604	582.08	2.7355	1.7570	581.91	2.7163
55	1.3428	586.64	2.7707	1.5360	586.47	2.7490	1.7295	586.31	2.7298
60	1.3222	591.06	2.7841	1.5124	590.90	2.7624	1.7028	590.74	2.7433
65	1.3023	595.52	2.7974	1.4895	595.36	2.7757	1.6770	595.21	2.7566
70	1.2830	600.01	2.8106	1.4673	599.87	2.7889	1.6520	599.72	2.7698
75	1.2642	604.54	2.8237	1.4458	604.40	2.8021	1.6277	604.26	2.7829
80	1.2460	609.11	2.8367	1.4250	608.98	2.8151	1.6041	608.84	2.7960
85	1.2283	613.72	2.8497	1.4047	613.59	2.8281	1.5813	613.46	2.8090
90	1.2112	618.37	2.8626	1.3850	618.24	2.8410	1.5591	618.12	2.8219
95	1.1945	623.05	2.8754	1.3659	622.93	2.8538	1.5375	622.81	2.8347
100	1.1782	627.78	2.8881	1.3473	627.66	2.8666	1.5165	627.54	2.8475
105	1.1625	632.54	2.9008	1.3292	632.43	2.8792	1.4961	632.32	2.8602
110	1.1471	637.34	2.9134	1.3116	637.24	2.8919	1.4763	637.13	2.8728
115	1.1321	642.19	2.9260	1.2945	642.08	2.9044	1.4570	641.97	2.8854
120	1.1176	647.07	2.9385	1.2778	646.97	2.9169	1.4382	646.86	2.8979
125	1.1034	651.99	2.9509	1.2615	651.89	2.9294	1.4198	651.79	2.9104
130	1.0895	656.95	2.9633	1.2457	656.85	2.9418	1.4020	656.76	2.9228
135	1.0761	661.95	2.9756	1.2303	661.86	2.9541	1.3846	661.76	2.9351
140	1.0629	666.99	2.9879	1.2152	666.90	2.9664	1.3676	666.81	2.9474
145	1.0501	672.07	3.0001	1.2005	671.98	2.9786	1.3511	671.89	2.9596
150	1.0376	677.19	3.0123	1.1862	677.10	2.9908	1.3349	677.01	2.9718
155	1.0253	682.34	3.0244	1.1722	682.26	3.0029	1.3191	682.18	2.9839
160	1.0134	687.54	3.0365	1.1585	687.46	3.0150	1.3038	687.38	2.9960

TABLE 14. Properties of liquid and vapor—Continued

	$p=100.0$ kPa			$p=101.325$ kPa			$p=120.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.3	62.26	0.4005	1301.3	62.26	0.4005	1301.3	62.27	0.4005
−80	1288.5	70.06	0.4414	1288.5	70.06	0.4414	1288.5	70.07	0.4414
−75	1275.5	77.87	0.4813	1275.5	77.87	0.4813	1275.6	77.88	0.4813
−70	1262.5	85.69	0.5203	1262.5	85.69	0.5203	1262.5	85.70	0.5203
−65	1249.2	93.53	0.5584	1249.2	93.53	0.5584	1249.2	93.54	0.5584
−60	1235.8	101.39	0.5958	1235.8	101.39	0.5958	1235.8	101.40	0.5957
−55	1222.2	109.29	0.6324	1222.2	109.29	0.6324	1222.2	109.30	0.6323
−50	2.9208	497.98	2.3894	2.9612	497.89	2.3869	1208.4	117.22	0.6683
−45	2.8451	502.25	2.4083	2.8843	502.17	2.4059	3.4414	501.02	2.3749
−40	2.7744	506.44	2.4265	2.8125	506.37	2.4241	3.3530	505.35	2.3937
−35	2.7080	510.59	2.4441	2.7451	510.52	2.4418	3.2705	509.60	2.4117
−30	2.6454	514.70	2.4612	2.6815	514.65	2.4589	3.1930	513.80	2.4292
−25	2.5862	518.80	2.4779	2.6214	518.75	2.4756	3.1199	517.98	2.4462
−20	2.5300	522.90	2.4942	2.5644	522.85	2.4919	3.0508	522.13	2.4628
−15	2.4766	526.99	2.5102	2.5101	526.94	2.5080	2.9852	526.28	2.4790
−10	2.4256	531.08	2.5259	2.4584	531.04	2.5237	2.9227	530.42	2.4949
−5	2.3770	535.19	2.5414	2.4091	535.15	2.5391	2.8632	534.57	2.5105
0	2.3304	539.30	2.5566	2.3619	539.27	2.5544	2.8064	538.73	2.5259
5	2.2859	543.44	2.5716	2.3167	543.40	2.5694	2.7521	542.89	2.5410
10	2.2431	547.59	2.5864	2.2733	547.56	2.5842	2.7000	547.08	2.5559
15	2.2021	551.76	2.6010	2.2317	551.73	2.5988	2.6501	551.28	2.5706
20	2.1626	555.96	2.6154	2.1917	555.93	2.6132	2.6021	555.50	2.5851
25	2.1246	560.18	2.6297	2.1531	560.15	2.6275	2.5560	559.75	2.5995
30	2.0880	564.43	2.6438	2.1160	564.41	2.6417	2.5116	564.02	2.6137
35	2.0528	568.71	2.6578	2.0803	568.69	2.6557	2.4688	568.32	2.6278
40	2.0187	573.02	2.6717	2.0458	573.00	2.6696	2.4275	572.65	2.6417
45	1.9858	577.36	2.6855	2.0124	577.34	2.6833	2.3877	577.01	2.6555
50	1.9541	581.74	2.6991	1.9802	581.72	2.6970	2.3492	581.40	2.6692
55	1.9233	586.15	2.7126	1.9490	586.12	2.7105	2.3120	585.82	2.6828
60	1.8936	590.59	2.7261	1.9189	590.57	2.7239	2.2761	590.27	2.6963
65	1.8648	595.06	2.7394	1.8897	595.04	2.7373	2.2413	594.76	2.7096
70	1.8369	599.58	2.7527	1.8614	599.56	2.7505	2.2075	599.29	2.7229
75	1.8098	604.12	2.7658	1.8340	604.11	2.7637	2.1748	603.85	2.7361
80	1.7836	608.71	2.7789	1.8074	608.69	2.7768	2.1432	608.44	2.7492
85	1.7581	613.33	2.7919	1.7815	613.32	2.7898	2.1124	613.07	2.7622
90	1.7334	617.99	2.8048	1.7565	617.98	2.8027	2.0825	617.74	2.7752
95	1.7093	622.69	2.8177	1.7321	622.67	2.8155	2.0535	622.45	2.7880
100	1.6860	627.43	2.8304	1.7084	627.41	2.8283	2.0254	627.19	2.8008
105	1.6632	632.20	2.8432	1.6854	632.19	2.8410	1.9980	631.98	2.8136
110	1.6411	637.02	2.8558	1.6630	637.00	2.8537	1.9713	636.80	2.8262
115	1.6196	641.87	2.8684	1.6412	641.85	2.8662	1.9454	641.66	2.8388
120	1.5987	646.76	2.8809	1.6200	646.75	2.8788	1.9201	646.55	2.8514
125	1.5783	651.69	2.8934	1.5993	651.68	2.8912	1.8956	651.49	2.8639
130	1.5584	656.66	2.9058	1.5791	656.65	2.9036	1.8716	656.46	2.8763
135	1.5390	661.67	2.9181	1.5595	661.66	2.9160	1.8483	661.48	2.8886
140	1.5201	666.72	2.9304	1.5404	666.70	2.9283	1.8255	666.53	2.9009
145	1.5017	671.80	2.9426	1.5217	671.79	2.9405	1.8034	671.62	2.9132
150	1.4837	676.93	2.9548	1.5035	676.92	2.9527	1.7817	676.75	2.9254
155	1.4662	682.09	2.9670	1.4857	682.08	2.9648	1.7606	681.92	2.9375
160	1.4491	687.29	2.9790	1.4683	687.28	2.9769	1.7400	687.13	2.9496

TABLE 14. Properties of liquid and vapor—Continued

	p = 140.0 kPa			p = 160.0 kPa			p = 180.0 kPa		
t °C	ϱ kg m⁻³	h kJ kg⁻¹	s kJ kg⁻¹ K⁻¹	ϱ kg m⁻³	h kJ kg⁻¹	s kJ kg⁻¹ K⁻¹	ϱ kg m⁻³	h kJ kg⁻¹	s kJ kg⁻¹ K⁻¹
−85	1301.4	62.28	0.4004	1301.4	62.29	0.4004	1301.4	62.30	0.4004
−80	1288.5	70.08	0.4413	1288.6	70.09	0.4413	1288.6	70.10	0.4413
−75	1275.6	77.88	0.4813	1275.6	77.89	0.4812	1275.7	77.90	0.4812
−70	1262.5	85.71	0.5202	1262.5	85.72	0.5202	1262.6	85.72	0.5202
−65	1249.3	93.55	0.5584	1249.3	93.56	0.5583	1249.3	93.56	0.5583
−60	1235.8	101.41	0.5957	1235.9	101.42	0.5957	1235.9	101.43	0.5956
−55	1222.2	109.31	0.6323	1222.3	109.31	0.6323	1222.3	109.32	0.6322
−50	1208.4	117.23	0.6682	1208.5	117.24	0.6682	1208.5	117.25	0.6682
−45	4.0482	499.75	2.3459	1194.4	125.21	0.7035	1194.5	125.22	0.7035
−40	3.9405	504.22	2.3653	4.5374	503.06	2.3400	1180.2	133.23	0.7382
−35	3.8406	508.59	2.3838	4.4188	507.56	2.3591	5.0053	506.50	2.3368
−30	3.7473	512.89	2.4017	4.3085	511.95	2.3774	4.8770	511.00	2.3555
−25	3.6596	517.14	2.4190	4.2053	516.29	2.3950	4.7573	515.42	2.3735
−20	3.5768	521.36	2.4358	4.1082	520.58	2.4121	4.6452	519.78	2.3909
−15	3.4985	525.56	2.4523	4.0166	524.84	2.4288	4.5396	524.11	2.4078
−10	3.4241	529.76	2.4684	3.9297	529.08	2.4451	4.4398	528.41	2.4243
−5	3.3533	533.95	2.4841	3.8473	533.32	2.4610	4.3452	532.69	2.4405
0	3.2859	538.14	2.4996	3.7688	537.56	2.4767	4.2553	536.97	2.4563
5	3.2214	542.35	2.5149	3.6939	541.80	2.4921	4.1697	541.24	2.4718
10	3.1597	546.56	2.5299	3.6224	546.04	2.5072	4.0879	545.52	2.4870
15	3.1006	550.79	2.5447	3.5539	550.30	2.5221	4.0098	549.81	2.5021
20	3.0439	555.04	2.5593	3.4882	554.58	2.5368	3.9350	554.12	2.5169
25	2.9895	559.31	2.5738	3.4252	558.88	2.5514	3.8632	558.44	2.5315
30	2.9371	563.61	2.5881	3.3647	563.19	2.5657	3.7943	562.77	2.5459
35	2.8866	567.93	2.6022	3.3064	567.53	2.5799	3.7281	567.13	2.5602
40	2.8380	572.27	2.6162	3.2503	571.90	2.5940	3.6643	571.52	2.5743
45	2.7911	576.65	2.6301	3.1962	576.29	2.6079	3.6029	575.93	2.5882
50	2.7459	581.05	2.6438	3.1440	580.71	2.6217	3.5436	580.36	2.6021
55	2.7021	585.49	2.6574	3.0936	585.16	2.6353	3.4865	584.83	2.6158
60	2.6598	589.96	2.6709	3.0449	589.64	2.6489	3.4312	589.33	2.6294
65	2.6189	594.46	2.6843	2.9978	594.16	2.6624	3.3778	593.85	2.6429
70	2.5793	598.99	2.6977	2.9522	598.70	2.6757	3.3262	598.41	2.6563
75	2.5409	603.57	2.7109	2.9080	603.28	2.6890	3.2762	603.00	2.6695
80	2.5037	608.17	2.7240	2.8652	607.90	2.7021	3.2277	607.63	2.6827
85	2.4676	612.81	2.7371	2.8237	612.55	2.7152	3.1808	612.29	2.6958
90	2.4326	617.49	2.7500	2.7835	617.24	2.7282	3.1352	616.99	2.7089
95	2.3986	622.21	2.7629	2.7444	621.96	2.7411	3.0910	621.72	2.7218
100	2.3655	626.96	2.7758	2.7064	626.72	2.7540	3.0481	626.49	2.7347
105	2.3334	631.75	2.7885	2.6695	631.52	2.7667	3.0064	631.29	2.7475
110	2.3022	636.58	2.8012	2.6337	636.36	2.7794	2.9658	636.14	2.7602
115	2.2718	641.44	2.8138	2.5988	641.23	2.7921	2.9264	641.02	2.7728
120	2.2422	646.35	2.8264	2.5648	646.14	2.8046	2.8881	645.93	2.7854
125	2.2134	651.29	2.8389	2.5318	651.09	2.8171	2.8507	650.89	2.7980
130	2.1854	656.27	2.8513	2.4996	656.08	2.8296	2.8144	655.88	2.8104
135	2.1580	661.29	2.8637	2.4683	661.10	2.8420	2.7790	660.91	2.8228
140	2.1314	666.35	2.8760	2.4377	666.16	2.8543	2.7445	665.98	2.8352
145	2.1054	671.44	2.8882	2.4079	671.27	2.8666	2.7109	671.09	2.8474
150	2.0801	676.58	2.9004	2.3789	676.41	2.8788	2.6781	676.23	2.8597
155	2.0554	681.75	2.9126	2.3505	681.58	2.8910	2.6461	681.41	2.8719
160	2.0312	686.96	2.9247	2.3229	686.80	2.9031	2.6149	686.64	2.8840

TABLE 14. Properties of liquid and vapor—Continued

	$p = 200.0$ kPa			$p = 220.0$ kPa			$p = 240.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.4	62.31	0.4003	1301.5	62.32	0.4003	1301.5	62.33	0.4003
−80	1288.6	70.11	0.4413	1288.6	70.11	0.4412	1288.7	70.12	0.4412
−75	1275.7	77.91	0.4812	1275.7	77.92	0.4811	1275.7	77.93	0.4811
−70	1262.6	85.73	0.5201	1262.6	85.74	0.5201	1262.7	85.75	0.5201
−65	1249.4	93.57	0.5583	1249.4	93.58	0.5582	1249.4	93.59	0.5582
−60	1235.9	101.44	0.5956	1236.0	101.45	0.5956	1236.0	101.45	0.5955
−55	1222.3	109.33	0.6322	1222.4	109.34	0.6322	1222.4	109.35	0.6321
−50	1208.5	117.26	0.6681	1208.6	117.27	0.6681	1208.6	117.27	0.6680
−45	1194.5	125.22	0.7034	1194.5	125.23	0.7034	1194.6	125.24	0.7033
−40	1180.2	133.24	0.7382	1180.2	133.24	0.7381	1180.3	133.25	0.7381
−35	5.6008	505.41	2.3164	6.2055	504.29	2.2975	1165.7	141.32	0.7723
−30	5.4530	510.03	2.3356	6.0369	509.04	2.3172	6.6291	508.03	2.3000
−25	5.3159	514.54	2.3540	5.8813	513.65	2.3360	6.4538	512.75	2.3192
−20	5.1879	518.98	2.3717	5.7366	518.17	2.3540	6.2913	517.35	2.3376
15	5.0677	523.37	2.3888	5.6011	522.62	2.3714	6.1398	521.87	2.3553
−10	4.9544	527.72	2.4055	5.4736	527.03	2.3883	5.9976	526.34	2.3724
−5	4.8472	532.05	2.4218	5.3533	531.41	2.4048	5.8637	530.77	2.3891
0	4.7455	536.37	2.4378	5.2394	535.77	2.4209	5.7371	535.17	2.4054
5	4.6487	540.69	2.4535	5.1312	540.13	2.4367	5.6170	539.56	2.4213
10	4.5565	545.00	2.4688	5.0281	544.47	2.4522	5.5029	543.94	2.4369
15	4.4684	549.32	2.4840	4.9299	548.82	2.4674	5.3941	548.33	2.4523
20	4.3842	553.65	2.4989	4.8360	553.18	2.4824	5.2903	552.71	2.4674
25	4.3035	558.00	2.5135	4.7461	557.55	2.4972	5.1910	557.11	2.4822
30	4.2260	562.36	2.5280	4.6599	561.94	2.5118	5.0959	561.51	2.4969
35	4.1517	566.74	2.5424	4.5772	566.34	2.5262	5.0047	565.94	2.5113
40	4.0801	571.14	2.5566	4.4977	570.76	2.5404	4.9171	570.38	2.5256
45	4.0112	575.57	2.5706	4.4212	575.20	2.5545	4.8328	574.84	2.5398
50	3.9448	580.02	2.5845	4.3475	579.67	2.5685	4.7517	579.32	2.5538
55	3.8807	584.50	2.5982	4.2764	584.17	2.5823	4.6736	583.83	2.5676
60	3.8189	589.01	2.6119	4.2079	588.69	2.5959	4.5982	588.37	2.5813
65	3.7591	593.55	2.6254	4.1416	593.24	2.6095	4.5254	592.94	2.5949
70	3.7013	598.12	2.6388	4.0776	597.83	2.6230	4.4550	597.53	2.6084
75	3.6454	602.72	2.6521	4.0157	602.44	2.6363	4.3870	602.16	2.6218
80	3.5912	607.36	2.6653	3.9557	607.09	2.6496	4.3212	606.82	2.6351
85	3.5387	612.03	2.6785	3.8976	611.77	2.6627	4.2574	611.51	2.6483
90	3.4878	616.74	2.6915	3.8413	616.48	2.6758	4.1956	616.23	2.6614
95	3.4384	621.48	2.7045	3.7867	621.23	2.6888	4.1357	620.99	2.6744
100	3.3905	626.25	2.7174	3.7336	626.02	2.7017	4.0776	625.78	2.6873
105	3.3439	631.07	2.7302	3.6822	630.84	2.7145	4.0211	630.61	2.7002
110	3.2987	635.92	2.7429	3.6322	635.70	2.7273	3.9663	635.47	2.7130
115	3.2547	640.80	2.7556	3.5835	640.59	2.7400	3.9131	640.37	2.7257
120	3.2119	645.73	2.7682	3.5363	645.52	2.7526	3.8613	645.31	2.7383
125	3.1702	650.69	2.7807	3.4903	650.49	2.7651	3.8109	650.28	2.7509
130	3.1297	655.69	2.7932	3.4455	655.49	2.7776	3.7619	655.30	2.7634
135	3.0902	660.72	2.8056	3.4019	660.53	2.7901	3.7141	660.34	2.7758
140	3.0517	665.80	2.8180	3.3595	665.61	2.8024	3.6676	665.43	2.7882
145	3.0143	670.91	2.8303	3.3181	670.73	2.8147	3.6223	670.55	2.8005
150	2.9777	676.06	2.8425	3.2777	675.88	2.8270	3.5782	675.71	2.8128
155	2.9421	681.24	2.8547	3.2384	681.08	2.8392	3.5351	680.91	2.8250
160	2.9073	686.47	2.8669	3.2000	686.31	2.8513	3.4931	686.14	2.8372

