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Refrigerant properties

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National foreword

This British Standard is the UK implementation of ISO 17584:2022. It supersedes BS ISO 17584:2005, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee RHE/18, Refrigeration safety.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Refrigerant properties

Propriétés des fluides frigorigènes

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 8, *Refrigerants and refrigeration lubricants*.

This second edition cancels and replaces the first edition (ISO 17584:2005), which has been technically revised.

The main changes are as follows:

— Addition of new refrigerants (R290, R600a, R1233zd(E), R1336mzz(Z), R1234yf, R1234ze(E));

— Update of Ammonia.

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Introduction

This document is consistent with and is intended to complement ISO 817. The purpose of this document is to address the differing performance ratings due to the differences between multiple property formulations, which is a problem especially in international trade. The fluids and properties included in this document represent those for which sufficient high-quality data were available.

This document allows for "alternative implementations" for the properties. These can take the form of simpler equations of state that may be applicable over limited ranges of conditions or simple correlations of single properties (e.g., expressions for vapour pressure or the enthalpy of the saturated vapour).

Tolerances in this document do not necessarily represent the uncertainty of the original experimental data or of the equation of state in fitting the data.

The tolerances are relative (i.e. plus or minus a percentage) for some properties and absolute for others (e.g. plus or minus a constant enthalpy value). Properties such as enthalpy and entropy, which can be negative, demand an absolute tolerance; any allowable percentage variation would be too strict at values near zero. The allowable tolerances for enthalpy and entropy are scaled by the enthalpy and entropy of vapourisation for each fluid. By scaling the tolerance to the vapourisation values, a greater tolerance is allowed for fluids, such as ammonia, with high heats of vapourisation.

The tolerances apply to individual thermodynamic states. In cycle and equipment analyses, it is the differences in enthalpy and/or entropy between two different states that are important. However, it is not possible to specify, in a simple way, allowable tolerances based on pairs of states because of the large number of possible pairs of interest.

The values of C_v and C_p approach infinity at the critical point, but the actual values returned by the equation of state are large numbers that vary from computer to computer due to round-off errors in the calculations. According to critical-region theory, the speed of sound is zero at the critical point; all traditional equations of state (including the ones in this document), however, do not reproduce this behaviour. Rather than list values that are inconsistent with either the theory or the specified equations of state, these points are not included as part of this document.

The values of the gas constant, R, vary from fluid to fluid. Similarly, the number of significant values given for the molecular mass, M, vary. The various values of R differ by less than 5×10^{-6} (equal to parts per million, a deprecated unit) from the currently accepted value of 8,314 462 618 J/(mol·K) and result in similarly small differences in the properties. The compositions of the refrigerant blends (R400- and R500-series) are defined on a mass basis, but the equations of state are given on a molar basis. The mass compositions have been converted to the equivalent molar basis and listed in Clause 5; a large number of significant values are given for consistency with the tables of "verification values" given in Annex D.

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Refrigerant properties

1 Scope

This document specifies the thermophysical properties of several commonly used refrigerants and refrigerant blends.

This document is applicable to refrigerants R12, R22, R32, R123, R125, R134a, R143a, R152a, R290, R600a, R717 (ammonia), R744 (carbon dioxide), R1233zd(E), R1336mzz(Z), R1234yf and R1234ze(E) and to the refrigerant blends R404A, R407C, R410A, and R507A. The following properties are included: density, pressure, internal energy, enthalpy, entropy, heat capacity at constant pressure, heat capacity at constant volume, speed of sound, and the Joule-Thomson coefficient, in both single-phase states and along the liquid-vapour saturation boundary. The numerical designation of these refrigerants is that defined in ISO 817.

NOTE 1 R12, R22, R123 are controlled substances under the Montreal Protocol, Annex A (R12) or Annex C Group I (R22, R123).

NOTE 2 R32, R125, R134a, R143a, R152a, R404A, R407C, R410A, and R507A are controlled substances under the Montreal Protocol, Annex F or blend thereof.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
algorithm
procedure for the computation of refrigerant properties

Note 1 to entry: An algorithm is most often a computer program. An algorithm may also consist of one or more single-property correlations as allowed under 4.4.

3.2
blend
mixture of two or more chemical compounds

3.3
critical point
state at which the properties of the saturated liquid and those of the saturated vapour become equal

Note 1 to entry: Separate liquid and vapour phases do not exist above the critical point temperature for a pure fluid. This is more completely referred to as the “gas-liquid critical point” as other “critical points” can be defined.

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3.4
equation of state
mathematical equation that is a complete and thermodynamically consistent representation of the thermodynamic properties of a fluid

Note 1 to entry: An equation of state most commonly expresses pressure or Helmholtz energy as a function of temperature, density, and (for a blend) composition. Other thermodynamic properties are obtained through integration and/or differentiation of the equation of state.