TABLE 14. Properties of liquid and vapor—Continued

t	p = 260.0 kPa			p = 280.0 kPa			p = 300.0 kPa		
°C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.5	62.34	0.4003	1301.5	62.35	0.4002	1301.6	62.36	0.4002
−80	1288.7	70.13	0.4412	1288.7	70.14	0.4411	1288.8	70.15	0.4411
−75	1275.8	77.94	0.4811	1275.8	77.95	0.4810	1275.8	77.96	0.4810
−70	1262.7	85.76	0.5200	1262.7	85.77	0.5200	1262.7	85.78	0.5200
−65	1249.4	93.60	0.5582	1249.5	93.61	0.5581	1249.5	93.62	0.5581
−60	1236.0	101.46	0.5955	1236.1	101.47	0.5955	1236.1	101.48	0.5954
−55	1222.4	109.36	0.6321	1222.5	109.36	0.6320	1222.5	109.37	0.6320
−50	1208.6	117.28	0.6680	1208.7	117.29	0.6680	1208.7	117.30	0.6679
−45	1194.6	125.25	0.7033	1194.6	125.25	0.7033	1194.7	125.26	0.7032
−40	1180.3	133.26	0.7380	1180.4	133.27	0.7380	1180.4	133.27	0.7380
−35	1165.8	141.32	0.7723	1165.8	141.33	0.7722	1165.9	141.34	0.7722
−30	7.2300	506.99	2.2839	1151.0	149.45	0.8060	1151.0	149.46	0.8059
−25	7.0336	511.82	2.3035	7.6210	510.88	2.2887	8.2166	509.92	2.2747
−20	6.8525	516.51	2.3223	7.4201	515.66	2.3078	7.9946	514.80	2.2942
−15	6.6841	521.10	2.3402	7.2340	520.33	2.3261	7.7899	519.55	2.3127
−10	6.5265	525.63	2.3576	7.0604	524.92	2.3437	7.5995	524.20	2.3306
−5	6.3784	530.11	2.3745	6.8976	529.46	2.3608	7.4213	528.79	2.3479
0	6.2387	534.56	2.3909	6.7442	533.95	2.3774	7.2538	533.34	2.3647
5	6.1063	538.99	2.4070	6.5992	538.42	2.3936	7.0958	537.85	2.3810
10	5.9807	543.41	2.4227	6.4618	542.88	2.4095	6.9462	542.34	2.3970
15	5.8612	547.83	2.4382	6.3312	547.32	2.4250	6.8042	546.82	2.4127
20	5.7472	552.24	2.4534	6.2068	551.76	2.4403	6.6690	551.29	2.4281
25	5.6383	556.66	2.4683	6.0880	556.21	2.4554	6.5402	555.76	2.4432
30	5.5341	561.09	2.4831	5.9745	560.66	2.4702	6.4171	560.24	2.4581
35	5.4342	565.53	2.4976	5.8657	565.13	2.4848	6.2993	564.72	2.4728
40	5.3383	569.99	2.5120	5.7614	569.61	2.4992	6.1864	569.22	2.4873
45	5.2462	574.47	2.5261	5.6613	574.11	2.5135	6.0780	573.74	2.5016
50	5.1575	578.98	2.5402	5.5649	578.63	2.5276	5.9739	578.27	2.5157
55	5.0721	583.50	2.5541	5.4722	583.17	2.5415	5.8737	582.83	2.5297
60	4.9898	588.05	2.5678	5.3828	587.73	2.5553	5.7772	587.41	2.5436
65	4.9104	592.63	2.5815	5.2966	592.32	2.5690	5.6841	592.02	2.5573
70	4.8336	597.24	2.5950	5.2134	596.94	2.5825	5.5943	596.65	2.5709
75	4.7594	601.88	2.6084	5.1329	601.59	2.5960	5.5075	601.31	2.5844
80	4.6876	606.54	2.6217	5.0551	606.27	2.6093	5.4236	606.00	2.5978
85	4.6182	611.24	2.6350	4.9798	610.98	2.6226	5.3425	610.72	2.6110
90	4.5508	615.98	2.6481	4.9069	615.72	2.6357	5.2639	615.47	2.6242
95	4.4856	620.74	2.6611	4.8363	620.50	2.6488	5.1878	620.25	2.6373
100	4.4223	625.55	2.6741	4.7677	625.31	2.6618	5.1140	625.07	2.6503
105	4.3608	630.38	2.6869	4.7013	630.15	2.6747	5.0424	629.92	2.6632
110	4.3012	635.25	2.6997	4.6367	635.03	2.6875	4.9729	634.81	2.6760
115	4.2432	640.16	2.7125	4.5740	639.95	2.7002	4.9054	639.73	2.6888
120	4.1869	645.10	2.7251	4.5130	644.90	2.7129	4.8398	644.69	2.7015
125	4.1321	650.08	2.7377	4.4538	649.88	2.7255	4.7761	649.68	2.7141
130	4.0787	655.10	2.7502	4.3961	654.90	2.7380	4.7141	654.71	2.7267
135	4.0268	660.15	2.7627	4.3400	659.96	2.7505	4.6537	659.77	2.7391
140	3.9763	665.24	2.7751	4.2854	665.06	2.7629	4.5950	664.87	2.7516
145	3.9270	670.37	2.7874	4.2322	670.19	2.7753	4.5378	670.01	2.7639
150	3.8790	675.53	2.7997	4.1803	675.36	2.7875	4.4820	675.19	2.7762
155	3.8322	680.74	2.8119	4.1298	680.57	2.7998	4.4277	680.40	2.7885
160	3.7866	685.97	2.8241	4.0805	685.81	2.8120	4.3747	685.64	2.8006

TABLE 14. Properties of liquid and vapor—Continued

	$p=350.0$ kPa			$p=400.0$ kPa			$p=450.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.6	62.38	0.4001	1301.7	62.40	0.4000	1301.7	62.43	0.4000
−80	1288.8	70.18	0.4410	1288.9	70.20	0.4409	1288.9	70.22	0.4409
−75	1275.9	77.98	0.4809	1276.0	78.01	0.4808	1276.0	78.03	0.4808
−70	1262.8	85.80	0.5199	1262.9	85.83	0.5198	1263.0	85.85	0.5197
−65	1249.6	93.64	0.5580	1249.7	93.66	0.5579	1249.7	93.69	0.5578
−60	1236.2	101.50	0.5953	1236.3	101.52	0.5952	1236.3	101.55	0.5952
−55	1222.6	109.39	0.6319	1222.7	109.41	0.6318	1222.8	109.43	0.6317
−50	1208.8	117.32	0.6678	1208.9	117.34	0.6677	1209.0	117.36	0.6676
−45	1194.8	125.28	0.7031	1194.9	125.30	0.7030	1195.0	125.32	0.7029
−40	1180.5	133.29	0.7379	1180.6	133.31	0.7378	1180.7	133.33	0.7377
−35	1166.0	141.35	0.7721	1166.1	141.37	0.7720	1166.2	141.39	0.7719
−30	1151.1	149.47	0.8058	1151.3	149.49	0.8057	1151.4	149.51	0.8056
−25	1136.0	157.66	0.8392	1136.1	157.68	0.8390	1136.2	157.69	0.8389
−20	9.4625	512.58	2.2627	10.979	510.25	2.2341	1120.7	165.95	0.8719
−15	9.2066	517.54	2.2821	10.665	515.46	2.2545	12.168	513.30	2.2292
−10	8.9706	522.37	2.3007	10.377	520.49	2.2738	11.823	518.54	2.2493
−5	8.7512	527.11	2.3185	10.112	525.38	2.2922	11.507	523.61	2.2683
0	8.5461	531.77	2.3357	9.8658	530.18	2.3100	11.215	528.55	2.2866
5	8.3534	536.39	2.3525	9.6354	534.91	2.3271	10.943	533.40	2.3042
10	8.1717	540.98	2.3688	9.4190	539.59	2.3438	10.689	538.19	2.3213
15	7.9998	545.54	2.3848	9.2149	544.24	2.3601	10.451	542.93	2.3379
20	7.8366	550.08	2.4004	9.0219	548.87	2.3760	10.225	547.63	2.3540
25	7.6815	554.62	2.4158	8.8387	553.47	2.3916	10.013	552.31	2.3699
30	7.5336	559.16	2.4309	8.6646	558.08	2.4069	9.8107	556.98	2.3854
35	7.3923	563.70	2.4457	8.4986	562.67	2.4219	9.6186	561.63	2.4006
40	7.2571	568.25	2.4604	8.3401	567.28	2.4367	9.4355	566.29	2.4156
45	7.1276	572.82	2.4748	8.1884	571.89	2.4513	9.2607	570.95	2.4304
50	7.0034	577.39	2.4891	8.0431	576.51	2.4658	9.0934	575.61	2.4449
55	6.8840	581.99	2.5032	7.9037	581.14	2.4800	8.9331	580.29	2.4593
60	6.7691	586.60	2.5172	7.7697	585.79	2.4941	8.7794	584.98	2.4735
65	6.6584	591.24	2.5310	7.6409	590.47	2.5080	8.6316	589.68	2.4875
70	6.5518	595.91	2.5447	7.5168	595.16	2.5218	8.4894	594.41	2.5014
75	6.4488	600.59	2.5583	7.3971	599.88	2.5354	8.3525	599.16	2.5151
80	6.3494	605.31	2.5717	7.2816	604.62	2.5489	8.2205	603.93	2.5287
85	6.2533	610.06	2.5850	7.1701	609.39	2.5624	8.0931	608.73	2.5422
90	6.1603	614.83	2.5983	7.0623	614.19	2.5757	7.9700	613.55	2.5556
95	6.0703	619.64	2.6114	6.9580	619.02	2.5889	7.8510	618.40	2.5688
100	5.9830	624.48	2.6245	6.8570	623.88	2.6020	7.7359	623.28	2.5820
105	5.8985	629.35	2.6375	6.7591	628.77	2.6150	7.6245	628.20	2.5951
110	5.8164	634.25	2.6503	6.6643	633.70	2.6279	7.5164	633.14	2.6081
115	5.7368	639.19	2.6632	6.5722	638.65	2.6408	7.4117	638.11	2.6210
120	5.6595	644.17	2.6759	6.4829	643.64	2.6536	7.3101	643.12	2.6338
125	5.5843	649.17	2.6885	6.3961	648.67	2.6663	7.2115	648.16	2.6465
130	5.5112	654.22	2.7011	6.3118	653.73	2.6789	7.1157	653.23	2.6592
135	5.4402	659.30	2.7136	6.2298	658.82	2.6915	7.0226	658.34	2.6718
140	5.3710	664.41	2.7261	6.1500	663.95	2.7039	6.9320	663.48	2.6843
145	5.3037	669.56	2.7385	6.0724	669.11	2.7164	6.8439	668.66	2.6967
150	5.2381	674.75	2.7508	5.9968	674.31	2.7287	6.7582	673.87	2.7091
155	5.1742	679.97	2.7631	5.9232	679.54	2.7410	6.6747	679.12	2.7215
160	5.1119	685.23	2.7753	5.8515	684.82	2.7533	6.5934	684.40	2.7337

TABLE 14. Properties of liquid and vapor—Continued

	$p=500.0$ kPa			$p=550.0$ kPa			$p=600.0$ kPa		
t C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1301.8	62.45	0.3999	1301.9	62.48	0.3998	1301.9	62.50	0.3997
−80	1289.0	70.25	0.4408	1289.1	70.27	0.4407	1289.1	70.30	0.4406
−75	1276.1	78.05	0.4807	1276.2	78.08	0.4806	1276.2	78.10	0.4805
−70	1263.0	85.87	0.5196	1263.1	85.89	0.5196	1263.2	85.92	0.5195
−65	1249.8	93.71	0.5578	1249.9	93.73	0.5577	1250.0	93.75	0.5576
−60	1236.4	101.57	0.5951	1236.5	101.59	0.5950	1236.6	101.61	0.5949
−55	1222.9	109.46	0.6316	1222.9	109.48	0.6316	1223.0	109.50	0.6315
−50	1209.1	117.38	0.6676	1209.2	117.40	0.6675	1209.3	117.42	0.6674
−45	1195.1	125.34	0.7028	1195.2	125.36	0.7027	1195.3	125.38	0.7026
−40	1180.8	133.35	0.7376	1180.9	133.36	0.7374	1181.0	133.38	0.7373
−35	1166.3	141.41	0.7717	1166.4	141.42	0.7716	1166.5	141.44	0.7715
−30	1151.5	149.52	0.8055	1151.6	149.54	0.8054	1151.7	149.55	0.8053
−25	1136.3	157.71	0.8388	1136.5	157.72	0.8387	1136.6	157.74	0.8386
−20	1120.8	165.97	0.8718	1121.0	165.98	0.8716	1121.1	165.99	0.8715
−15	1104.9	174.31	0.9044	1105.0	174.32	0.9043	1105.2	174.33	0.9041
−10	13.310	516.53	2.2265	14.842	514.43	2.2050	1088.8	182.77	0.9365
−5	12.936	521.79	2.2463	14.405	519.91	2.2256	15.915	517.97	2.2060
0	12.594	526.88	2.2651	14.007	525.17	2.2451	15.455	523.42	2.2262
5	12.278	531.86	2.2832	13.641	530.29	2.2636	15.035	528.68	2.2453
10	11.983	536.76	2.3006	13.302	535.30	2.2815	14.648	533.82	2.2636
15	11.707	541.59	2.3175	12.987	540.24	2.2988	14.289	538.86	2.2812
20	11.448	546.38	2.3340	12.691	545.11	2.3155	13.954	543.83	2.2983
25	11.204	551.14	2.3501	12.413	549.94	2.3319	13.640	548.74	2.3150
30	10.972	555.87	2.3658	12.150	554.74	2.3478	13.344	553.61	2.3312
35	10.753	560.58	2.3813	11.901	559.52	2.3635	13.065	558.45	2.3470
40	10.544	565.29	2.3964	11.665	564.29	2.3788	12.801	563.27	2.3625
45	10.345	570.00	2.4113	11.441	569.05	2.3939	12.549	568.08	2.3778
50	10.154	574.71	2.4260	11.227	573.80	2.4087	12.310	572.89	2.3927
55	9.9725	579.43	2.4405	11.022	578.56	2.4233	12.082	577.69	2.4075
60	9.7981	584.16	2.4548	10.826	583.33	2.4378	11.864	582.50	2.4220
65	9.6307	588.90	2.4689	10.638	588.11	2.4520	11.655	587.31	2.4364
70	9.4699	593.66	2.4829	10.458	592.90	2.4661	11.455	592.14	2.4505
75	9.3151	598.44	2.4967	10.285	597.71	2.4800	11.262	596.98	2.4645
80	9.1660	603.24	2.5104	10.118	602.54	2.4937	11.078	601.84	2.4784
85	9.0223	608.06	2.5240	9.9578	607.39	2.5074	10.900	606.71	2.4921
90	8.8835	612.91	2.5374	9.8030	612.26	2.5209	10.728	611.61	2.5057
95	8.7495	617.78	2.5508	9.6535	617.16	2.5343	10.563	616.53	2.5192
100	8.6199	622.69	2.5640	9.5090	622.08	2.5476	10.403	621.48	2.5325
105	8.4945	627.62	2.5771	9.3693	627.04	2.5608	10.249	626.45	2.5457
110	8.3731	632.58	2.5902	9.2341	632.02	2.5739	10.100	631.45	2.5589
115	8.2554	637.57	2.6031	9.1032	637.03	2.5868	9.9552	636.48	2.5719
120	8.1412	642.60	2.6160	8.9763	642.07	2.5998	9.8153	641.54	2.5849
125	8.0305	647.65	2.6287	8.8532	647.14	2.6126	9.6796	646.63	2.5977
130	7.9230	652.74	2.6414	8.7338	652.25	2.6253	9.5480	651.75	2.6105
135	7.8185	657.86	2.6541	8.6178	657.38	2.6380	9.4203	656.90	2.6232
140	7.7170	663.02	2.6666	8.5051	662.55	2.6506	9.2962	662.09	2.6358
145	7.6183	668.21	2.6791	8.3955	667.76	2.6631	9.1756	667.30	2.6484
150	7.5222	673.43	2.6915	8.2890	672.99	2.6755	9.0584	672.55	2.6609
155	7.4287	678.69	2.7039	8.1853	678.26	2.6879	8.9444	677.83	2.6733
160	7.3377	683.98	2.7162	8.0844	683.57	2.7002	8.8335	683.15	2.6856

TABLE 14. Properties of liquid and vapor—Continued

	$p=650.0$ kPa			$p=700.0$ kPa			$p=800.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1302.0	62.53	0.3997	1302.1	62.55	0.3996	1302.2	62.60	0.3994
−80	1289.2	70.32	0.4406	1289.3	70.34	0.4405	1289.4	70.39	0.4403
−75	1276.3	78.12	0.4804	1276.4	78.15	0.4804	1276.5	78.19	0.4802
−70	1263.2	85.94	0.5194	1263.3	85.96	0.5193	1263.5	86.01	0.5191
−65	1250.0	93.77	0.5575	1250.1	93.80	0.5574	1250.3	93.84	0.5572
−60	1236.7	101.63	0.5948	1236.7	101.65	0.5947	1236.9	101.70	0.5945
−55	1223.1	109.52	0.6314	1223.2	109.54	0.6313	1223.4	109.58	0.6311
−50	1209.3	117.44	0.6673	1209.4	117.46	0.6672	1209.6	117.50	0.6670
−45	1195.4	125.40	0.7025	1195.5	125.42	0.7024	1195.7	125.46	0.7022
−40	1181.1	133.40	0.7372	1181.2	133.42	0.7371	1181.4	133.46	0.7369
−35	1166.6	141.46	0.7714	1166.7	141.47	0.7713	1167.0	141.51	0.7711
−30	1151.8	149.57	0.8051	1152.0	149.59	0.8050	1152.2	149.62	0.8048
−25	1136.7	157.75	0.8384	1136.8	157.77	0.8383	1137.1	157.79	0.8381
−20	1121.2	166.01	0.8714	1121.4	166.02	0.8713	1121.6	166.04	0.8710
−15	1105.3	174.34	0.9040	1105.5	174.36	0.9039	1105.8	174.38	0.9036
−10	1089.0	182.78	0.9364	1089.1	182.79	0.9362	1089.5	182.81	0.9359
−5	17.470	515.95	2.1874	1072.3	191.33	0.9684	1072.6	191.34	0.9681
0	16.941	521.61	2.2083	18.467	519.75	2.1911	21.658	515.84	2.1585
5	16.461	527.04	2.2280	17.922	525.35	2.2114	20.957	521.84	2.1803
10	16.022	532.31	2.2467	17.425	530.76	2.2307	20.329	527.57	2.2007
15	15.616	537.46	2.2648	16.969	536.03	2.2492	19.758	533.10	2.2200
20	15.239	542.52	2.2822	16.547	541.19	2.2669	19.235	538.48	2.2385
25	14.887	547.52	2.2991	16.154	546.28	2.2841	18.751	543.75	2.2564
30	14.556	552.46	2.3155	15.786	551.30	2.3008	18.301	548.93	2.2736
35	14.244	557.37	2.3316	15.440	556.27	2.3171	17.881	554.05	2.2904
40	13.950	562.25	2.3473	15.114	561.22	2.3330	17.486	559.12	2.3067
45	13.671	567.11	2.3627	14.805	566.13	2.3486	17.115	564.15	2.3226
50	13.405	571.96	2.3778	14.512	571.04	2.3639	16.763	569.15	2.3382
55	13.152	576.81	2.3927	14.234	575.93	2.3789	16.430	574.14	2.3535
60	12.911	581.66	2.4074	13.968	580.82	2.3937	16.114	579.11	2.3686
65	12.680	586.51	2.4218	13.715	585.70	2.4082	15.812	584.08	2.3834
70	12.459	591.37	2.4361	13.473	590.60	2.4226	15.525	589.05	2.3980
75	12.248	596.24	2.4502	13.240	595.50	2.4368	15.250	594.02	2.4123
80	12.044	601.13	2.4641	13.017	600.42	2.4508	14.986	598.99	2.4265
85	11.848	606.03	2.4779	12.803	605.35	2.4647	14.734	603.98	2.4406
90	11.660	610.96	2.4916	12.597	610.30	2.4784	14.491	608.99	2.4544
95	11.478	615.90	2.5051	12.399	615.27	2.4920	14.258	614.00	2.4682
100	11.303	620.87	2.5185	12.208	620.27	2.5055	14.033	619.04	2.4817
105	11.133	625.87	2.5318	12.023	625.28	2.5188	13.817	624.10	2.4952
110	10.970	630.89	2.5450	11.845	630.32	2.5321	13.608	629.18	2.5086
115	10.812	635.94	2.5581	11.672	635.39	2.5452	13.406	634.29	2.5218
120	10.658	641.01	2.5711	11.505	640.48	2.5583	13.211	639.42	2.5349
125	10.510	646.12	2.5840	11.344	645.60	2.5712	13.023	644.57	2.5480
130	10.366	651.25	2.5968	11.187	650.76	2.5841	12.840	649.76	2.5609
135	10.226	656.42	2.6095	11.035	655.94	2.5968	12.663	654.97	2.5737
140	10.090	661.62	2.6222	10.888	661.15	2.6095	12.492	660.21	2.5865
145	9.9587	666.85	2.6348	10.745	666.39	2.6221	12.325	665.48	2.5992
150	9.8306	672.11	2.6173	10.606	671.67	2.6347	12.161	670.78	2.6118
155	9.7061	677.41	2.6597	10.470	676.98	2.6472	12.007	676.12	2.6243
160	9.5850	682.73	2.6721	10.339	682.32	2.6596	11.854	681.48	2.6368

TABLE 14. Properties of liquid and vapor—Continued

	$p=900.0$ kPa			$p=1000.0$ kPa			$p=1100.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1302.3	62.65	0.3993	1302.4	62.70	0.3991	1302.5	62.74	0.3990
−80	1289.5	70.44	0.4402	1289.7	70.49	0.4400	1289.8	70.53	0.4399
−75	1276.6	78.24	0.4800	1276.8	78.29	0.4799	1276.9	78.33	0.4797
−70	1263.6	86.05	0.5190	1263.7	86.10	0.5188	1263.9	86.15	0.5187
−65	1250.4	93.89	0.5571	1250.6	93.93	0.5569	1250.7	93.98	0.5567
−60	1237.1	101.74	0.5944	1237.2	101.78	0.5942	1237.4	101.83	0.5940
−55	1223.5	109.62	0.6309	1223.7	109.67	0.6307	1223.9	109.71	0.6306
−50	1209.8	117.54	0.6668	1210.0	117.58	0.6666	1210.2	117.62	0.6664
−45	1195.8	125.49	0.7020	1196.0	125.53	0.7018	1196.2	125.57	0.7017
−40	1181.6	133.49	0.7367	1181.9	133.53	0.7365	1182.1	133.57	0.7363
−35	1167.2	141.54	0.7709	1167.4	141.58	0.7707	1167.6	141.61	0.7705
−30	1152.4	149.65	0.8046	1152.7	149.68	0.8044	1152.9	149.72	0.8041
−25	1137.4	157.82	0.8379	1137.6	157.85	0.8376	1137.9	157.88	0.8374
−20	1121.9	166.07	0.8708	1122.2	166.10	0.8705	1122.5	166.12	0.8703
−15	1106.1	174.40	0.9033	1106.4	174.42	0.9031	1106.7	174.45	0.9028
−10	1089.8	182.83	0.9357	1090.1	182.84	0.9354	1090.4	182.86	0.9351
−5	1073.0	191.36	0.9678	1073.3	191.37	0.9675	1073.7	191.38	0.9672
0	1055.6	200.01	0.9997	1056.0	200.02	0.9994	1056.4	200.03	0.9991
5	24.164	518.12	2.1509	1038.0	208.80	1.0313	1038.4	208.81	1.0310
10	23.375	524.22	2.1727	26.586	520.69	2.1460	29.989	516.93	2.1202
15	22.669	530.04	2.1930	25.716	526.85	2.1676	28.919	523.50	2.1432
20	22.027	535.67	2.2124	24.936	532.75	2.1879	27.975	529.71	2.1646
25	21.440	541.14	2.2309	24.229	538.45	2.2072	27.129	535.66	2.1847
30	20.898	546.50	2.2487	23.581	544.00	2.2256	26.360	541.42	2.2039
35	20.394	551.77	2.2660	22.983	549.43	2.2434	25.656	547.04	2.2223
40	19.923	556.97	2.2827	22.428	554.78	2.2606	25.006	552.54	2.2400
45	19.481	562.12	2.2990	21.909	560.06	2.2774	24.402	557.96	2.2571
50	19.066	567.24	2.3150	21.423	565.29	2.2937	23.839	563.30	2.2738
55	18.673	572.32	2.3306	20.966	570.47	2.3096	23.310	568.60	2.2901
60	18.301	577.38	2.3459	20.534	575.63	2.3252	22.813	573.85	2.3060
65	17.948	582.43	2.3610	20.125	580.76	2.3405	22.344	579.07	2.3215
70	17.612	587.47	2.3758	19.737	585.88	2.3555	21.900	584.27	2.3368
75	17.292	592.51	2.3903	19.368	590.99	2.3703	21.479	589.45	2.3518
80	16.985	597.55	2.4047	19.015	596.10	2.3848	21.078	594.62	2.3665
85	16.692	602.60	2.4189	18.679	601.20	2.3992	20.695	599.79	2.3811
90	16.411	607.66	2.4329	18.357	606.32	2.4134	20.330	604.96	2.3954
95	16.141	612.73	2.4468	18.048	611.44	2.4274	19.980	610.14	2.4095
100	15.881	617.81	2.4605	17.752	616.57	2.4412	19.645	615.32	2.4235
105	15.631	622.91	2.4741	17.467	621.72	2.4549	19.324	620.52	2.4374
110	15.391	628.04	2.4875	17.193	626.88	2.4685	19.015	625.72	2.4510
115	15.158	633.18	2.5009	16.929	632.07	2.4819	18.717	630.95	2.4646
120	14.934	638.35	2.5141	16.674	637.27	2.4953	18.431	636.19	2.4780
125	14.718	643.54	2.5272	16.428	642.50	2.5085	18.155	641.45	2.4913
130	14.508	648.75	2.5402	16.190	647.75	2.5216	17.888	646.73	2.5045
135	14.305	654.00	2.5532	15.961	653.02	2.5346	17.630	652.04	2.5176
140	14.109	659.27	2.5660	15.738	658.32	2.5475	17.381	657.37	2.5306
145	13.918	664.57	2.5788	15.523	663.65	2.5603	17.140	662.73	2.5434
150	13.733	669.89	2.5914	15.314	669.00	2.5730	16.906	668.11	2.5562
155	13.554	675.25	2.6040	15.111	674.39	2.5857	16.680	673.52	2.5689
160	13.379	680.64	2.6165	14.915	679.80	2.5982	16.460	678.95	2.5816

TABLE 14. Properties of liquid and vapor—Continued

	$p=1200.0$ kPa			$p=1400.0$ kPa			$p=1600.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1302.7	62.79	0.3988	1302.9	62.89	0.3985	1303.1	62.99	0.3983
−80	1289.9	70.58	0.4397	1290.2	70.68	0.4394	1290.4	70.77	0.4391
−75	1277.0	78.38	0.4796	1277.3	78.47	0.4792	1277.6	78.57	0.4789
−70	1264.0	86.19	0.5185	1264.3	86.28	0.5182	1264.6	86.37	0.5178
−65	1250.9	94.02	0.5566	1251.2	94.11	0.5562	1251.5	94.20	0.5559
−60	1237.5	101.87	0.5938	1237.9	101.96	0.5935	1238.2	102.05	0.5931
−55	1224.0	109.75	0.6304	1224.4	109.83	0.6300	1224.7	109.92	0.6296
−50	1210.3	117.66	0.6662	1210.7	117.74	0.6658	1211.1	117.82	0.6655
−45	1196.4	125.61	0.7015	1196.8	125.69	0.7011	1197.2	125.77	0.7007
−40	1182.3	133.60	0.7361	1182.7	133.68	0.7357	1183.1	133.75	0.7353
−35	1167.8	141.65	0.7702	1168.3	141.72	0.7698	1168.7	141.79	0.7694
−30	1153.1	149.75	0.8039	1153.6	149.81	0.8035	1154.1	149.88	0.8030
−25	1138.1	157.91	0.8371	1138.6	157.97	0.8367	1139.1	158.03	0.8362
−20	1122.7	166.15	0.8700	1123.3	166.20	0.8695	1123.8	166.26	0.8690
−15	1106.9	174.47	0.9026	1107.5	174.52	0.9020	1108.1	174.56	0.9015
−10	1090.7	182.88	0.9348	1091.4	182.92	0.9343	1092.0	182.96	0.9337
−5	1074.0	191.40	0.9669	1074.7	191.43	0.9663	1075.4	191.46	0.9657
0	1056.7	200.03	0.9988	1057.5	200.05	0.9982	1058.2	200.07	0.9975
5	1038.8	208.81	1.0306	1039.6	208.81	1.0299	1040.4	208.82	1.0293
10	1020.1	217.74	1.0625	1021.0	217.73	1.0617	1021.9	217.72	1.0610
15	32.303	519.96	2.1196	1001.5	226.83	1.0936	1002.5	226.80	1.0928
20	31.161	526.53	2.1422	38.063	519.67	2.0990	982.11	236.09	1.1247
25	30.151	532.77	2.1633	36.626	526.61	2.1225	43.819	519.82	2.0829
30	29.243	538.76	2.1832	35.369	533.16	2.1442	42.071	527.09	2.1071
35	28.418	544.57	2.2023	34.248	539.42	2.1647	40.555	533.91	2.1294
40	27.662	550.24	2.2205	33.237	545.47	2.1842	39.215	540.41	2.1504
45	26.964	555.81	2.2381	32.316	551.35	2.2029	38.012	546.68	2.1702
50	26.315	561.28	2.2552	31.469	557.11	2.2208	36.922	552.75	2.1892
55	25.710	566.69	2.2718	30.686	562.76	2.2382	35.924	558.69	2.2074
60	25.142	572.04	2.2880	29.958	568.34	2.2550	35.005	564.50	2.2250
65	24.608	577.35	2.3038	29.277	573.85	2.2714	34.152	570.23	2.2420
70	24.104	582.64	2.3193	28.639	579.30	2.2875	33.358	575.88	2.2586
75	23.626	587.89	2.3346	28.038	584.72	2.3031	32.615	581.47	2.2748
80	23.173	593.14	2.3495	27.470	590.11	2.3185	31.916	587.02	2.2906
85	22.742	598.37	2.3642	26.932	595.48	2.3336	31.258	592.53	2.3061
90	22.331	603.60	2.3787	26.422	600.83	2.3484	30.636	598.01	2.3213
95	21.939	608.83	2.3930	25.936	606.18	2.3631	30.046	603.48	2.3363
100	21.563	614.06	2.4071	25.472	611.52	2.3775	29.485	608.93	2.3510
105	21.203	619.30	2.4211	25.029	616.85	2.3917	28.951	614.37	2.3655
110	20.857	624.56	2.4349	24.605	622.20	2.4057	28.441	619.81	2.3798
115	20.525	629.82	2.4485	24.199	627.55	2.4196	27.954	625.25	2.3939
120	20.206	635.10	2.4621	23.809	632.91	2.4333	27.487	630.69	2.4078
125	19.898	640.40	2.4755	23.434	638.28	2.4469	27.040	636.14	2.4216
130	19.601	645.72	2.4887	23.073	643.67	2.4603	26.610	641.60	2.4352
135	19.314	651.06	2.5019	22.726	649.07	2.4737	26.197	647.07	2.4487
140	19.037	656.42	2.5149	22.390	654.50	2.4869	25.799	652.56	2.4621
145	18.769	661.80	2.5279	22.067	659.94	2.5000	25.416	658.07	2.4753
150	18.510	667.21	2.5408	21.754	665.41	2.5130	25.046	663.59	2.4884
155	18.259	672.65	2.5535	21.451	670.90	2.5259	24.689	669.13	2.5015
160	18.016	678.11	2.5662	21.158	676.41	2.5387	24.343	674.70	2.5144

TABLE 14. Properties of liquid and vapor—Continued

	$p=1800.0$ kPa			$p=2000.0$ kPa			$p=2200.0$ kPa		
t C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1303.4	63.09	0.3980	1303.6	63.18	0.3977	1303.9	63.28	0.3974
−80	1290.7	70.87	0.4388	1290.9	70.97	0.4385	1291.2	71.06	0.4382
−75	1277.8	78.66	0.4786	1278.1	78.76	0.4783	1278.4	78.85	0.4780
−70	1264.9	86.47	0.5175	1265.2	86.56	0.5172	1265.5	86.65	0.5169
−65	1251.8	94.29	0.5556	1252.1	94.38	0.5552	1252.4	94.47	0.5549
−60	1238.5	102.13	0.5928	1238.8	102.22	0.5924	1239.1	102.31	0.5921
−55	1225.1	110.00	0.6293	1225.4	110.09	0.6289	1225.7	110.17	0.6286
−50	1211.4	117.90	0.6651	1211.8	117.99	0.6647	1212.1	118.07	0.6644
−45	1197.6	125.84	0.7003	1197.9	125.92	0.6999	1198.3	126.00	0.6995
−40	1183.5	133.83	0.7349	1183.9	133.90	0.7345	1184.3	133.98	0.7341
−35	1169.1	141.86	0.7690	1169.6	141.93	0.7685	1170.0	142.00	0.7681
−30	1154.5	149.94	0.8026	1155.0	150.01	0.8021	1155.4	150.07	0.8017
−25	1139.6	158.09	0.8357	1140.1	158.15	0.8353	1140.6	158.21	0.8348
−20	1124.3	166.31	0.8685	1124.9	166.37	0.8681	1125.4	166.42	0.8676
−15	1108.7	174.61	0.9010	1109.3	174.66	0.9005	1109.8	174.70	0.9000
−10	1092.6	183.00	0.9332	1093.2	183.04	0.9326	1093.9	183.08	0.9321
−5	1076.1	191.49	0.9651	1076.7	191.52	0.9646	1077.4	191.55	0.9640
0	1059.0	200.09	0.9969	1059.7	200.11	0.9963	1060.4	200.13	0.9957
5	1041.3	208.82	1.0286	1042.1	208.83	1.0279	1042.9	208.84	1.0273
10	1022.8	217.71	1.0603	1023.7	217.70	1.0596	1024.6	217.69	1.0588
15	1003.5	226.77	1.0920	1004.6	226.74	1.0912	1005.5	226.72	1.0904
20	983.26	236.04	1.1239	984.39	235.99	1.1230	985.51	235.94	1.1222
25	961.73	245.56	1.1561	963.03	245.48	1.1551	964.31	245.41	1.1542
30	49.519	520.41	2.0706	940.17	255.28	1.1877	941.66	255.17	1.1866
35	47.454	527.96	2.0953	55.117	521.42	2.0614	917.14	265.30	1.2198
40	45.677	535.02	2.1181	52.739	529.20	2.0865	60.568	522.84	2.0549
45	44.115	541.73	2.1393	50.703	536.47	2.1095	57.890	530.81	2.0801
50	42.720	548.18	2.1595	48.922	543.36	2.1310	55.606	538.25	2.1033
55	41.460	554.43	2.1786	47.338	549.98	2.1513	53.614	545.30	2.1249
60	40.311	560.53	2.1971	45.911	556.38	2.1707	51.847	552.06	2.1454
65	39.256	566.49	2.2148	44.614	562.62	2.1893	50.259	558.59	2.1649
70	38.279	572.35	2.2321	43.424	568.71	2.2072	48.818	564.95	2.1835
75	37.372	578.14	2.2488	42.327	574.70	2.2245	47.499	571.17	2.2015
80	36.525	583.85	2.2651	41.309	580.60	2.2413	46.284	577.27	2.2189
85	35.730	589.52	2.2810	40.359	586.43	2.2577	45.159	583.28	2.2358
90	34.982	595.14	2.2966	39.470	592.21	2.2737	44.110	589.21	2.2523
95	34.276	600.73	2.3119	38.634	597.93	2.2894	43.129	595.08	2.2683
100	33.607	606.30	2.3269	37.846	603.62	2.3047	42.208	600.90	2.2840
105	32.973	611.85	2.3417	37.101	609.29	2.3198	41.340	606.68	2.2994
110	32.369	617.39	2.3562	36.394	614.93	2.3346	40.520	612.44	2.3145
115	31.794	622.92	2.3706	35.722	620.56	2.3492	39.743	618.17	2.3294
120	31.244	628.45	2.3847	35.082	626.18	2.3636	39.006	623.88	2.3440
125	30.718	633.98	2.3987	34.471	631.79	2.3778	38.303	629.58	2.3584
130	30.214	639.51	2.4125	33.888	637.41	2.3918	37.633	635.28	2.3726
135	29.731	645.06	2.4262	33.329	643.02	2.4057	36.993	640.97	2.3867
140	29.266	650.61	2.4397	32.792	648.65	2.4194	36.380	646.67	2.4005
145	28.819	656.18	2.4531	32.277	654.28	2.4329	35.793	652.36	2.4143
150	28.388	661.76	2.4664	31.782	659.92	2.4463	35.229	658.07	2.4278
155	27.973	667.36	2.4796	31.306	665.58	2.4596	34.687	663.78	2.4412
160	27.572	672.98	2.4926	30.846	671.25	2.4728	34.166	669.51	2.4545

TABLE 14. Properties of liquid and vapor—Continued

	$p=2400.0$ kPa			$p=2600.0$ kPa			$p=2800.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1304.1	63.38	0.3971	1304.4	63.48	0.3968	1304.6	63.57	0.3965
−80	1291.4	71.16	0.4379	1291.7	71.25	0.4376	1291.9	71.35	0.4373
−75	1278.7	78.94	0.4777	1278.9	79.04	0.4774	1279.2	79.13	0.4770
−70	1265.7	86.74	0.5165	1266.0	86.83	0.5162	1266.3	86.93	0.5159
−65	1252.7	94.56	0.5545	1253.0	94.65	0.5542	1253.3	94.74	0.5539
−60	1239.5	102.39	0.5917	1239.8	102.48	0.5914	1240.1	102.57	0.5911
−55	1226.1	110.26	0.6282	1226.4	110.34	0.6278	1226.7	110.43	0.6275
−50	1212.5	118.15	0.6640	1212.8	118.23	0.6636	1213.2	118.31	0.6632
−45	1198.7	126.08	0.6991	1199.1	126.16	0.6987	1199.4	126.24	0.6983
−40	1184.7	134.05	0.7337	1185.1	134.13	0.7333	1185.5	134.20	0.7329
−35	1170.4	142.07	0.7677	1170.9	142.14	0.7673	1171.3	142.21	0.7669
−30	1155.9	150.14	0.8013	1156.4	150.21	0.8008	1156.8	150.27	0.8004
−25	1141.1	158.27	0.8344	1141.6	158.33	0.8339	1142.1	158.40	0.8334
−20	1125.9	166.47	0.8671	1126.4	166.53	0.8666	1127.0	166.59	0.8661
−15	1110.4	174.75	0.8995	1111.0	174.80	0.8990	1111.5	174.85	0.8984
−10	1094.5	183.12	0.9316	1095.1	183.16	0.9310	1095.7	183.20	0.9305
−5	1078.1	191.58	0.9634	1078.7	191.61	0.9628	1079.4	191.64	0.9623
0	1061.2	200.15	0.9951	1061.9	200.17	0.9945	1062.6	200.20	0.9939
5	1043.7	208.85	1.0266	1044.5	208.86	1.0260	1045.3	208.87	1.0253
10	1025.5	217.69	1.0581	1026.4	217.68	1.0574	1027.3	217.68	1.0567
15	1006.5	226.70	1.0897	1007.5	226.68	1.0889	1008.5	226.66	1.0881
20	986.62	235.90	1.1213	987.72	235.86	1.1205	988.81	235.82	1.1197
25	965.58	245.34	1.1532	966.83	245.27	1.1523	968.06	245.20	1.1514
30	943.12	255.06	1.1856	944.57	254.96	1.1845	945.99	254.86	1.1835
35	918.87	265.14	1.2186	920.58	264.99	1.2174	922.25	264.85	1.2162
40	69.429	515.75	2.0223	894.29	275.48	1.2512	896.32	275.28	1.2498
45	65.835	524.66	2.0506	74.784	517.84	2.0202	867.33	286.30	1.2847
50	62.878	532.77	2.0759	70.886	526.84	2.0482	79.855	520.32	2.0198
55	60.362	540.34	2.0991	67.679	535.06	2.0735	75.702	529.36	2.0476
60	58.171	547.52	2.1208	64.952	542.73	2.0967	72.277	537.65	2.0727
65	56.231	554.40	2.1413	62.578	550.01	2.1184	69.361	545.40	2.0958
70	54.490	561.05	2.1609	60.477	556.99	2.1389	66.822	552.76	2.1174
75	52.912	567.52	2.1796	58.593	563.74	2.1584	64.575	559.82	2.1378
80	51.470	573.84	2.1976	56.887	570.30	2.1771	62.560	566.65	2.1573
85	50.143	580.04	2.2150	55.329	576.71	2.1951	60.736	573.29	2.1760
90	48.914	586.14	2.2320	53.895	583.00	2.2126	59.069	579.79	2.1940
95	47.770	592.17	2.2484	52.569	589.19	2.2295	57.537	586.16	2.2114
100	46.702	598.13	2.2645	51.335	595.30	2.2460	56.119	592.42	2.2283
105	45.699	604.04	2.2803	50.183	601.35	2.2621	54.800	598.61	2.2448
110	44.754	609.91	2.2957	49.102	607.34	2.2778	53.569	604.73	2.2609
115	43.863	615.74	2.3108	48.084	613.29	2.2933	52.414	610.80	2.2766
120	43.018	621.56	2.3257	47.124	619.20	2.3084	51.327	616.82	2.2920
125	42.216	627.35	2.3403	46.215	625.09	2.3233	50.302	622.80	2.3071
130	41.454	633.13	2.3548	45.352	630.95	2.3379	49.331	628.76	2.3220
135	40.726	638.90	2.3690	44.531	636.81	2.3523	48.410	634.70	2.3366
140	40.032	644.67	2.3830	43.749	642.65	2.3666	47.534	640.62	2.3510
145	39.367	650.43	2.3969	43.002	648.49	2.3806	46.700	646.53	2.3653
150	38.730	656.20	2.4106	42.288	654.32	2.3945	45.903	652.43	2.3793
155	38.119	661.98	2.4242	41.603	660.16	2.4082	45.141	658.33	2.3932
160	37.532	667.76	2.4376	40.947	666.00	2.4218	44.411	664.23	2.4069

TABLE 14. Properties of liquid and vapor—Continued

t	p = 3000.0 kPa			p = 3200.0 kPa			p = 3400.0 kPa		
°C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1304.8	63.67	0.3962	1305.1	63.77	0.3959	1305.3	63.87	0.3956
−80	1292.2	71.44	0.4370	1292.5	71.54	0.4366	1292.7	71.64	0.4363
−75	1279.5	79.23	0.4767	1279.7	79.32	0.4764	1280.0	79.42	0.4761
−70	1266.6	87.02	0.5156	1266.9	87.11	0.5152	1267.1	87.20	0.5149
−65	1253.6	94.83	0.5535	1253.9	94.92	0.5532	1254.2	95.01	0.5529
−60	1240.4	102.66	0.5907	1240.7	102.75	0.5904	1241.0	102.83	0.5900
−55	1227.1	110.51	0.6271	1227.4	110.60	0.6268	1227.7	110.68	0.6264
−50	1213.5	118.40	0.6629	1213.9	118.48	0.6625	1214.2	118.56	0.6621
−45	1199.8	126.32	0.6980	1200.2	126.39	0.6976	1200.6	126.47	0.6972
−40	1185.9	134.28	0.7325	1186.3	134.35	0.7321	1186.7	134.43	0.7317
−35	1171.7	142.28	0.7665	1172.1	142.35	0.7660	1172.5	142.43	0.7656
−30	1157.3	150.34	0.7999	1157.7	150.41	0.7995	1158.2	150.47	0.7991
−25	1142.5	158.46	0.8330	1143.0	158.52	0.8325	1143.5	158.58	0.8321
−20	1127.5	166.64	0.8656	1128.0	166.70	0.8652	1128.5	166.75	0.8647
−15	1112.1	174.90	0.8979	1112.6	174.95	0.8974	1113.2	175.00	0.8969
−10	1096.3	183.24	0.9299	1096.9	183.28	0.9294	1097.5	183.33	0.9289
−5	1080.1	191.68	0.9617	1080.7	191.71	0.9611	1081.4	191.75	0.9606
0	1063.3	200.22	0.9933	1064.1	200.24	0.9927	1064.8	200.27	0.9921
5	1046.1	208.88	1.0247	1046.8	208.89	1.0240	1047.6	208.91	1.0234
10	1028.1	217.68	1.0560	1029.0	217.68	1.0553	1029.8	217.68	1.0547
15	1009.4	226.64	1.0874	1010.4	226.62	1.0866	1011.3	226.60	1.0859
20	989.89	235.78	1.1188	990.95	235.74	1.1180	992.01	235.71	1.1172
25	969.28	245.14	1.1505	970.49	245.08	1.1496	971.68	245.02	1.1487
30	947.39	254.76	1.1825	948.78	254.67	1.1815	950.14	254.58	1.1805
35	923.89	264.71	1.2151	925.51	264.58	1.2139	927.10	264.45	1.2128
40	898.29	275.08	1.2484	900.23	274.89	1.2471	902.12	274.71	1.2458
45	869.80	286.02	1.2831	872.21	285.74	1.2815	874.54	285.48	1.2800
50	90.147	512.98	1.9898	840.17	297.37	1.3178	843.21	296.98	1.3158
55	84.627	523.15	2.0211	94.763	516.25	1.9932	106.64	508.36	1.9631
60	80.268	532.20	2.0485	89.095	526.31	2.0237	99.014	519.84	1.9978
65	76.660	540.52	2.0732	84.579	535.33	2.0505	93.264	529.76	2.0274
70	73.581	548.33	2.0962	80.822	543.66	2.0750	88.637	538.73	2.0537
75	70.896	555.75	2.1176	77.606	551.50	2.0977	84.764	547.04	2.0778
80	68.518	562.88	2.1380	74.796	558.96	2.1190	81.436	554.89	2.1002
85	66.385	569.77	2.1573	72.303	566.14	2.1391	78.520	562.38	2.1212
90	64.452	576.48	2.1760	70.065	573.09	2.1584	75.928	569.60	2.1412
95	62.687	583.05	2.1939	68.035	579.86	2.1769	73.597	576.59	2.1604
100	61.063	589.48	2.2113	66.179	586.48	2.1948	71.481	583.41	2.1788
105	59.560	595.82	2.2281	64.471	592.98	2.2121	69.545	590.08	2.1965
110	58.163	602.08	2.2446	62.891	599.38	2.2289	67.762	596.64	2.2137
115	56.857	608.27	2.2606	61.421	605.70	2.2453	66.110	603.09	2.2305
120	55.633	614.40	2.2763	60.047	611.95	2.2613	64.573	609.46	2.2468
125	54.482	620.49	2.2917	58.758	618.14	2.2769	63.137	615.77	2.2627
130	53.395	626.54	2.3068	57.546	624.29	2.2923	61.789	622.02	2.2784
135	52.366	632.56	2.3217	56.402	630.41	2.3074	60.520	628.23	2.2937
140	51.390	638.56	2.3363	55.318	636.49	2.3222	59.322	634.40	2.3087
145	50.462	644.55	2.3507	54.290	642.56	2.3368	58.188	640.55	2.3235
150	49.577	650.52	2.3649	53.313	648.60	2.3512	57.112	646.67	2.3380
155	48.733	656.49	2.3789	52.382	654.64	2.3653	56.088	652.77	2.3524
160	47.926	662.45	2.3928	51.492	660.66	2.3793	55.112	658.86	2.3665

TABLE 14. Properties of liquid and vapor—Continued

	$p=3600.0$ kPa			$p=3800.0$ kPa			$p=4000.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1305.6	63.96	0.3953	1305.8	64.06	0.3950	1306.0	64.16	0.3947
−80	1293.0	71.73	0.4360	1293.2	71.83	0.4357	1293.5	71.93	0.4354
−75	1280.2	79.51	0.4758	1280.5	79.60	0.4755	1280.8	79.70	0.4752
−70	1267.4	87.30	0.5146	1267.7	87.39	0.5143	1268.0	87.48	0.5140
−65	1254.4	95.10	0.5525	1254.7	95.19	0.5522	1255.0	95.28	0.5519
−60	1241.3	102.92	0.5897	1241.6	103.01	0.5893	1242.0	103.10	0.5890
−55	1228.0	110.77	0.6261	1228.4	110.85	0.6257	1228.7	110.94	0.6254
−50	1214.6	118.64	0.6618	1214.9	118.73	0.6614	1215.3	118.81	0.6610
−45	1200.9	126.55	0.6968	1201.3	126.63	0.6964	1201.7	126.71	0.6961
−40	1187.1	134.50	0.7313	1187.5	134.58	0.7309	1187.9	134.65	0.7305
−35	1173.0	142.50	0.7652	1173.4	142.57	0.7648	1173.8	142.64	0.7644
−30	1158.6	150.54	0.7986	1159.1	150.61	0.7982	1159.5	150.68	0.7978
−25	1144.0	158.64	0.8316	1144.5	158.71	0.8312	1144.9	158.77	0.8307
−20	1129.0	166.81	0.8642	1129.5	166.87	0.8637	1130.1	166.93	0.8633
−15	1113.8	175.05	0.8964	1114.3	175.10	0.8959	1114.9	175.15	0.8954
−10	1098.1	183.37	0.9284	1098.7	183.41	0.9278	1099.3	183.46	0.9273
−5	1082.0	191.78	0.9600	1082.7	191.82	0.9595	1083.3	191.85	0.9589
0	1065.5	200.29	0.9915	1066.2	200.32	0.9909	1066.9	200.35	0.9903
5	1048.4	208.92	1.0228	1049.1	208.94	1.0221	1049.9	208.95	1.0215
10	1030.7	217.68	1.0540	1031.5	217.68	1.0533	1032.3	217.69	1.0526
15	1012.3	226.59	1.0852	1013.2	226.58	1.0844	1014.1	226.56	1.0837
20	993.05	235.67	1.1164	994.09	235.64	1.1156	995.11	235.61	1.1148
25	972.86	244.96	1.1478	974.02	244.91	1.1470	975.18	244.85	1.1461
30	951.49	254.49	1.1795	952.81	254.41	1.1786	954.12	254.33	1.1776
35	928.66	264.32	1.2117	930.20	264.20	1.2106	931.71	264.08	1.2095
40	903.97	274.53	1.2445	905.79	274.36	1.2433	907.58	274.19	1.2421
45	876.81	285.23	1.2784	879.03	284.99	1.2770	881.19	284.75	1.2755
50	846.13	296.62	1.3140	848.95	296.27	1.3121	851.68	295.93	1.3104
55	809.93	309.06	1.3522	813.81	308.52	1.3498	817.49	308.02	1.3475
60	110.44	512.57	1.9703	124.11	504.11	1.9398	775.16	321.65	1.3887
65	102.92	523.70	2.0034	113.87	517.00	1.9782	126.63	509.42	1.9508
70	97.144	533.46	2.0321	106.51	527.79	2.0098	116.98	521.62	1.9866
75	92.446	542.35	2.0578	100.75	537.39	2.0376	109.81	532.09	2.0169
80	88.488	550.64	2.0815	96.017	546.19	2.0627	104.10	541.51	2.0438
85	85.072	558.49	2.1035	92.002	554.44	2.0859	99.362	550.22	2.0683
90	82.070	566.00	2.1244	88.519	562.28	2.1076	95.313	558.42	2.0910
95	79.394	573.24	2.1442	85.448	569.79	2.1282	91.784	566.23	2.1124
100	76.984	580.27	2.1631	82.704	577.05	2.1478	88.660	573.74	2.1327
105	74.792	587.12	2.1814	80.226	584.10	2.1666	85.860	581.01	2.1520
110	72.785	593.84	2.1990	77.969	590.99	2.1847	83.327	588.09	2.1706
115	70.934	600.44	2.2161	75.900	597.74	2.2022	81.015	595.00	2.1885
120	69.219	606.94	2.2328	73.989	604.39	2.2192	78.892	601.79	2.2059
125	67.621	613.37	2.2490	72.217	610.93	2.2357	76.929	608.47	2.2228
130	66.127	619.73	2.2649	70.565	617.40	2.2519	75.106	615.05	2.2392
135	64.725	626.03	2.2804	69.019	623.81	2.2677	73.406	621.56	2.2553
140	63.404	632.29	2.2957	67.566	630.16	2.2831	71.813	628.02	2.2710
145	62.156	638.52	2.3107	66.198	636.48	2.2983	70.315	634.41	2.2864
150	60.975	644.72	2.3254	64.905	642.75	2.3132	68.904	640.77	2.3015
155	59.853	650.89	2.3399	63.680	649.00	2.3279	67.569	647.09	2.3163
160	58.786	657.05	2.3542	62.517	655.23	2.3424	66.304	653.39	2.3310

TABLE 14. Properties of liquid and vapor—Continued

	$p=4500.0$ kPa			$p=5000.0$ kPa			$p=5500.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1306.6	64.40	0.3940	1307.2	64.65	0.3932	1307.8	64.90	0.3925
−80	1294.1	72.17	0.4347	1294.7	72.41	0.4339	1295.3	72.65	0.4332
−75	1281.4	79.94	0.4744	1282.1	80.17	0.4736	1282.7	80.41	0.4729
−70	1268.7	87.71	0.5132	1269.4	87.95	0.5124	1270.0	88.18	0.5116
−65	1255.8	95.51	0.5511	1256.5	95.73	0.5502	1257.2	95.96	0.5494
−60	1242.7	103.32	0.5881	1243.5	103.54	0.5873	1244.3	103.76	0.5865
−55	1229.5	111.15	0.6245	1230.3	111.37	0.6236	1231.1	111.58	0.6227
−50	1216.1	119.02	0.6601	1217.0	119.23	0.6592	1217.9	119.43	0.6583
−45	1202.6	126.91	0.6951	1203.5	127.11	0.6942	1204.4	127.31	0.6932
−40	1188.8	134.85	0.7295	1189.8	135.04	0.7285	1190.8	135.23	0.7276
−35	1174.8	142.82	0.7634	1175.9	143.01	0.7623	1176.9	143.19	0.7613
−30	1160.6	150.85	0.7967	1161.7	151.02	0.7956	1162.8	151.19	0.7946
−25	1146.1	158.93	0.8296	1147.3	159.09	0.8285	1148.4	159.25	0.8274
−20	1131.3	167.07	0.8621	1132.6	167.22	0.8609	1133.8	167.37	0.8598
−15	1116.2	175.28	0.8942	1117.6	175.42	0.8930	1118.9	175.55	0.8918
−10	1100.7	183.57	0.9260	1102.2	183.69	0.9247	1103.6	183.81	0.9234
−5	1084.9	191.95	0.9575	1086.4	192.04	0.9562	1088.0	192.14	0.9548
0	1068.6	200.42	0.9888	1070.3	200.49	0.9874	1071.9	200.57	0.9860
5	1051.8	209.00	1.0200	1053.6	209.05	1.0184	1055.4	209.10	1.0169
10	1034.4	217.70	1.0510	1036.4	217.72	1.0493	1038.4	217.74	1.0477
15	1016.4	226.54	1.0819	1018.6	226.52	1.0802	1020.8	226.51	1.0784
20	997.63	235.54	1.1129	1000.1	235.48	1.1110	1002.5	235.43	1.1091
25	978.00	244.73	1.1440	980.76	244.62	1.1419	983.44	244.52	1.1398
30	957.33	254.14	1.1753	960.44	253.96	1.1730	963.46	253.81	1.1707
35	935.40	263.81	1.2069	938.95	263.56	1.2043	942.38	263.32	1.2019
40	911.89	273.80	1.2391	916.02	273.45	1.2362	919.98	273.12	1.2334
45	886.37	284.21	1.2720	891.27	283.71	1.2687	895.93	283.26	1.2655
50	858.13	295.16	1.3062	864.13	294.47	1.3022	869.75	293.84	1.2985
55	825.99	306.88	1.3422	833.67	305.88	1.3373	840.71	304.99	1.3328
60	787.63	319.80	1.3812	798.24	318.27	1.3748	807.57	316.97	1.3690
65	737.02	335.04	1.4266	754.22	332.33	1.4166	767.94	330.23	1.4085
70	151.11	502.57	1.9201	689.76	350.24	1.4692	715.90	345.89	1.4544
75	137.17	516.81	1.9613	177.56	496.13	1.8926	622.17	369.47	1.5226
80	127.52	528.49	1.9946	158.13	512.61	1.9396	204.74	490.72	1.8697
85	120.11	538.75	2.0235	145.59	525.48	1.9758	179.19	509.28	1.9219
90	114.11	548.11	2.0494	136.31	536.56	2.0066	163.62	523.23	1.9606
95	109.07	556.83	2.0733	128.94	546.52	2.0338	152.39	535.01	1.9928
100	104.73	565.08	2.0955	122.85	555.73	2.0586	143.64	545.51	2.0212
105	100.93	572.96	2.1165	117.67	564.38	2.0817	136.49	555.15	2.0468
110	97.557	580.56	2.1365	113.17	572.61	2.1033	130.46	564.16	2.0705
115	94.524	587.93	2.1556	109.20	580.52	2.1238	125.26	572.71	2.0927
120	91.773	595.11	2.1740	105.66	588.16	2.1434	120.69	580.88	2.1136
125	89.259	602.14	2.1917	102.45	595.59	2.1621	116.64	588.77	2.1335
130	86.945	609.04	2.2090	99.542	602.84	2.1803	112.99	596.43	2.1526
135	84.805	615.84	2.2257	96.872	609.95	2.1978	109.68	603.89	2.1710
140	82.815	622.55	2.2421	94.410	616.94	2.2148	106.66	611.19	2.1888
145	80.957	629.18	2.2580	92.128	623.83	2.2314	103.87	618.35	2.2061
150	79.215	635.75	2.2736	90.003	630.63	2.2475	101.30	625.41	2.2228
155	77.577	642.27	2.2890	88.015	637.36	2.2634	98.912	632.37	2.2392
160	76.032	648.75	2.3040	86.150	644.04	2.2789	96.681	639.25	2.2552

TABLE 14. Properties of liquid and vapor—Continued

t	$p = 6000.0$ kPa			$p = 6500.0$ kPa			$p = 7000.0$ kPa		
°C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1308.4	65.14	0.3918	1309.0	65.39	0.3911	1309.6	65.63	0.3903
−80	1295.9	72.89	0.4324	1296.6	73.13	0.4317	1297.2	73.38	0.4310
−75	1283.4	80.65	0.4721	1284.0	80.89	0.4713	1284.7	81.12	0.4706
−70	1270.7	88.41	0.5108	1271.4	88.65	0.5100	1272.1	88.88	0.5092
−65	1257.9	96.19	0.5486	1258.7	96.42	0.5478	1259.4	96.65	0.5470
−60	1245.0	103.98	0.5856	1245.8	104.21	0.5848	1246.5	104.43	0.5839
−55	1231.9	111.80	0.6219	1232.7	112.02	0.6210	1233.5	112.24	0.6201
−50	1218.7	119.64	0.6574	1219.6	119.85	0.6565	1220.4	120.07	0.6556
−45	1205.3	127.52	0.6923	1206.2	127.72	0.6914	1207.1	127.92	0.6904
−40	1191.7	135.43	0.7266	1192.7	135.62	0.7256	1193.6	135.82	0.7247
−35	1177.9	143.37	0.7603	1178.9	143.56	0.7593	1179.9	143.75	0.7583
−30	1163.9	151.37	0.7935	1164.9	151.55	0.7925	1166.0	151.72	0.7915
−25	1149.6	159.42	0.8263	1150.7	159.58	0.8252	1151.9	159.75	0.8241
−20	1135.1	167.52	0.8586	1136.3	167.67	0.8575	1137.5	167.83	0.8564
−15	1120.2	175.69	0.8906	1121.5	175.83	0.8894	1122.8	175.97	0.8882
−10	1105.0	183.93	0.9222	1106.4	184.05	0.9209	1107.8	184.17	0.9197
−5	1089.5	192.24	0.9535	1091.0	192.35	0.9522	1092.5	192.46	0.9509
0	1073.6	200.65	0.9846	1075.2	200.74	0.9832	1076.8	200.82	0.9818
5	1057.2	209.16	1.0154	1059.0	209.22	1.0139	1060.7	209.28	1.0125
10	1040.4	217.77	1.0461	1042.3	217.81	1.0445	1044.2	217.85	1.0430
15	1022.9	226.51	1.0767	1025.0	226.51	1.0750	1027.1	226.52	1.0734
20	1004.9	235.39	1.1073	1007.2	235.36	1.1055	1009.5	235.33	1.1037
25	986.07	244.43	1.1379	988.63	244.36	1.1359	991.13	244.29	1.1340
30	966.40	253.66	1.1685	969.26	253.53	1.1664	972.04	253.42	1.1643
35	945.71	263.11	1.1995	948.93	262.92	1.1971	952.06	262.74	1.1948
40	923.79	272.82	1.2307	927.47	272.54	1.2281	931.02	272.29	1.2256
45	900.37	282.85	1.2625	904.62	282.46	1.2595	908.70	282.11	1.2567
50	875.04	293.27	1.2950	880.06	292.74	1.2916	884.82	292.27	1.2884
55	847.21	304.20	1.3285	853.28	303.49	1.3246	858.97	302.84	1.3208
60	815.93	315.84	1.3637	823.54	314.84	1.3589	830.55	313.94	1.3544
65	779.51	328.50	1.4015	789.61	327.04	1.3953	798.62	325.77	1.3897
70	734.43	342.88	1.4437	749.16	340.56	1.4349	761.55	338.66	1.4275
75	670.51	360.96	1.4959	696.97	356.43	1.4808	716.20	353.23	1.4696
80	387.02	426.87	1.6833	614.83	378.31	1.5432	654.91	371.07	1.5205
85	230.38	487.15	1.8532	351.45	445.17	1.7309	547.14	398.74	1.5982
90	199.45	507.10	1.9086	252.24	485.90	1.8440	347.04	454.30	1.7523
95	181.09	521.85	1.9489	218.08	506.23	1.8996	269.51	486.82	1.8413
100	168.04	534.20	1.9822	197.53	521.42	1.9406	234.51	506.69	1.8949
105	157.97	545.14	2.0113	182.95	534.15	1.9745	212.60	521.97	1.9356
110	149.81	555.13	2.0376	171.72	545.41	2.0041	196.87	534.88	1.9695
115	142.96	564.45	2.0618	162.63	555.68	2.0307	184.70	546.34	1.9992
120	137.08	573.26	2.0843	155.04	565.25	2.0552	174.84	556.80	2.0260
125	131.94	581.68	2.1056	148.53	574.28	2.0780	166.59	566.55	2.0506
130	127.39	589.78	2.1258	142.86	582.90	2.0995	159.53	575.75	2.0736
135	123.30	597.63	2.1452	137.84	591.18	2.1200	153.37	584.53	2.0953
140	119.61	605.28	2.1638	133.34	599.21	2.1395	147.92	592.97	2.1158
145	116.24	612.75	2.1818	129.29	607.01	2.1583	143.05	601.14	2.1355
150	113.15	620.07	2.1992	125.59	614.63	2.1764	138.66	609.08	2.1543
155	110.30	627.28	2.2161	122.20	622.10	2.1940	134.66	616.83	2.1726
160	107.65	634.38	2.2326	119.08	629.44	2.2110	130.99	624.43	2.1902

TABLE 14. Properties of liquid and vapor—Continued

	$p=7000.0$ kPa			$p=8000.0$ kPa			$p=9000.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1309.6	65.63	0.3903	1310.7	66.12	0.3889	1311.9	66.62	0.3875
−80	1297.2	73.37	0.4309	1298.4	73.86	0.4295	1299.6	74.35	0.4280
−75	1284.7	81.12	0.4705	1285.9	81.60	0.4690	1287.2	82.08	0.4675
−70	1272.1	88.88	0.5092	1273.4	89.35	0.5076	1274.7	89.82	0.5061
−65	1259.4	96.64	0.5470	1260.8	97.10	0.5454	1262.2	97.57	0.5438
−60	1246.5	104.43	0.5839	1248.0	104.88	0.5823	1249.5	105.33	0.5806
−55	1233.5	112.23	0.6201	1235.1	112.67	0.6184	1236.7	113.11	0.6167
−50	1220.4	120.06	0.6556	1222.1	120.49	0.6538	1223.7	120.91	0.6521
−45	1207.1	127.92	0.6904	1208.8	128.33	0.6886	1210.6	128.75	0.6868
−40	1193.6	135.81	0.7246	1195.5	136.21	0.7227	1197.3	136.61	0.7209
−35	1179.9	143.75	0.7583	1181.9	144.12	0.7563	1183.8	144.51	0.7544
−30	1166.0	151.72	0.7914	1168.1	152.08	0.7894	1170.2	152.44	0.7874
−25	1151.9	159.75	0.8241	1154.1	160.08	0.8220	1156.3	160.43	0.8199
−20	1137.5	167.82	0.8563	1139.9	168.14	0.8541	1142.2	168.46	0.8519
−15	1122.8	175.96	0.8882	1125.4	176.25	0.8859	1127.9	176.55	0.8836
−10	1107.8	184.17	0.9197	1110.6	184.43	0.9172	1113.2	184.70	0.9148
−5	1092.5	192.46	0.9509	1095.4	192.68	0.9483	1098.3	192.92	0.9458
0	1076.8	200.82	0.9818	1080.0	201.01	0.9791	1083.1	201.21	0.9764
5	1060.7	209.28	1.0125	1064.1	209.42	1.0096	1067.5	209.58	1.0068
10	1044.2	217.84	1.0430	1047.9	217.94	1.0399	1051.5	218.05	1.0370
15	1027.1	226.52	1.0733	1031.1	226.56	1.0701	1035.0	226.62	1.0670
20	1009.5	235.33	1.1037	1013.9	235.30	1.1002	1018.1	235.30	1.0968
25	991.13	244.29	1.1339	995.98	244.18	1.1302	1000.6	244.11	1.1266
30	972.04	253.41	1.1643	977.42	253.21	1.1603	982.55	253.05	1.1564
35	952.06	262.73	1.1948	958.06	262.42	1.1904	963.75	262.16	1.1862
40	931.02	272.29	1.2255	937.78	271.83	1.2207	944.14	271.45	1.2161
45	908.70	282.11	1.2567	916.40	281.49	1.2513	923.58	280.95	1.2462
50	884.82	292.26	1.2883	893.72	291.42	1.2822	901.91	290.70	1.2766
55	858.97	302.83	1.3208	869.44	301.70	1.3138	878.91	300.74	1.3074
60	830.55	313.94	1.3544	843.15	312.41	1.3462	854.29	311.14	1.3388
65	798.62	325.77	1.3896	814.27	323.67	1.3797	827.66	321.97	1.3711
70	761.55	338.66	1.4274	781.90	335.66	1.4149	798.48	333.35	1.4045
75	716.20	353.23	1.4696	744.59	348.69	1.4526	765.93	345.46	1.4396
80	654.91	371.07	1.5205	699.78	363.31	1.4943	728.82	358.57	1.4769
85	547.15	398.74	1.5982	642.33	380.65	1.5431	685.23	373.10	1.5178
90	347.04	454.30	1.7522	560.48	403.53	1.6065	632.13	389.80	1.5641
95	269.51	486.82	1.8413	441.63	436.83	1.6975	564.99	409.94	1.6191
100	234.51	506.69	1.8949	345.57	469.64	1.7861	482.49	434.70	1.6860
105	212.60	521.97	1.9356	292.71	493.12	1.8486	403.25	461.05	1.7561
110	196.87	534.88	1.9695	260.40	510.96	1.8955	345.74	483.89	1.8161
115	184.70	546.33	1.9992	238.02	525.68	1.9337	306.51	502.64	1.8647
120	174.84	556.80	2.0260	221.23	538.50	1.9665	278.55	518.42	1.9051
125	166.59	566.54	2.0506	207.94	550.03	1.9956	257.49	532.19	1.9399
130	159.53	575.75	2.0736	197.03	560.65	2.0221	240.90	544.54	1.9708
135	153.37	584.53	2.0952	187.82	570.59	2.0466	227.37	555.86	1.9987
140	147.92	592.97	2.1158	179.90	580.00	2.0695	216.04	566.41	2.0244
145	143.05	601.14	2.1354	172.97	588.99	2.0912	206.35	576.36	2.0483
150	138.66	609.08	2.1543	166.83	597.65	2.1118	197.93	585.83	2.0708
155	134.66	616.83	2.1725	161.34	606.03	2.1315	190.51	594.91	2.0922
160	130.99	624.43	2.1902	156.37	614.18	2.1504	183.90	603.68	2.1125

TABLE 14. Properties of liquid and vapor—Continued

	$p=10000.0$ kPa			$p=12000.0$ kPa			$p=14000.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1313.0	67.11	0.3860	1315.2	68.11	0.3832	1317.5	69.10	0.3805
−80	1300.8	74.84	0.4265	1303.1	75.82	0.4237	1305.4	76.80	0.4208
−75	1288.5	82.56	0.4660	1290.9	83.52	0.4631	1293.4	84.49	0.4602
−70	1276.1	90.29	0.5045	1278.7	91.24	0.5015	1281.2	92.19	0.4985
−65	1263.6	98.03	0.5422	1266.3	98.96	0.5391	1269.0	99.90	0.5360
−60	1250.9	105.78	0.5790	1253.8	106.69	0.5758	1256.6	107.61	0.5726
−55	1238.2	113.55	0.6150	1241.2	114.44	0.6117	1244.2	115.34	0.6085
−50	1225.3	121.34	0.6503	1228.5	122.21	0.6469	1231.6	123.09	0.6436
−45	1212.3	129.16	0.6850	1215.7	130.00	0.6815	1218.9	130.86	0.6780
−40	1199.1	137.01	0.7190	1202.7	137.82	0.7154	1206.1	138.65	0.7118
−35	1185.7	144.89	0.7525	1189.5	145.67	0.7487	1193.2	146.47	0.7450
−30	1172.2	152.81	0.7854	1176.2	153.56	0.7814	1180.1	154.33	0.7776
−25	1158.5	160.77	0.8178	1162.7	161.49	0.8137	1166.8	162.22	0.8097
−20	1144.5	168.79	0.8498	1149.0	169.46	0.8455	1153.3	170.15	0.8414
−15	1130.3	176.85	0.8813	1135.1	177.47	0.8769	1139.7	178.12	0.8726
−10	1115.8	184.97	0.9125	1120.9	185.55	0.9078	1125.8	186.15	0.9034
−5	1101.1	193.16	0.9433	1106.5	193.68	0.9385	1111.7	194.23	0.9338
0	1086.1	201.42	0.9738	1091.9	201.87	0.9687	1097.4	202.37	0.9639
5	1070.7	209.76	1.0040	1076.9	210.14	0.9987	1082.9	210.57	0.9936
10	1055.0	218.18	1.0341	1061.7	218.48	1.0285	1068.0	218.84	1.0231
15	1038.8	226.70	1.0639	1046.0	226.91	1.0580	1052.9	227.19	1.0523
20	1022.2	235.32	1.0935	1030.0	235.43	1.0873	1037.4	235.62	1.0813
25	1005.1	244.06	1.1231	1013.6	244.05	1.1164	1021.6	244.14	1.1101
30	987.46	252.93	1.1526	996.72	252.79	1.1455	1005.3	252.75	1.1388
35	969.17	261.95	1.1821	979.31	261.64	1.1745	988.67	261.48	1.1673
40	950.16	271.13	1.2117	961.33	270.64	1.2034	971.53	270.32	1.1958
45	930.32	280.50	1.2414	942.69	279.79	1.2324	953.88	279.29	1.2242
50	909.52	290.09	1.2713	923.32	289.11	1.2615	935.64	288.40	1.2526
55	887.59	299.93	1.3015	903.11	298.63	1.2907	916.76	297.67	1.2811
60	864.33	310.07	1.3321	881.94	308.37	1.3202	897.15	307.12	1.3097
65	839.45	320.56	1.3634	859.66	318.38	1.3500	876.74	316.76	1.3384
70	812.61	331.50	1.3955	836.10	328.68	1.3802	855.41	326.63	1.3674
75	783.30	342.98	1.4287	811.02	339.33	1.4110	833.05	336.75	1.3966
80	750.86	355.16	1.4635	784.16	350.40	1.4426	809.52	347.15	1.4263
85	714.35	368.26	1.5003	755.19	361.96	1.4751	784.69	357.88	1.4565
90	672.50	382.59	1.5400	723.73	374.13	1.5089	758.38	368.98	1.4872
95	623.75	398.60	1.5838	689.38	387.01	1.5441	730.45	380.49	1.5187
100	566.69	416.83	1.6330	651.81	400.74	1.5811	700.79	392.47	1.5511
105	502.58	437.46	1.6879	610.91	415.42	1.6202	669.33	404.96	1.5843
110	439.43	459.16	1.7449	567.13	431.08	1.6613	636.19	417.99	1.6185
115	386.65	479.62	1.7980	521.89	447.54	1.7040	601.65	431.52	1.6536
120	346.14	497.74	1.8444	477.72	464.33	1.7470	566.30	445.51	1.6894
125	315.33	513.66	1.8846	437.26	480.83	1.7887	531.03	459.78	1.7255
130	291.38	527.81	1.9199	402.02	496.54	1.8279	496.90	474.13	1.7613
135	272.23	540.62	1.9515	372.13	511.25	1.8642	464.90	488.31	1.7963
140	256.51	552.41	1.9802	347.00	524.95	1.8975	435.69	502.11	1.8299
145	243.32	563.39	2.0066	325.80	537.72	1.9283	409.53	515.40	1.8618
150	232.04	573.74	2.0312	307.77	549.70	1.9568	386.35	528.13	1.8921
155	222.24	583.59	2.0544	292.28	561.01	1.9833	365.90	540.29	1.9207
160	213.62	593.02	2.0763	278.83	571.74	2.0082	347.85	551.92	1.9477

TABLE 14. Properties of liquid and vapor—Continued

	$p = 16000.0$ kPa			$p = 18000.0$ kPa			$p = 20000.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1319.6	70.10	0.3777	1321.8	71.11	0.3750	1323.9	72.12	0.3723
−80	1307.7	77.79	0.4180	1310.0	78.78	0.4152	1312.2	79.78	0.4125
−75	1295.8	85.47	0.4573	1298.1	86.45	0.4544	1300.4	87.43	0.4516
−70	1283.7	93.15	0.4956	1286.2	94.12	0.4927	1288.6	95.09	0.4898
−65	1271.6	100.84	0.5330	1274.2	101.79	0.5300	1276.7	102.75	0.5270
−60	1259.4	108.54	0.5695	1262.1	109.47	0.5664	1264.8	110.41	0.5634
−55	1247.1	116.25	0.6053	1249.9	117.16	0.6021	1252.7	118.08	0.5990
−50	1234.7	123.97	0.6403	1237.7	124.87	0.6370	1240.6	125.77	0.6338
−45	1222.2	131.72	0.6746	1225.3	132.59	0.6713	1228.4	133.47	0.6680
−40	1209.5	139.49	0.7083	1212.8	140.34	0.7048	1216.0	141.20	0.7015
−35	1196.7	147.28	0.7414	1200.2	148.11	0.7378	1203.6	148.94	0.7343
−30	1183.8	155.11	0.7739	1187.5	155.90	0.7702	1191.1	156.71	0.7666
−25	1170.8	162.97	0.8059	1174.6	163.73	0.8021	1178.4	164.51	0.7984
−20	1157.5	170.86	0.8374	1161.6	171.59	0.8334	1165.6	172.34	0.8296
−15	1144.1	178.80	0.8684	1148.4	179.49	0.8643	1152.6	180.21	0.8604
−10	1130.5	186.78	0.8990	1135.1	187.43	0.8948	1139.5	188.11	0.8907
−5	1116.8	194.81	0.9293	1121.6	195.42	0.9249	1126.3	196.06	0.9206
0	1102.8	202.90	0.9591	1107.9	203.46	0.9546	1112.9	204.05	0.9501
5	1088.6	211.04	0.9887	1094.0	211.55	0.9839	1099.3	212.09	0.9793
10	1074.1	219.25	1.0179	1079.9	219.70	1.0130	1085.5	220.19	1.0082
15	1059.4	227.52	1.0469	1065.5	227.91	1.0417	1071.5	228.34	1.0367
20	1044.3	235.87	1.0756	1051.0	236.19	1.0702	1057.2	236.55	1.0650
25	1029.0	244.30	1.1041	1036.1	244.53	1.0984	1042.8	244.83	1.0930
30	1013.4	252.82	1.1325	1021.0	252.96	1.1264	1028.1	253.17	1.1207
35	997.36	261.42	1.1606	1005.5	261.47	1.1543	1013.2	261.59	1.1483
40	980.96	270.13	1.1887	989.73	270.06	1.1820	997.94	270.09	1.1756
45	964.12	278.96	1.2166	973.59	278.76	1.2095	982.41	278.67	1.2028
50	946.82	287.90	1.2445	957.07	287.55	1.2369	966.56	287.35	1.2299
55	929.00	296.97	1.2723	940.14	296.46	1.2643	950.38	296.12	1.2568
60	910.62	306.18	1.3002	922.75	305.49	1.2916	933.82	304.99	1.2836
65	891.63	315.56	1.3281	904.89	314.65	1.3189	916.88	313.97	1.3104
70	871.95	325.10	1.3562	886.49	323.94	1.3462	899.53	323.07	1.3371
75	851.52	334.84	1.3843	867.53	333.40	1.3735	881.73	332.29	1.3638
80	830.27	344.79	1.4127	847.97	343.01	1.4009	863.47	341.65	1.3905
85	808.13	354.97	1.4413	827.75	352.81	1.4285	844.71	351.15	1.4172
90	785.01	365.41	1.4703	806.84	362.79	1.4562	825.45	360.80	1.4439
95	760.85	376.13	1.4996	785.20	372.98	1.4840	805.65	370.61	1.4708
100	735.59	387.16	1.5294	762.82	383.40	1.5121	785.31	380.59	1.4977
105	709.22	398.51	1.5596	739.68	394.04	1.5404	764.43	390.74	1.5247
110	681.78	410.20	1.5903	715.81	404.91	1.5690	743.03	401.07	1.5518
115	653.39	422.22	1.6214	691.27	416.03	1.5978	721.15	411.58	1.5791
120	624.26	434.56	1.6530	666.18	427.37	1.6269	698.84	422.26	1.6064
125	594.71	447.17	1.6849	640.68	438.92	1.6561	676.21	433.10	1.6338
130	565.20	459.97	1.7169	614.99	450.65	1.6853	653.37	444.09	1.6613
135	536.22	472.88	1.7487	589.37	462.52	1.7146	630.46	455.20	1.6887
140	508.30	485.76	1.7801	564.11	474.46	1.7437	607.67	466.41	1.7159
145	481.88	498.51	1.8107	539.51	486.41	1.7724	585.16	177.68	1.7431
150	457.27	511.01	1.8404	515.84	498.31	1.8007	563.14	488.96	1.7699
155	434.62	523.21	1.8691	493.33	510.09	1.8284	541.78	500.22	1.7963
160	413.94	535.06	1.8966	472.13	521.70	1.8554	521.22	511.42	1.8223

TABLE 14. Properties of liquid and vapor—Continued

	$p = 25000.0$ kPa			$p = 30000.0$ kPa			$p = 40000.0$ kPa		
t °C	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	ϱ kg m^{-3}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
−85	1329.1	74.65	0.3657	1334.1	77.20	0.3593	1343.6	82.35	0.3470
−80	1317.6	82.28	0.4058	1322.8	84.81	0.3993	1332.7	89.91	0.3867
−75	1306.1	89.91	0.4448	1311.5	92.41	0.4381	1321.8	97.46	0.4253
−70	1294.5	97.53	0.4828	1300.2	100.00	0.4759	1310.9	105.01	0.4629
−65	1282.9	105.15	0.5198	1288.8	107.59	0.5129	1300.0	112.55	0.4995
−60	1271.2	112.78	0.5560	1277.4	115.19	0.5489	1289.1	120.08	0.5353
−55	1259.5	120.42	0.5914	1265.9	122.78	0.5841	1278.1	127.62	0.5703
−50	1247.7	128.06	0.6261	1254.4	130.39	0.6186	1267.1	135.15	0.6044
−45	1235.8	135.71	0.6600	1242.8	138.00	0.6523	1256.0	142.69	0.6378
−40	1223.8	143.38	0.6933	1231.2	145.63	0.6854	1245.0	150.24	0.6706
−35	1211.8	151.07	0.7259	1219.5	153.27	0.7178	1233.8	157.80	0.7026
−30	1199.6	158.78	0.7579	1207.7	160.92	0.7496	1222.7	165.37	0.7341
−25	1187.4	166.52	0.7894	1195.9	168.60	0.7809	1211.5	172.95	0.7650
−20	1175.0	174.28	0.8204	1183.9	176.30	0.8116	1200.2	180.55	0.7953
−15	1162.6	182.07	0.8509	1171.9	184.02	0.8418	1188.9	188.17	0.8251
−10	1150.0	189.89	0.8809	1159.8	191.78	0.8716	1177.6	195.80	0.8544
−5	1137.3	197.75	0.9104	1147.6	199.56	0.9009	1166.2	203.46	0.8832
0	1124.5	205.64	0.9396	1135.3	207.37	0.9297	1154.7	211.14	0.9116
5	1111.6	213.58	0.9684	1122.9	215.22	0.9582	1143.2	218.85	0.9395
10	1098.5	221.56	0.9968	1110.4	223.10	0.9863	1131.6	226.59	0.9671
15	1085.2	229.58	1.0249	1097.8	231.02	1.0140	1120.0	234.35	0.9943
20	1071.8	237.66	1.0527	1085.0	238.98	1.0414	1108.3	242.14	1.0211
25	1058.3	245.78	1.0802	1072.2	246.99	1.0685	1096.6	249.96	1.0476
30	1044.5	253.96	1.1074	1059.2	255.04	1.0953	1084.8	257.82	1.0737
35	1030.6	262.20	1.1344	1046.1	263.14	1.1218	1072.9	265.71	1.0995
40	1016.5	270.50	1.1611	1032.9	271.28	1.1480	1061.0	273.64	1.1250
45	1002.2	278.86	1.1876	1019.5	279.18	1.1740	1048.9	281.60	1.1502
50	987.69	287.29	1.2139	1006.0	287.73	1.1997	1036.9	289.60	1.1752
55	972.96	295.79	1.2400	992.35	296.04	1.2252	1024.8	297.63	1.1999
60	958.00	304.37	1.2659	978.55	304.40	1.2505	1012.6	305.71	1.2243
65	942.81	313.02	1.2917	964.60	312.82	1.2756	1000.3	313.83	1.2485
70	927.36	321.76	1.3173	950.50	321.30	1.3005	987.99	321.98	1.2724
75	911.67	330.57	1.3428	936.23	329.85	1.3252	975.61	330.18	1.2961
80	895.71	339.48	1.3682	921.81	338.46	1.3498	963.17	338.42	1.3196
85	879.48	348.48	1.3935	907.24	347.14	1.3742	950.68	346.70	1.3429
90	862.98	357.57	1.4187	892.50	355.88	1.3984	938.14	355.02	1.3660
95	846.20	366.77	1.4439	877.60	364.70	1.4225	925.54	363.39	1.3889
100	829.15	376.06	1.4690	862.56	373.58	1.4465	912.90	371.80	1.4116
105	811.83	385.45	1.4940	847.37	382.54	1.4703	900.21	380.25	1.4341
110	794.26	394.95	1.5189	832.04	391.56	1.4940	887.49	388.75	1.4564
115	776.45	404.55	1.5438	816.58	400.65	1.5176	874.75	397.29	1.4785
120	758.42	414.25	1.5686	801.02	409.82	1.5411	861.97	405.87	1.5005
125	740.22	424.05	1.5934	785.36	419.05	1.5644	849.19	414.49	1.5223
130	721.88	433.95	1.6181	769.63	428.35	1.5876	836.39	423.15	1.5439
135	703.46	443.93	1.6427	753.85	437.70	1.6107	823.61	431.84	1.5653
140	685.01	453.98	1.6672	738.05	447.12	1.6336	810.83	440.58	1.5866
145	666.61	464.11	1.6916	722.27	456.59	1.6564	798.08	449.35	1.6077
150	648.32	474.28	1.7157	706.54	466.11	1.6790	785.37	458.16	1.6286
155	630.23	484.49	1.7397	690.89	475.66	1.7015	772.71	467.00	1.6494
160	612.42	494.73	1.7635	675.37	485.25	1.7237	760.12	475.86	1.6700

TABLE 15. Isobaric heat capacity (kJ kg^{-1} K^{-1})

t (°C)	p/kPa 20	40	60	80	100	101.3	150	200	300	400	500	600
−85	1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.559	1.558	1.558
−80	1.561	1.561	1.561	1.561	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560
−75	0.752	1.563	1.563	1.563	1.563	1.563	1.563	1.563	1.562	1.562	1.562	1.562
−70	0.749	1.566	1.566	1.566	1.566	1.566	1.566	1.566	1.566	1.566	1.565	1.565
−65	0.747	0.789	1.571	1.571	1.570	1.570	1.570	1.570	1.570	1.570	1.569	1.569
−60	0.747	0.780	0.822	1.576	1.576	1.576	1.576	1.575	1.575	1.575	1.575	1.574
−55	0.749	0.776	0.808	0.846	1.582	1.582	1.582	1.582	1.581	1.581	1.581	1.581
−50	0.751	0.774	0.800	0.829	0.864	0.866	1.589	1.589	1.589	1.589	1.588	1.588
−45	0.753	0.773	0.795	0.818	0.845	0.847	1.598	1.598	1.597	1.597	1.597	1.596
−40	0.757	0.774	0.792	0.812	0.833	0.835	0.897	1.608	1.607	1.607	1.606	1.606
−35	0.760	0.776	0.791	0.808	0.826	0.827	0.876	0.939	1.618	1.618	1.617	1.617
−30	0.764	0.778	0.792	0.806	0.821	0.822	0.863	0.912	1.631	1.630	1.630	1.629
−25	0.769	0.781	0.793	0.806	0.819	0.820	0.854	0.894	0.994	1.645	1.644	1.643
−20	0.774	0.785	0.795	0.807	0.818	0.819	0.848	0.882	0.962	1.068	1.660	1.659
−15	0.779	0.789	0.798	0.808	0.818	0.819	0.845	0.874	0.939	1.021	1.678	1.677
−10	0.785	0.793	0.802	0.811	0.820	0.820	0.843	0.868	0.924	0.990	1.072	1.698
−5	0.791	0.798	0.806	0.814	0.822	0.823	0.843	0.865	0.913	0.968	1.034	1.113
0	0.797	0.804	0.811	0.818	0.825	0.825	0.844	0.863	0.905	0.952	1.006	1.070
5	0.803	0.809	0.816	0.822	0.828	0.829	0.845	0.863	0.900	0.941	0.987	1.039
10	0.809	0.815	0.821	0.827	0.833	0.833	0.848	0.863	0.897	0.933	0.972	1.017
15	0.816	0.821	0.826	0.832	0.837	0.837	0.851	0.865	0.895	0.927	0.962	1.000
20	0.823	0.828	0.832	0.837	0.842	0.842	0.854	0.867	0.894	0.923	0.954	0.987
25	0.830	0.834	0.838	0.843	0.847	0.848	0.859	0.870	0.895	0.921	0.948	0.978
30	0.837	0.841	0.845	0.849	0.853	0.853	0.863	0.874	0.896	0.920	0.945	0.971
35	0.844	0.848	0.851	0.855	0.859	0.859	0.868	0.878	0.899	0.920	0.942	0.966
40	0.851	0.855	0.858	0.862	0.865	0.865	0.874	0.883	0.901	0.921	0.941	0.963
45	0.859	0.862	0.865	0.868	0.871	0.872	0.880	0.888	0.905	0.923	0.942	0.961
50	0.866	0.869	0.872	0.875	0.878	0.878	0.886	0.893	0.909	0.925	0.943	0.960
55	0.874	0.877	0.879	0.882	0.885	0.885	0.892	0.899	0.914	0.929	0.944	0.961
60	0.882	0.884	0.887	0.889	0.892	0.892	0.898	0.905	0.918	0.932	0.947	0.962
65	0.889	0.892	0.894	0.896	0.899	0.899	0.905	0.911	0.924	0.937	0.950	0.964
70	0.897	0.899	0.902	0.904	0.906	0.906	0.912	0.917	0.929	0.941	0.954	0.967
75	0.905	0.907	0.909	0.911	0.913	0.914	0.919	0.924	0.935	0.946	0.958	0.970
80	0.913	0.915	0.917	0.919	0.921	0.921	0.926	0.931	0.941	0.951	0.962	0.973
85	0.921	0.923	0.925	0.926	0.928	0.928	0.933	0.938	0.947	0.957	0.967	0.978
90	0.929	0.931	0.932	0.934	0.936	0.936	0.940	0.945	0.954	0.963	0.972	0.982
95	0.937	0.939	0.940	0.942	0.943	0.944	0.948	0.952	0.960	0.969	0.978	0.987
100	0.945	0.947	0.948	0.950	0.951	0.951	0.955	0.959	0.967	0.975	0.983	0.992
105	0.953	0.954	0.956	0.957	0.959	0.959	0.963	0.966	0.974	0.981	0.989	0.997
110	0.961	0.962	0.964	0.965	0.967	0.967	0.970	0.974	0.981	0.988	0.995	1.003
115	0.969	0.970	0.972	0.973	0.974	0.974	0.978	0.981	0.988	0.995	1.002	1.009
120	0.977	0.978	0.980	0.981	0.982	0.982	0.985	0.988	0.995	1.001	1.008	1.015
125	0.985	0.986	0.988	0.989	0.990	0.990	0.993	0.996	1.002	1.008	1.014	1.021
130	0.993	0.994	0.996	0.997	0.998	0.998	1.001	1.003	1.009	1.015	1.021	1.027
135	1.001	1.002	1.003	1.005	1.006	1.006	1.008	1.011	1.017	1.022	1.028	1.034
140	1.009	1.010	1.011	1.012	1.013	1.013	1.016	1.019	1.024	1.029	1.035	1.040
145	1.017	1.018	1.019	1.020	1.021	1.021	1.024	1.026	1.031	1.036	1.041	1.047
150	1.025	1.026	1.027	1.028	1.029	1.029	1.031	1.034	1.039	1.043	1.048	1.053
155	1.033	1.034	1.035	1.036	1.037	1.037	1.039	1.041	1.046	1.051	1.055	1.060
160	1.041	1.042	1.043	1.044	1.044	1.045	1.047	1.049	1.053	1.058	1.062	1.067

TABLE 15. Isobaric heat capacity (kJ kg^{-1} K^{-1})—Continued

t	p/kPa											
°C	800	1000	1200	1400	1600	2000	2500	3000	3500	4000	5000	6000
−85	1.558	1.558	1.557	1.557	1.557	1.556	1.555	1.554	1.554	1.553	1.551	1.550
−80	1.559	1.559	1.559	1.558	1.558	1.557	1.556	1.555	1.555	1.554	1.552	1.551
−75	1.561	1.561	1.561	1.560	1.560	1.559	1.558	1.557	1.556	1.555	1.554	1.552
−70	1.565	1.564	1.564	1.563	1.563	1.562	1.561	1.560	1.559	1.558	1.556	1.554
−65	1.569	1.568	1.568	1.567	1.567	1.566	1.565	1.564	1.563	1.561	1.559	1.557
−60	1.574	1.573	1.573	1.572	1.572	1.571	1.569	1.568	1.567	1.566	1.563	1.561
−55	1.580	1.579	1.579	1.578	1.578	1.577	1.575	1.574	1.572	1.571	1.568	1.566
−50	1.587	1.587	1.586	1.585	1.585	1.583	1.582	1.580	1.579	1.577	1.574	1.571
−45	1.596	1.595	1.594	1.593	1.593	1.591	1.589	1.588	1.586	1.584	1.581	1.578
−40	1.605	1.604	1.603	1.603	1.602	1.600	1.598	1.596	1.595	1.593	1.589	1.586
−35	1.616	1.615	1.614	1.613	1.612	1.611	1.608	1.606	1.604	1.602	1.598	1.594
−30	1.628	1.627	1.626	1.625	1.624	1.622	1.620	1.617	1.615	1.613	1.608	1.604
−25	1.642	1.641	1.640	1.639	1.638	1.635	1.633	1.630	1.627	1.625	1.620	1.615
−20	1.658	1.657	1.655	1.654	1.653	1.650	1.647	1.644	1.641	1.638	1.632	1.627
−15	1.676	1.674	1.673	1.671	1.670	1.667	1.663	1.660	1.656	1.653	1.647	1.640
−10	1.696	1.694	1.692	1.691	1.689	1.686	1.681	1.677	1.673	1.670	1.662	1.655
−5	1.719	1.717	1.715	1.713	1.711	1.707	1.702	1.697	1.693	1.688	1.680	1.672
0	1.237	1.743	1.740	1.738	1.736	1.731	1.725	1.720	1.715	1.710	1.700	1.691
5	1.170	1.773	1.770	1.767	1.764	1.758	1.752	1.745	1.739	1.733	1.722	1.712
10	1.123	1.266	1.804	1.801	1.797	1.790	1.782	1.775	1.767	1.760	1.747	1.735
15	1.089	1.203	1.356	1.840	1.836	1.828	1.818	1.809	1.800	1.792	1.776	1.761
20	1.064	1.157	1.277	1.438	1.883	1.872	1.860	1.849	1.838	1.828	1.809	1.792
25	1.044	1.124	1.221	1.344	1.510	1.926	1.911	1.897	1.883	1.870	1.847	1.826
30	1.030	1.098	1.179	1.278	1.404	1.994	1.974	1.955	1.937	1.921	1.892	1.866
35	1.018	1.078	1.147	1.229	1.329	1.622	2.054	2.028	2.005	1.984	1.946	1.914
40	1.010	1.062	1.122	1.192	1.274	1.499	2.161	2.124	2.092	2.063	2.013	1.971
45	1.003	1.050	1.103	1.163	1.232	1.413	1.788	2.258	2.209	2.167	2.097	2.042
50	0.999	1.041	1.088	1.140	1.200	1.349	1.632	2.190	2.381	2.313	2.209	2.131
55	0.996	1.034	1.076	1.122	1.174	1.300	1.524	1.905	2.795	2.541	2.367	2.249
60	0.994	1.029	1.066	1.108	1.154	1.262	1.446	1.728	2.251	2.966	2.612	2.415
65	0.993	1.025	1.059	1.096	1.137	1.232	1.386	1.607	1.964	2.698	3.067	2.672
70	0.994	1.023	1.054	1.087	1.124	1.208	1.340	1.519	1.784	2.235	4.428	3.135
75	0.995	1.021	1.050	1.081	1.114	1.188	1.303	1.452	1.660	1.974	3.944	4.338
80	0.997	1.021	1.047	1.075	1.105	1.173	1.273	1.401	1.569	1.805	2.839	61.802
85	0.999	1.022	1.046	1.072	1.099	1.160	1.249	1.359	1.500	1.686	2.362	5.008
90	1.002	1.023	1.046	1.069	1.094	1.150	1.230	1.326	1.445	1.598	2.088	3.313
95	1.006	1.025	1.046	1.068	1.091	1.141	1.214	1.299	1.402	1.530	1.908	2.663
100	1.010	1.028	1.047	1.068	1.089	1.135	1.201	1.277	1.367	1.476	1.780	2.308
105	1.014	1.031	1.049	1.068	1.088	1.130	1.190	1.259	1.339	1.433	1.685	2.082
110	1.018	1.035	1.052	1.069	1.088	1.127	1.182	1.244	1.315	1.398	1.611	1.924
115	1.023	1.039	1.054	1.071	1.088	1.125	1.175	1.232	1.296	1.369	1.553	1.809
120	1.029	1.043	1.058	1.073	1.089	1.123	1.170	1.222	1.280	1.346	1.506	1.720
125	1.034	1.048	1.062	1.076	1.091	1.123	1.166	1.214	1.267	1.326	1.467	1.650
130	1.040	1.052	1.066	1.079	1.093	1.123	1.163	1.207	1.256	1.309	1.436	1.594
135	1.045	1.057	1.070	1.083	1.096	1.124	1.161	1.202	1.247	1.296	1.409	1.548
140	1.051	1.063	1.075	1.087	1.099	1.125	1.161	1.199	1.240	1.285	1.387	1.510
145	1.057	1.068	1.079	1.091	1.103	1.127	1.160	1.196	1.234	1.275	1.369	1.479
150	1.063	1.074	1.084	1.095	1.107	1.130	1.161	1.194	1.230	1.268	1.353	1.453
155	1.070	1.080	1.090	1.100	1.111	1.133	1.162	1.193	1.226	1.262	1.340	1.430
160	1.076	1.085	1.095	1.105	1.115	1.136	1.163	1.193	1.224	1.257	1.329	1.412

TABLE 15. Isobaric heat capacity (kJ kg^{-1} K^{-1})—Continued

t	p/kPa											
°C	7000	8000	9000	10 000	12 000	14 000	16 000	18 000	20 000	30 000	40 000	50 000
−85	1.549	1.547	1.546	1.544	1.542	1.539	1.537	1.535	1.532	1.522	1.514	1.507
−80	1.549	1.547	1.546	1.545	1.542	1.539	1.536	1.534	1.531	1.521	1.511	1.504
−75	1.550	1.549	1.547	1.545	1.542	1.539	1.536	1.534	1.531	1.519	1.509	1.501
−70	1.552	1.550	1.549	1.547	1.543	1.540	1.537	1.534	1.531	1.519	1.508	1.499
−65	1.555	1.553	1.551	1.549	1.545	1.542	1.539	1.535	1.532	1.518	1.507	1.498
−60	1.559	1.557	1.554	1.552	1.548	1.544	1.541	1.537	1.534	1.519	1.507	1.497
−55	1.563	1.561	1.558	1.556	1.552	1.547	1.543	1.540	1.536	1.520	1.507	1.496
−50	1.569	1.566	1.563	1.561	1.556	1.551	1.547	1.543	1.539	1.522	1.508	1.496
−45	1.575	1.572	1.569	1.566	1.561	1.556	1.551	1.547	1.542	1.524	1.509	1.497
−40	1.582	1.579	1.576	1.573	1.567	1.561	1.556	1.551	1.547	1.526	1.510	1.498
−35	1.590	1.587	1.583	1.580	1.574	1.567	1.562	1.556	1.551	1.530	1.513	1.499
−30	1.600	1.596	1.592	1.588	1.581	1.574	1.568	1.562	1.557	1.533	1.515	1.501
−25	1.610	1.606	1.601	1.597	1.589	1.582	1.575	1.569	1.563	1.538	1.518	1.503
−20	1.622	1.617	1.612	1.607	1.599	1.591	1.583	1.576	1.570	1.542	1.522	1.505
−15	1.635	1.629	1.624	1.619	1.609	1.600	1.592	1.584	1.577	1.548	1.525	1.508
−10	1.649	1.643	1.637	1.631	1.620	1.610	1.601	1.593	1.585	1.553	1.529	1.511
−5	1.665	1.658	1.651	1.644	1.632	1.622	1.612	1.602	1.594	1.559	1.534	1.515
0	1.682	1.674	1.667	1.659	1.646	1.634	1.623	1.613	1.603	1.566	1.539	1.518
5	1.702	1.693	1.684	1.676	1.661	1.647	1.635	1.624	1.614	1.573	1.544	1.522
10	1.724	1.713	1.703	1.694	1.677	1.662	1.648	1.636	1.624	1.580	1.550	1.527
15	1.748	1.736	1.724	1.714	1.695	1.677	1.662	1.649	1.636	1.588	1.555	1.531
20	1.776	1.762	1.748	1.736	1.714	1.695	1.678	1.662	1.649	1.597	1.562	1.536
25	1.807	1.790	1.775	1.761	1.735	1.713	1.694	1.677	1.662	1.605	1.568	1.541
30	1.844	1.823	1.805	1.788	1.759	1.734	1.712	1.693	1.676	1.615	1.575	1.546
35	1.886	1.861	1.839	1.819	1.785	1.756	1.732	1.710	1.692	1.624	1.582	1.552
40	1.936	1.905	1.878	1.854	1.814	1.781	1.753	1.729	1.708	1.634	1.589	1.557
45	1.996	1.957	1.924	1.895	1.847	1.808	1.776	1.749	1.725	1.645	1.596	1.563
50	2.069	2.019	1.977	1.941	1.883	1.838	1.801	1.770	1.744	1.656	1.604	1.569
55	2.163	2.095	2.041	1.996	1.925	1.871	1.828	1.793	1.764	1.667	1.611	1.575
60	2.286	2.192	2.119	2.061	1.973	1.908	1.858	1.818	1.785	1.678	1.619	1.581
65	2.457	2.317	2.217	2.140	2.028	1.950	1.891	1.845	1.808	1.690	1.627	1.587
70	2.716	2.490	2.343	2.237	2.093	1.997	1.928	1.875	1.832	1.703	1.635	1.593
75	3.159	2.741	2.511	2.360	2.170	2.051	1.968	1.906	1.858	1.716	1.644	1.599
80	4.127	3.142	2.745	2.519	2.261	2.112	2.012	1.941	1.886	1.729	1.652	1.606
85	8.128	3.877	3.091	2.731	2.370	2.181	2.061	1.978	1.915	1.742	1.661	1.612
90	9.312	5.504	3.630	3.017	2.501	2.260	2.115	2.017	1.946	1.756	1.669	1.618
95	4.752	7.340	4.481	3.406	2.657	2.348	2.174	2.060	1.979	1.770	1.678	1.625
100	3.400	5.540	5.323	3.897	2.838	2.446	2.237	2.105	2.013	1.784	1.686	1.631
105	2.777	4.014	5.010	4.311	3.035	2.551	2.304	2.152	2.048	1.798	1.695	1.637
110	2.416	3.201	4.126	4.281	3.223	2.657	2.371	2.199	2.083	1.812	1.703	1.644
115	2.180	2.726	3.415	3.867	3.346	2.756	2.437	2.246	2.119	1.826	1.712	1.650
120	2.014	2.419	2.930	3.390	3.350	2.832	2.497	2.290	2.153	1.840	1.720	1.656
125	1.890	2.206	2.596	2.992	3.232	2.871	2.545	2.330	2.184	1.853	1.728	1.662
130	1.795	2.050	2.358	2.684	3.045	2.861	2.575	2.361	2.211	1.866	1.736	1.668
135	1.720	1.931	2.180	2.450	2.839	2.803	2.583	2.383	2.233	1.878	1.744	1.673
140	1.659	1.837	2.045	2.270	2.644	2.712	2.566	2.392	2.249	1.889	1.751	1.679
145	1.609	1.763	1.938	2.129	2.472	2.603	2.528	2.388	2.257	1.899	1.758	1.684
150	1.568	1.702	1.853	2.016	2.325	2.488	2.473	2.370	2.256	1.907	1.764	1.690
155	1.534	1.652	1.783	1.925	2.201	2.377	2.406	2.341	2.247	1.915	1.770	1.695
160	1.505	1.610	1.726	1.850	2.096	2.274	2.334	2.302	2.230	1.921	1.776	1.700

TABLE 16. Isochoric heat capacity (kJ kg^{-1} K^{-1})

t	p/kPa											
°C	20	40	60	80	100	101.325	150	200	300	400	500	600
−85	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970
−80	0.964	0.964	0.964	0.964	0.964	0.964	0.964	0.964	0.964	0.964	0.964	0.964
−75	0.575	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959
−70	0.574	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954	0.954
−65	0.575	0.601	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950
−60	0.577	0.598	0.624	0.946	0.946	0.946	0.946	0.946	0.946	0.946	0.946	0.946
−55	0.579	0.596	0.616	0.640	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.943
−50	0.582	0.597	0.612	0.631	0.652	0.654	0.940	0.940	0.940	0.940	0.940	0.940
−45	0.586	0.598	0.611	0.625	0.641	0.643	0.938	0.938	0.938	0.938	0.938	0.938
−40	0.590	0.600	0.611	0.623	0.636	0.637	0.674	0.936	0.936	0.936	0.936	0.936
−35	0.595	0.604	0.613	0.623	0.633	0.634	0.663	0.699	0.935	0.935	0.935	0.935
−30	0.599	0.607	0.615	0.624	0.632	0.633	0.656	0.684	0.934	0.934	0.934	0.934
−25	0.604	0.611	0.618	0.626	0.633	0.634	0.653	0.675	0.731	0.933	0.933	0.933
−20	0.610	0.616	0.622	0.628	0.635	0.635	0.652	0.670	0.713	0.770	0.934	0.934
−15	0.616	0.621	0.626	0.632	0.637	0.638	0.652	0.667	0.702	0.745	0.934	0.934
−10	0.621	0.626	0.631	0.636	0.641	0.641	0.653	0.667	0.696	0.730	0.771	0.935
−5	0.627	0.632	0.636	0.640	0.645	0.645	0.656	0.667	0.692	0.720	0.752	0.790
0	0.634	0.638	0.641	0.645	0.649	0.649	0.659	0.669	0.691	0.714	0.740	0.770
5	0.640	0.644	0.647	0.650	0.654	0.654	0.663	0.672	0.690	0.711	0.732	0.756
10	0.647	0.650	0.653	0.656	0.659	0.659	0.667	0.675	0.692	0.709	0.728	0.748
15	0.654	0.656	0.659	0.662	0.665	0.665	0.672	0.679	0.694	0.709	0.725	0.742
20	0.661	0.663	0.666	0.668	0.671	0.671	0.677	0.683	0.696	0.710	0.724	0.739
25	0.668	0.670	0.672	0.674	0.677	0.677	0.682	0.688	0.700	0.712	0.725	0.738
30	0.675	0.677	0.679	0.681	0.683	0.683	0.688	0.693	0.704	0.715	0.726	0.738
35	0.682	0.684	0.686	0.688	0.690	0.690	0.694	0.699	0.709	0.718	0.728	0.739
40	0.690	0.691	0.693	0.695	0.696	0.697	0.701	0.705	0.714	0.722	0.731	0.741
45	0.697	0.699	0.700	0.702	0.703	0.704	0.707	0.711	0.719	0.727	0.735	0.743
50	0.705	0.706	0.708	0.709	0.710	0.711	0.714	0.718	0.725	0.732	0.739	0.747
55	0.713	0.714	0.715	0.716	0.718	0.718	0.721	0.724	0.731	0.737	0.744	0.751
60	0.720	0.722	0.723	0.724	0.725	0.725	0.728	0.731	0.737	0.743	0.749	0.755
65	0.728	0.729	0.730	0.731	0.733	0.733	0.735	0.738	0.743	0.749	0.755	0.760
70	0.736	0.737	0.738	0.739	0.740	0.740	0.743	0.745	0.750	0.755	0.760	0.765
75	0.744	0.745	0.746	0.747	0.748	0.748	0.750	0.752	0.757	0.762	0.766	0.771
80	0.752	0.753	0.754	0.755	0.755	0.755	0.758	0.760	0.764	0.768	0.773	0.777
85	0.760	0.761	0.762	0.762	0.763	0.763	0.765	0.767	0.771	0.775	0.779	0.783
90	0.768	0.769	0.770	0.770	0.771	0.771	0.773	0.775	0.778	0.782	0.786	0.789
95	0.776	0.777	0.778	0.778	0.779	0.779	0.781	0.782	0.786	0.789	0.792	0.796
100	0.784	0.785	0.786	0.786	0.787	0.787	0.788	0.790	0.793	0.796	0.799	0.803
105	0.792	0.793	0.794	0.794	0.795	0.795	0.796	0.798	0.800	0.803	0.806	0.809
110	0.800	0.801	0.802	0.802	0.803	0.803	0.804	0.805	0.808	0.811	0.814	0.816
115	0.809	0.809	0.810	0.810	0.811	0.811	0.812	0.813	0.816	0.818	0.821	0.823
120	0.817	0.817	0.818	0.818	0.819	0.819	0.820	0.821	0.823	0.826	0.828	0.831
125	0.825	0.825	0.826	0.826	0.826	0.826	0.828	0.829	0.831	0.833	0.835	0.838
130	0.833	0.833	0.834	0.834	0.834	0.834	0.835	0.837	0.839	0.841	0.843	0.845
135	0.841	0.841	0.842	0.842	0.842	0.842	0.843	0.844	0.846	0.848	0.850	0.852
140	0.849	0.849	0.850	0.850	0.850	0.850	0.851	0.852	0.854	0.856	0.858	0.860
145	0.857	0.857	0.858	0.858	0.858	0.858	0.859	0.860	0.862	0.864	0.865	0.867
150	0.865	0.865	0.865	0.866	0.866	0.866	0.867	0.868	0.869	0.871	0.873	0.874
155	0.873	0.873	0.873	0.874	0.874	0.874	0.875	0.876	0.877	0.879	0.880	0.882
160	0.881	0.881	0.881	0.882	0.882	0.882	0.883	0.883	0.885	0.886	0.888	0.889

TABLE 16. Isochoric heat capacity (kJ kg^{-1} K^{-1})—Continued

t	p/kPa											
°C	800	1000	1200	1400	1600	2000	2500	3000	3500	4000	5000	6000
−85	0.970	0.970	0.970	0.970	0.970	0.971	0.971	0.971	0.971	0.971	0.971	0.972
−80	0.964	0.964	0.964	0.964	0.965	0.965	0.965	0.965	0.965	0.965	0.966	0.966
−75	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.960	0.960	0.960	0.960	0.960
−70	0.954	0.954	0.954	0.954	0.954	0.955	0.955	0.955	0.955	0.955	0.955	0.956
−65	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.951	0.951	0.951	0.951	0.951
−60	0.946	0.946	0.946	0.946	0.946	0.947	0.947	0.947	0.947	0.947	0.947	0.948
−55	0.943	0.943	0.943	0.943	0.943	0.943	0.943	0.944	0.944	0.944	0.944	0.944
−50	0.940	0.940	0.940	0.940	0.940	0.940	0.941	0.941	0.941	0.941	0.941	0.942
−45	0.938	0.938	0.938	0.938	0.938	0.938	0.938	0.938	0.939	0.939	0.939	0.939
−40	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.937	0.937	0.937	0.937	0.937
−35	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.936	0.936
−30	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.935	0.935	0.935
−25	0.933	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934
−20	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934
−15	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.934	0.935	0.935
−10	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
−5	0.937	0.937	0.937	0.937	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.937
0	0.845	0.939	0.939	0.938	0.938	0.938	0.938	0.938	0.938	0.938	0.938	0.938
5	0.814	0.941	0.941	0.941	0.941	0.941	0.941	0.940	0.940	0.940	0.940	0.940
10	0.794	0.853	0.944	0.944	0.944	0.944	0.943	0.943	0.943	0.943	0.943	0.942
15	0.781	0.827	0.884	0.948	0.948	0.947	0.947	0.947	0.946	0.946	0.946	0.945
20	0.772	0.809	0.854	0.909	0.952	0.952	0.951	0.951	0.950	0.950	0.949	0.949
25	0.766	0.797	0.833	0.876	0.927	0.957	0.956	0.955	0.955	0.954	0.953	0.953
30	0.762	0.789	0.819	0.853	0.893	0.964	0.962	0.961	0.960	0.959	0.958	0.957
35	0.760	0.784	0.809	0.838	0.870	0.950	0.970	0.968	0.967	0.966	0.964	0.962
40	0.760	0.781	0.803	0.827	0.853	0.917	0.980	0.977	0.975	0.973	0.970	0.968
45	0.761	0.779	0.798	0.819	0.842	0.894	0.980	0.989	0.986	0.983	0.978	0.975
50	0.762	0.779	0.796	0.814	0.834	0.877	0.946	1.044	1.000	0.995	0.988	0.983
55	0.765	0.780	0.795	0.811	0.828	0.866	0.922	0.995	1.109	1.013	1.001	0.993
60	0.768	0.781	0.795	0.810	0.825	0.857	0.905	0.963	1.042	1.041	1.019	1.006
65	0.772	0.784	0.796	0.809	0.823	0.852	0.892	0.940	1.000	1.084	1.047	1.024
70	0.776	0.787	0.798	0.810	0.822	0.848	0.883	0.924	0.972	1.033	1.106	1.051
75	0.781	0.791	0.801	0.812	0.823	0.846	0.877	0.912	0.952	1.000	1.151	1.103
80	0.786	0.795	0.804	0.814	0.824	0.845	0.873	0.903	0.938	0.977	1.082	1.411
85	0.791	0.800	0.808	0.817	0.826	0.845	0.870	0.897	0.927	0.960	1.042	1.175
90	0.797	0.805	0.813	0.821	0.829	0.846	0.869	0.893	0.919	0.948	1.015	1.105
95	0.803	0.810	0.817	0.825	0.832	0.848	0.869	0.891	0.914	0.939	0.995	1.065
100	0.809	0.816	0.822	0.829	0.836	0.851	0.870	0.889	0.910	0.932	0.981	1.038
105	0.815	0.822	0.828	0.834	0.841	0.854	0.871	0.889	0.908	0.928	0.971	1.019
110	0.822	0.828	0.833	0.839	0.845	0.858	0.873	0.890	0.907	0.925	0.963	1.005
115	0.829	0.834	0.839	0.845	0.850	0.862	0.876	0.891	0.907	0.923	0.958	0.995
120	0.835	0.840	0.845	0.851	0.856	0.866	0.880	0.894	0.908	0.923	0.954	0.987
125	0.842	0.847	0.852	0.856	0.861	0.871	0.883	0.896	0.910	0.923	0.952	0.981
130	0.849	0.854	0.858	0.862	0.867	0.876	0.888	0.900	0.912	0.924	0.950	0.977
135	0.856	0.860	0.865	0.869	0.873	0.881	0.892	0.903	0.915	0.926	0.950	0.975
140	0.863	0.867	0.871	0.875	0.879	0.887	0.897	0.907	0.918	0.929	0.951	0.973
145	0.871	0.874	0.878	0.882	0.885	0.893	0.902	0.912	0.922	0.932	0.952	0.973
150	0.878	0.881	0.885	0.888	0.892	0.899	0.908	0.917	0.926	0.935	0.954	0.973
155	0.885	0.888	0.892	0.895	0.898	0.905	0.913	0.922	0.930	0.939	0.957	0.974
160	0.892	0.895	0.899	0.902	0.905	0.911	0.919	0.927	0.935	0.943	0.959	0.976

TABLE 16. Isochoric heat capacity (kJ kg^{-1} K^{-1})—Continued

t	p/kPa											
°C	7000	8000	9000	10 000	12 000	14 000	16 000	18 000	20 000	30 000	40 000	50 000
−85	0.972	0.972	0.973	0.973	0.973	0.974	0.975	0.975	0.976	0.979	0.982	0.985
−80	0.966	0.966	0.967	0.967	0.968	0.968	0.969	0.969	0.970	0.973	0.976	0.979
−75	0.961	0.961	0.961	0.962	0.962	0.963	0.963	0.964	0.965	0.968	0.971	0.973
−70	0.956	0.956	0.957	0.957	0.957	0.958	0.959	0.959	0.960	0.963	0.966	0.969
−65	0.952	0.952	0.952	0.953	0.953	0.954	0.954	0.955	0.956	0.959	0.962	0.964
−60	0.948	0.948	0.949	0.949	0.949	0.950	0.951	0.951	0.952	0.955	0.958	0.961
−55	0.945	0.945	0.945	0.946	0.946	0.947	0.947	0.948	0.949	0.952	0.955	0.957
−50	0.942	0.942	0.942	0.943	0.943	0.944	0.944	0.945	0.946	0.949	0.952	0.955
−45	0.940	0.940	0.940	0.940	0.941	0.942	0.942	0.943	0.943	0.946	0.949	0.952
−40	0.938	0.938	0.938	0.938	0.939	0.940	0.940	0.941	0.941	0.944	0.947	0.950
−35	0.936	0.937	0.937	0.937	0.938	0.938	0.939	0.939	0.940	0.943	0.946	0.949
−30	0.935	0.936	0.936	0.936	0.937	0.937	0.938	0.938	0.939	0.942	0.945	0.948
−25	0.935	0.935	0.935	0.935	0.936	0.937	0.937	0.938	0.938	0.941	0.944	0.947
−20	0.935	0.935	0.935	0.935	0.936	0.936	0.937	0.937	0.938	0.941	0.944	0.947
−15	0.935	0.935	0.935	0.935	0.936	0.936	0.937	0.938	0.938	0.941	0.944	0.947
−10	0.936	0.936	0.936	0.936	0.937	0.937	0.938	0.938	0.939	0.941	0.944	0.947
−5	0.937	0.937	0.937	0.937	0.938	0.938	0.938	0.939	0.939	0.942	0.945	0.948
0	0.938	0.938	0.938	0.938	0.939	0.939	0.940	0.940	0.941	0.943	0.946	0.949
5	0.940	0.940	0.940	0.940	0.941	0.941	0.941	0.942	0.942	0.945	0.948	0.951
10	0.942	0.942	0.942	0.942	0.943	0.943	0.943	0.944	0.944	0.947	0.950	0.953
15	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.946	0.946	0.949	0.952	0.955
20	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.949	0.951	0.954	0.957
25	0.952	0.951	0.951	0.951	0.951	0.951	0.951	0.951	0.951	0.954	0.957	0.960
30	0.956	0.955	0.955	0.955	0.954	0.954	0.954	0.954	0.954	0.957	0.959	0.962
35	0.961	0.960	0.959	0.959	0.958	0.957	0.957	0.957	0.958	0.960	0.962	0.965
40	0.966	0.965	0.964	0.963	0.962	0.961	0.961	0.961	0.961	0.963	0.966	0.969
45	0.972	0.970	0.969	0.968	0.966	0.965	0.965	0.965	0.965	0.967	0.969	0.972
50	0.979	0.977	0.975	0.973	0.971	0.970	0.969	0.969	0.969	0.970	0.973	0.976
55	0.988	0.984	0.981	0.979	0.976	0.975	0.974	0.973	0.973	0.974	0.977	0.980
60	0.998	0.993	0.989	0.986	0.982	0.980	0.979	0.978	0.977	0.978	0.981	0.984
65	1.011	1.003	0.997	0.993	0.988	0.985	0.984	0.983	0.982	0.983	0.985	0.988
70	1.029	1.016	1.008	1.002	0.995	0.991	0.989	0.988	0.987	0.987	0.989	0.992
75	1.054	1.032	1.020	1.012	1.002	0.997	0.994	0.993	0.992	0.992	0.994	0.997
80	1.096	1.054	1.035	1.023	1.011	1.004	1.000	0.998	0.997	0.996	0.998	1.001
85	1.192	1.087	1.054	1.037	1.019	1.011	1.006	1.004	1.002	1.001	1.003	1.006
90	1.242	1.139	1.079	1.053	1.029	1.019	1.013	1.010	1.008	1.006	1.008	1.011
95	1.154	1.191	1.111	1.072	1.040	1.026	1.019	1.015	1.013	1.011	1.013	1.016
100	1.104	1.165	1.140	1.093	1.051	1.035	1.026	1.022	1.019	1.016	1.018	1.021
105	1.072	1.124	1.142	1.111	1.063	1.043	1.033	1.028	1.025	1.021	1.023	1.026
110	1.050	1.093	1.122	1.117	1.074	1.052	1.040	1.034	1.030	1.026	1.028	1.031
115	1.033	1.071	1.101	1.110	1.083	1.059	1.047	1.040	1.036	1.031	1.033	1.036
120	1.021	1.054	1.082	1.098	1.088	1.067	1.054	1.046	1.042	1.036	1.038	1.041
125	1.011	1.041	1.067	1.086	1.089	1.072	1.060	1.052	1.047	1.041	1.043	1.047
130	1.005	1.031	1.056	1.074	1.086	1.076	1.065	1.058	1.053	1.047	1.049	1.052
135	0.999	1.024	1.046	1.065	1.082	1.079	1.070	1.063	1.058	1.052	1.054	1.057
140	0.996	1.018	1.039	1.057	1.078	1.079	1.073	1.067	1.063	1.057	1.059	1.063
145	0.994	1.014	1.033	1.050	1.073	1.079	1.076	1.071	1.068	1.062	1.064	1.068
150	0.992	1.011	1.029	1.045	1.069	1.078	1.078	1.075	1.072	1.067	1.070	1.073
155	0.992	1.010	1.026	1.041	1.065	1.077	1.079	1.078	1.076	1.072	1.075	1.079
160	0.993	1.009	1.024	1.039	1.062	1.075	1.080	1.081	1.079	1.077	1.080	1.084

TABLE 17. Speed of sound (m s^{-1})

t	p/kPa											
C	20	40	60	80	100	101.325	150	200	300	400	500	600
-85	1143.4	1143.5	1143.6	1143.7	1143.8	1143.8	1144.0	1144.2	1144.6	1145.0	1145.5	1145.9
-80	1117.5	1117.6	1117.7	1117.8	1117.9	1117.9	1118.1	1118.3	1118.8	1119.2	1119.6	1120.1
-75	200.75	1091.7	1091.8	1091.9	1092.0	1092.0	1092.2	1092.4	1092.9	1093.3	1093.8	1094.2
-70	203.27	1065.8	1065.9	1066.0	1066.1	1066.1	1066.3	1066.6	1067.0	1067.5	1068.0	1068.4
-65	205.73	204.30	1040.0	1040.1	1040.2	1040.2	1040.4	1040.7	1041.2	1041.7	1042.1	1042.6
-60	208.12	206.86	205.50	1014.2	1014.3	1014.3	1014.5	1014.8	1015.3	1015.8	1016.3	1016.8
-55	210.45	209.33	208.14	206.86	988.26	988.26	988.52	988.78	989.30	989.82	990.34	990.86
-50	212.74	211.72	210.66	209.55	208.37	208.29	962.46	962.73	963.27	963.82	964.36	964.90
-45	214.98	214.05	213.09	212.10	211.07	211.00	936.30	936.59	937.15	937.72	938.29	938.85
-40	217.17	216.32	215.45	214.55	213.63	213.57	211.19	910.32	910.92	911.51	912.10	912.69
-35	219.33	218.54	217.74	216.92	216.09	216.03	213.91	211.56	884.54	885.16	885.78	886.40
-30	221.45	220.72	219.98	219.23	218.46	218.41	216.49	214.40	857.97	858.63	859.28	859.93
-25	223.53	222.85	222.17	221.47	220.77	220.72	218.96	217.08	213.00	831.88	832.57	833.25
-20	225.58	224.95	224.31	223.66	223.01	222.97	221.35	219.63	215.97	211.93	805.61	806.33
-15	227.59	227.00	226.41	225.81	225.20	225.16	223.66	222.08	218.75	215.15	778.34	779.10
-10	229.58	229.03	228.47	227.91	227.35	227.31	225.91	224.44	221.39	218.13	214.63	751.51
-5	231.53	231.02	230.49	229.97	229.44	229.41	228.11	226.74	223.91	220.94	217.78	214.40
0	233.46	232.97	232.49	231.99	231.50	231.47	230.25	228.97	226.35	223.60	220.72	217.68
5	235.36	234.90	234.44	233.98	233.52	233.49	232.34	231.15	228.70	226.16	223.51	220.73
10	237.24	236.81	236.37	235.94	235.50	235.47	234.39	233.27	230.98	228.61	226.16	223.61
15	239.09	238.68	238.27	237.86	237.45	237.42	236.41	235.35	233.20	230.99	228.71	226.35
20	240.92	240.53	240.15	239.76	239.37	239.34	238.38	237.39	235.37	233.29	231.16	228.97
25	242.72	242.36	241.99	241.63	241.26	241.23	240.33	239.39	237.48	235.53	233.53	231.49
30	244.51	244.17	243.82	243.47	243.12	243.10	242.24	241.35	239.55	237.71	235.84	233.92
35	246.28	245.95	245.62	245.29	244.96	244.94	244.12	243.28	241.58	239.85	238.08	236.28
40	248.02	247.71	247.40	247.09	246.77	246.75	245.98	245.18	243.57	241.93	240.26	238.57
45	249.75	249.46	249.16	248.86	248.56	248.54	247.81	247.05	245.52	243.97	242.39	240.79
50	251.47	251.18	250.90	250.61	250.33	250.31	249.61	248.90	247.44	245.97	244.48	242.97
55	253.16	252.89	252.62	252.35	252.08	252.06	251.40	250.71	249.33	247.93	246.52	245.09
60	254.84	254.58	254.32	254.07	253.81	253.79	253.16	252.51	251.19	249.86	248.52	247.16
65	256.50	256.26	256.01	255.77	255.52	255.50	254.90	254.28	253.03	251.76	250.49	249.20
70	258.15	257.92	257.68	257.45	257.21	257.20	256.62	256.03	254.84	253.63	252.42	251.19
75	259.79	259.56	259.34	259.12	258.89	258.88	258.33	257.76	256.62	255.48	254.32	253.15
80	261.41	261.20	260.98	260.77	260.55	260.54	260.01	259.47	258.39	257.29	256.19	255.08
85	263.02	262.81	262.61	262.40	262.20	262.18	261.68	261.17	260.13	259.08	258.03	256.98
90	264.62	264.42	264.22	264.03	263.83	263.82	263.34	262.84	261.85	260.85	259.85	258.84
95	266.20	266.01	265.82	265.64	265.45	265.44	264.98	264.50	263.56	262.60	261.64	260.68
100	267.77	267.59	267.41	267.23	267.05	267.04	266.60	266.15	265.24	264.33	263.41	262.50
105	269.34	269.16	268.99	268.82	268.65	268.63	268.21	267.78	266.91	266.04	265.16	264.28
110	270.89	270.72	270.56	270.39	270.23	270.22	269.81	269.40	268.56	267.73	266.89	266.05
115	272.43	272.27	272.11	271.95	271.79	271.78	271.40	271.00	270.20	269.40	268.60	267.80
120	273.96	273.81	273.66	273.50	273.35	273.34	272.97	272.59	271.83	271.06	270.29	269.52
125	275.48	275.34	275.19	275.04	274.90	274.89	274.53	274.17	273.44	272.70	271.97	271.23
130	276.99	276.85	276.71	276.57	276.43	276.43	276.08	275.73	275.03	274.33	273.63	272.92
135	278.50	278.36	278.23	278.09	277.96	277.95	277.62	277.29	276.62	275.94	275.27	274.59
140	279.99	279.86	279.73	279.61	279.48	279.47	279.15	278.83	278.19	277.54	276.89	276.25
145	281.48	281.35	281.23	281.11	280.98	280.97	280.67	280.36	279.75	279.13	278.51	277.89
150	282.95	282.84	282.72	282.60	282.48	282.47	282.18	281.89	281.29	280.70	280.11	279.51
155	284.42	284.31	284.20	284.08	283.97	283.96	283.68	283.40	282.83	282.26	281.69	281.12
160	285.89	285.78	285.67	285.56	285.45	285.44	285.18	284.90	284.36	283.81	283.26	282.72

TABLE 17. Speed of sound (m s⁻¹)—Continued

t °C	p/kPa 800	1000	1200	1400	1600	2000	2500	3000	3500	4000	5000	6000
−85	1146.7	1147.5	1148.4	1149.2	1150.0	1151.7	1153.8	1155.8	1157.9	1159.9	1164.0	1168.0
−80	1120.9	1121.8	1122.6	1123.5	1124.4	1126.1	1128.2	1130.3	1132.5	1134.6	1138.8	1142.9
−75	1095.1	1096.0	1096.9	1097.8	1098.7	1100.5	1102.7	1104.9	1107.1	1109.3	1113.6	1117.9
−70	1069.4	1070.3	1071.2	1072.1	1073.1	1074.9	1077.2	1079.5	1081.7	1084.0	1088.5	1092.9
−65	1043.6	1044.5	1045.5	1046.5	1047.4	1049.3	1051.7	1054.0	1056.4	1058.7	1063.3	1067.9
−60	1017.8	1018.8	1019.8	1020.7	1021.7	1023.7	1026.2	1028.6	1031.0	1033.5	1038.3	1043.0
−55	991.90	992.94	993.97	995.00	996.03	998.08	1000.6	1003.2	1005.7	1008.2	1013.2	1018.1
−50	965.98	967.06	968.14	969.21	970.28	972.41	975.07	977.70	980.32	982.93	988.09	993.20
−45	939.98	941.11	942.23	943.35	944.46	946.68	949.45	952.19	954.92	957.63	962.99	968.29
−40	913.87	915.05	916.22	917.39	918.55	920.87	923.75	926.62	929.46	932.28	937.86	943.38
−35	887.63	888.86	890.09	891.31	892.53	894.96	897.97	900.96	903.92	906.86	912.69	918.43
−30	861.23	862.52	863.80	865.09	866.36	868.91	872.06	875.19	878.29	881.37	887.45	893.43
−25	834.62	835.98	837.33	838.68	840.03	842.70	846.01	849.29	852.54	855.76	862.12	868.37
−20	807.77	809.21	810.64	812.06	813.47	816.29	819.78	823.22	826.64	830.02	836.69	843.23
−15	780.63	782.15	783.66	785.17	786.67	789.64	793.32	796.96	800.56	804.12	811.12	817.99
−10	753.14	754.75	756.36	757.96	759.55	762.71	766.61	770.46	774.26	778.01	785.40	792.62
−5	725.21	726.94	728.66	730.37	732.06	735.42	739.57	743.66	747.69	751.67	759.47	767.09
0	210.96	698.63	700.47	702.30	704.12	707.72	712.15	716.51	720.81	725.03	733.31	741.36
5	214.73	669.69	671.69	673.66	675.62	679.50	684.26	688.94	693.53	698.05	706.86	715.41
10	218.16	212.11	642.17	644.32	646.45	650.65	655.81	660.85	665.79	670.64	680.07	689.17
15	221.36	215.92	209.87	614.10	616.43	621.03	626.65	632.13	637.48	642.72	652.86	662.61
20	224.37	219.42	214.03	208.03	585.35	590.44	596.62	602.63	608.47	614.17	625.15	635.64
25	227.22	222.68	217.80	212.49	206.60	558.60	565.49	572.15	578.60	584.85	596.82	608.18
30	229.94	225.75	221.29	216.51	211.32	525.14	532.95	540.43	547.63	554.56	567.74	580.14
35	232.56	228.66	224.56	220.21	215.55	204.95	498.52	507.08	515.25	523.05	537.73	551.38
40	235.08	231.44	227.64	223.65	219.42	210.04	461.48	471.54	481.00	489.94	506.54	521.74
45	237.51	234.11	230.58	226.88	223.01	214.57	202.09	432.87	444.18	454.69	473.82	490.99
50	239.87	236.68	233.38	229.95	226.38	218.71	207.73	194.05	403.60	416.42	439.08	458.83
55	242.17	239.16	236.07	232.87	229.56	222.52	212.70	201.09	185.90	373.56	401.53	424.83
60	244.40	241.57	238.66	235.67	232.58	226.09	217.19	207.03	194.75	322.70	359.79	388.33
65	246.58	243.91	241.17	238.36	235.47	229.45	221.31	212.25	201.81	188.89	311.00	348.25
70	248.71	246.18	243.59	240.95	238.25	232.63	225.13	216.95	207.81	197.19	246.29	302.51
75	250.79	248.39	245.95	243.46	240.92	235.66	228.72	221.25	213.10	203.98	179.74	245.76
80	252.84	250.56	248.24	245.89	243.49	238.56	232.10	225.24	217.87	209.85	190.51	150.04
85	254.84	252.68	250.48	248.25	245.99	241.35	235.32	228.97	222.25	215.06	198.67	177.08
90	256.81	254.75	252.66	250.55	248.41	244.04	238.38	232.48	226.30	219.78	205.45	188.59
95	258.74	256.78	254.80	252.79	250.77	246.64	241.32	235.82	230.10	224.14	211.35	197.18
100	260.64	258.78	256.89	254.98	253.06	249.15	244.15	238.99	233.68	228.18	216.62	204.28
105	262.52	260.73	258.94	257.13	255.30	251.60	246.87	242.03	237.07	231.98	221.42	210.44
110	264.36	262.66	260.95	259.22	257.49	253.97	249.50	244.95	240.30	235.56	225.85	215.94
115	266.18	264.56	262.93	261.28	259.63	256.29	252.05	247.75	243.39	238.97	229.97	220.94
120	267.98	266.43	264.87	263.30	261.72	258.55	254.53	250.47	246.36	242.21	233.85	225.54
125	269.75	268.27	266.78	265.28	263.78	260.76	256.94	253.09	249.22	245.32	237.51	229.83
130	271.51	270.09	268.66	267.23	265.80	262.92	259.29	255.64	251.98	248.31	240.99	233.84
135	273.24	271.88	270.52	269.15	267.78	265.03	261.58	258.12	254.65	251.18	244.31	237.64
140	274.95	273.65	272.35	271.04	269.73	267.11	263.82	260.53	257.24	253.96	247.49	241.24
145	276.64	275.40	274.15	272.90	271.65	269.15	266.02	262.88	259.76	256.65	250.54	244.68
150	278.32	277.13	275.93	274.74	273.54	271.15	268.16	265.18	262.21	259.26	253.48	247.96
155	279.98	278.84	277.69	276.55	275.41	273.12	270.27	267.42	264.60	261.80	256.33	251.12
160	281.62	280.53	279.43	278.34	277.24	275.06	272.33	269.62	266.93	264.27	259.08	254.16

TABLE 17. Speed of sound (m s^{-1})—Continued

t / C	p/kPa 7000	8000	9000	10 000	12 000	14 000	16 000	18 000	20 000	30 000	40 000	50 000
−85	1172.0	1176.0	1180.0	1183.9	1191.7	1199.4	1206.9	1214.4	1221.8	1257.6	1291.5	1323.8
−80	1147.1	1151.2	1155.2	1159.3	1167.3	1175.2	1183.0	1190.7	1198.3	1234.9	1269.5	1302.5
−75	1122.2	1126.4	1130.6	1134.8	1143.0	1151.1	1159.1	1167.0	1174.8	1212.4	1247.8	1281.4
−70	1097.3	1101.7	1106.0	1110.3	1118.8	1127.1	1135.4	1143.5	1151.5	1190.0	1226.2	1260.5
−65	1072.5	1077.0	1081.5	1085.9	1094.7	1103.3	1111.7	1120.1	1128.3	1167.8	1204.8	1239.9
−60	1047.7	1052.4	1057.0	1061.6	1070.6	1079.5	1088.2	1096.8	1105.3	1145.7	1183.6	1219.4
−55	1023.0	1027.8	1032.6	1037.3	1046.6	1055.8	1064.8	1073.6	1082.3	1123.9	1162.6	1199.1
−50	998.25	1003.2	1008.2	1013.1	1022.7	1032.2	1041.4	1050.5	1059.5	1102.1	1141.8	1179.0
−45	973.53	978.71	983.83	988.89	998.86	1008.6	1018.2	1027.6	1036.8	1080.6	1121.2	1159.1
−40	948.82	954.19	959.50	964.75	975.06	985.15	995.02	1004.7	1014.2	1059.2	1100.7	1139.5
−35	924.09	929.67	935.18	940.62	951.31	961.74	971.94	981.93	991.71	1037.9	1080.4	1120.0
−30	899.33	905.14	910.87	916.52	927.60	938.40	948.95	959.25	969.34	1016.8	1060.4	1100.8
−25	874.53	880.58	886.55	892.42	903.92	915.12	926.03	936.68	947.08	995.93	1040.5	1081.7
−20	849.67	855.99	862.20	868.32	880.28	891.89	903.19	914.19	924.93	975.18	1020.8	1062.9
−15	824.73	831.33	837.82	844.20	856.65	868.71	880.42	891.80	902.90	954.60	1001.3	1044.3
−10	799.69	806.61	813.40	820.06	833.03	845.57	857.71	869.50	880.97	934.20	982.06	1025.9
−5	774.52	781.79	788.91	795.88	809.41	822.46	835.08	847.30	859.15	913.97	962.99	1007.7
0	749.21	756.86	764.33	771.64	785.79	799.39	812.50	825.18	837.45	893.92	944.14	989.78
5	723.71	731.78	739.65	747.32	762.15	776.34	789.99	803.15	815.86	874.06	925.51	972.08
10	697.99	706.54	714.84	722.92	738.47	753.32	767.54	781.21	794.38	854.39	907.10	954.61
15	672.01	681.08	689.87	698.40	714.76	730.30	745.13	759.35	773.02	834.91	888.91	937.39
20	645.70	655.38	664.72	673.74	690.99	707.29	722.79	737.59	751.78	815.64	870.96	920.41
25	619.02	629.38	639.34	648.92	667.14	684.27	700.49	715.92	730.66	796.57	853.25	903.69
30	591.88	603.03	613.69	623.91	643.21	661.25	678.24	694.34	709.67	777.72	835.79	887.21
35	564.19	576.27	587.73	598.66	619.18	638.21	656.04	672.85	688.81	759.09	818.58	871.00
40	535.83	549.00	561.40	573.15	595.02	615.15	633.89	651.47	668.09	740.69	801.62	855.06
45	506.66	521.13	534.63	547.32	570.73	592.07	611.79	630.19	647.52	722.54	784.93	839.38
50	476.49	492.55	507.35	521.13	546.28	568.96	589.75	609.04	627.10	704.63	768.51	823.98
55	445.06	463.09	479.46	494.52	521.66	545.83	567.78	588.01	606.86	686.98	752.37	808.85
60	412.04	432.58	450.86	467.44	496.86	522.67	545.89	567.13	586.81	669.61	736.52	794.01
65	376.93	400.77	421.43	439.83	471.87	499.52	524.10	546.42	566.97	652.52	720.96	779.46
70	338.99	367.35	391.04	411.64	446.71	476.39	502.45	525.91	547.37	635.73	705.70	765.20
75	297.02	331.95	359.56	382.84	421.41	453.33	480.98	505.63	528.03	619.26	690.75	751.23
80	248.71	294.12	326.93	353.47	396.04	430.40	459.73	485.63	509.00	603.12	676.11	737.57
85	189.40	253.54	293.29	323.70	370.75	407.70	438.79	465.97	490.33	587.33	661.81	724.21
90	170.04	211.36	259.24	294.00	345.76	385.39	418.25	446.72	472.07	571.91	647.84	711.15
95	182.24	183.83	226.91	265.28	321.48	363.67	398.26	427.97	454.28	556.89	634.21	698.41
100	191.79	184.53	203.27	239.37	298.46	342.83	378.96	409.84	437.05	542.27	620.94	685.99
105	199.61	191.53	195.58	219.74	277.44	323.21	360.57	392.44	420.45	528.10	608.03	673.88
110	206.33	198.60	197.33	209.62	259.33	305.21	343.31	375.92	404.59	514.39	595.48	662.10
115	212.28	205.08	201.93	207.28	245.13	289.23	327.41	360.43	389.56	501.16	583.32	650.64
120	217.65	210.98	207.16	208.95	235.51	275.63	313.09	346.11	375.47	488.44	571.55	639.51
125	222.58	216.39	212.37	212.32	230.20	264.73	300.52	333.10	362.41	476.26	560.17	628.72
130	227.15	221.39	217.38	216.34	228.15	256.62	289.84	321.48	350.45	464.64	549.19	618.25
135	231.42	226.05	222.13	220.56	228.27	251.15	281.12	311.34	339.67	453.59	538.63	608.12
140	235.44	230.41	226.64	224.77	229.72	247.90	274.33	302.69	330.09	443.14	528.48	598.33
145	239.25	234.53	230.91	228.90	231.96	246.38	269.32	295.51	321.72	433.30	518.76	588.87
150	242.86	238.43	234.97	232.89	234.66	246.15	265.88	289.75	314.54	424.09	509.45	579.75
155	246.32	242.14	238.84	236.76	237.62	246.83	263.74	285.30	308.52	415.49	500.58	570.97
160	249.63	245.69	242.55	240.48	240.70	248.15	262.66	282.00	303.58	407.53	492.14	562.52

11. References

[1] M. W. Chase, C. A. Davies, J. R. Downey, D. J. Frurip, R. A. McDonald, and A. N. Syverund, J. Phys. Chem. Ref. Data **14**, 593(1985).
[2] A. S. Rodgers, J. Chao, R. C. Wilhoit, and B. J. Zwolinski, J. Phys. Chem. Ref. Data **3**, 131(1974).
[3] J. Kilner and R. J. B. Craven, Comparisons of equations of state with experimental data for R-32 and R-125, IEA Heat Pump Programme Report No. HPP-AN18-4, Sittard, The Netherlands, 1997.
[4] T. O. D. Lüddecke and J. W. Magee, Int. J. Thermophys. **17**, 823(1996).
[5] Y. Higashi, Survey of the critical parameters for HFC refrigerants, Report to the IEA Annex 18, Iwaki Meisei University, 1996.
[6] D. R. Defibaugh, G. Morrison, and L. A. Weber, J. Chem. Eng. Data **39**, 333(1994).
[7] Y.-D. Fu, L.-Z. Han, and M.-S. Zhu, Fluid Phase Equil. **11**, 273(1995).
[8] M. Fukushima, S. Ohotoshi, and T. Miki, Proceedings of the 19th International Congress on Refrigeration 1995, Vol. IVa, p. 207.
[9] Y. Higashi, Int. J. Refrig. **17**, 524 (1994).
[10] C. D. Holcomb, V. G. Niesen, and L. J. van Poolen, Fluid Phase Equil. **91**, 145(1993).
[11] S. Kuwabara, H. Aoyama, H. Sato, and K. Watanabe, J. Chem. Eng. Data **40**, 112(1995).
[12] P. F. Malbrunot, P. A. Meunier, G. M. Scatena, W. H. Mears, K. P. Murphy, and J. V. Sinka, J. Chem. Eng. Data **13**, 16(1968).
[13] M. Nagel and K. Bier, Int. J. Refrig. **18**, 534(1995).
[14] A. Nishimura, Z. Y. Quian, H. Sato, and K. Watanabe, Proceedings of the 13th Japan Symposium on Thermophysical Properties, Akita, 1992, p. 57.
[15] T. Sato, H. Sato, and K. Watanabe, J. Chem. Eng. Data **39**, 851(1994).
[16] J. W. Schmidt and M. R. Moldover, J. Chem. Eng. Data **39**, 39(1994).
[17] L. A. Weber and A. M. Silva, J. Chem. Eng. Data **39**, 808(1994).
[18] V. Zhelezny, Y. Chernyak, and P. Zhelezny, Proceedings of the 4th Asian Thermophysics Property Conference, 1995, Vol. 2, p. 291.
[19] C. Bouchot and D. Richon, Joint Meeting of IIR Commissions B1, B2, E1, and E2, Padova, Italy, September 21–23, 1994, p. 517.
[20] B. de Vries, *Thermodynamische Eigenschaften der alternativen Kltemittel R-32, R-125 und R-143a*, DKV-Forsch.-Ber. Nr. 55 (DKV, Stuttgart, 1997) (in German).
[21] J. C. Holste, H. A. Duarte-Garza, and M. A. Villamanan-Olfos, "Thermodynamic properties measurements," ASME Winter Annual Meeting, New Orleans, LA, 1993.
[22] J. W. Magee, Int. J. Thermophys. **17**, 803(1996).
[23] Z. Y. Quian, H. Nishimura, H. Sato, and K. Watanabe, Int. J. JSME, Ser. B **36**, 665(1993).
[24] A. J. Grebenkov, Y. G. Kotelevsky, V. V. Saplitza, O. V. Beljaeva, T. A. Zajatz, and B. D. Timofeev, Joint Meeting of IIR Commissions, Padova, Italy, September 21–23, 1994, p. 419.
[25] T. Hozumi, H. Sato, and K. Watanabe, J. Chem. Eng. Data **39**, 493(1994).
[26] T. Takagi, High Temp.–High Press. **25**, 685(1993).
[27] M. Yomo, H. Sato, and K. Watanabe, Measurements of isobaric hea capacity for liquid difluoromethane (HFC-32), High Temp.–High Press **26**, 267(1994).
[28] O. V. Belyaeva, A. J. Grebenkov, T. A. Zayats, and B. D. Timofeev, Kho Tekh. **1**, 26(1995).
[29] R. A. Adams and F. P. Stein, J. Chem. Eng. Data **16**, 146(1971).
[30] A. Kanungo, T. Oi, A. Popowicz, and T. Ishida, J. Phys. Chem. **91** 4198(1987).
[31] K. Omata, T. Namiki, and K. Oguchi, Proceedings of the 15th Japa Symposium on Thermophysical Properties, 1994, p. 13.
[32] R. Tillner-Roth, Int. J. Thermophys. **17**, 1365(1996).
[33] M. Türk, J. Zhai, M. Nagel, and K. Bier, *Messung des Dampfdruckes un der Kritischen Zustandsgrößen von neuen Kältemitteln*, VDI-Fortschr. Ber. Reihe 19, No. 79 (VDI, Düsseldorf, 1994) (in German).
[34] L. A. Weber and A. R. H. Goodwin, J. Chem. Eng. Data **38**, 254(1993)
[35] J. V. Widiatmo, H. Sato, and K. Watanabe, J. Chem. Eng. Data **39** 304(1994).
[36] M. S. Zhu, J. Li, and B. X. Wang, Int. J. Thermophys. **14**, 1221(1993).
[37] K. Shinsaka, N. Gee, and G. R. Freeman, J. Chem. Thermodyn. **17** 1111(1985).
[38] R. E. Pennington and K. A. Kobe, J. Chem. Phys. **22**, 1442(1954).
[39] I. Suzuki and T. Shimanouchi, J. Mol. Spectrosc. **46**, 130(1973).
[40] B. T. Darling and D. M. Dennison, Phys. Rev. **57**, 128(1940)
[41] E. Hirota, J. Mol. Spectrosc. **71**, 145(1978).
[42] P. Wagner and A. B. F. Duncan, J. Am. Chem. Soc. **77**, 2609(1955).
[43] G. Herzberg, *Infrared and Raman Spectra of Polyatomic Molecules* (Van Nostrand, New York, 1945).
[44] A. R. Gordon, J. Chem. Phys. **2**, 65(1934).
[45] M. R. Moldover, J. P. M. Trusler, T. J. Edwards, J. B. Mehl, and R. S Davis, J. Res. Natl. Bur. Stand. **93**, 85(1988).
[46] W. Wagner, *Eine mathematisch statistische Methode zum Aufstellen thermodynamischer Gleichungen—gezeigt am Beispiel der Dampfdruckkurve reiner fluider Stoffe*, VDI Fortschr.-Ber., Reihe 3, 39 (VDI, Düsseldorf, 1974) (in German).
[47] R. Tillner-Roth and H. D. Baehr, J. Phys. Chem. Ref. Data **23**, 657(1994).
[48] M. Bischoff, Die Berechnung der thermischen zustandsgleichung für Methanol unter Verwendung der Wagner'schen Regressionsanalyse, Diplomarbeit, University Hannover, Germany, 1988.
[49] K. M. Watson, Ind. Eng. Chem. **35**, 398(1943).
[50] V. Svoboda and P. Basarova, Fluid Phase Equil. **93**, 167(1994).
[51] K. M. de Reuck and R. J. B. Craven, *Methanol—International Thermodynamic Tables of the Fluid State—12*, (Blackwell Scientific, Oxford, 1993), Vol. 12, part I.
[52] E. R. Cohen and B. N. Taylor, *The 1986 Adjustment of the Fundamental Physical Constants, CODATA*, Bulletin No. 63, *Committee on Data for Science and Technology, Int. Council of Scientific Unions* (Pergamon, Oxford, 1986).