3.5
fluid
refrigerant
substance, present in liquid and/or gaseous states, used for heat transfer in a refrigerating system

Note 1 to entry: The fluid absorbs heat at a low temperature and low pressure, then releases the heat at a higher temperature and a higher pressure, usually through a change of state.

3.6
liquid-vapour saturation
state at which liquid and vapour phases of a fluid are in thermodynamic equilibrium with each other at a common temperature and pressure

Note 1 to entry: Such states exist from the triple point to the critical point.

3.7
transport properties
viscosity, thermal conductivity, and diffusion coefficient

3.8
thermodynamic properties
density, pressure, fugacity, internal energy, enthalpy, entropy, Gibbs and Helmholtz energies, heat capacities, speed of sound, and the Joule-Thomson coefficient, in both single-phase states and along the liquid-vapour saturation boundary

3.9
thermophysical properties
thermodynamic, transport, and other miscellaneous properties

3.10
triple point
state at which solid, liquid, and vapour phases of a substance are in thermodynamic equilibrium

4 Calculation of refrigerant properties

4.1 General

This document specifies properties for the refrigerants listed in Clause 1. These properties are derived from experimental measurements.

The properties enumerated in this document are calculated from specified equations of state, although alternative algorithms are allowed. The properties themselves constitute this document. The equations of state serve as a convenient means to represent and reproduce the properties. The properties enumerated in the tables in this document thus represent only a subset of the properties specified by this document; the full range of conditions is given for each fluid in Clause 5. An equation of state is a mathematical equation that is a complete and thermodynamically consistent representation of the thermodynamic properties of a fluid. These equations have been selected based on the following criteria:

a) accuracy in reproducing the available experimental data;

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b) applicability over wide ranges of temperature, pressure, and density;

c) proper behavior on extrapolation beyond the available experimental data; and

d) preference has been given to fully documented and published formulations.

4.2 Pure-fluid equations of state

An equation of state for a pure fluid may express the reduced molar Helmholtz energy, A, as a function of temperature, T, and density. The equation of state is composed of separate terms arising from ideal-gas behaviour (subscript "id") and a "residual" or "real-fluid" (subscript "r") contribution as given in Formula (1):

$$\phi = \frac{A}{RT} = \phi_{\mathrm{id}} + \phi_{\mathrm{r}} \tag{1}$$

where R is the gas constant.

Formulae of this form may be written on either a molar basis or a mass basis. For a consistent representation in this document, the equations of state originally published on a mass basis have been converted to a molar basis. The "residual" or "real-fluid" contribution is given by Formula (2):

$$\phi_{\mathrm{r}} = \sum_k N_k \tau^{t_k} \delta^{d_k} \exp\left[-\alpha_k (\delta - \varepsilon_k)^{l_k}\right] \exp\left[-\beta_k (\tau - \gamma_k)^{m_k}\right] \tag{2}$$

where

τ	is the dimensionless temperature variable T^*/T;
T^*	is the reducing parameter that is often equal to the critical temperature;
δ	is the dimensionless density variable ρ/ρ^*;
ρ^*	is the reducing parameter that is often equal to the critical density;
N_{k}	are numerical coefficients fitted to experimental data;
α_{k}, β_{k}, ε_{k} and γ_{k}	are parameters optimized for a particular fluid or group of fluids by a selection algorithm starting with a large bank of terms or by use of a non-linear fitting process;
t_{k}, d_{k}, l_{k} and m_{k}	are exponents optimized for a particular fluid or group of fluids by a selection algorithm starting with a large bank of terms or by use of a non-linear fitting process.

The ideal-gas contribution can be represented in one of several ways. One representation is in terms of the heat capacity of the ideal-gas state, as given in Formula (3):

$$\phi_{\mathrm{id}} = \frac{h_{\mathrm{ref}}}{\mathrm{R}T} - \frac{s_{\mathrm{ref}}}{\mathrm{R}} - 1 + \ln\left(\frac{RT\rho}{p_{\mathrm{ref}}}\right) + \frac{1}{RT}\int_{T_{\mathrm{ref}}}^{T} C_{p,\mathrm{id}}\,\mathrm{d}T - \frac{1}{R}\int_{T_{\mathrm{ref}}}^{T} \frac{C_{p,\mathrm{id}}}{T}\,\mathrm{d}T \tag{3}$$

where

h_{ref}	is the arbitrary reference enthalpy for the ideal gas at the reference state specified by T_{ref};
s_{ref}	is the arbitrary reference entropy for the ideal gas at the reference state specified by T_{ref} and p_{ref}.

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In this document, the h_{ref} and s_{ref} are chosen to yield a reference state for enthalpy of 200 kJ/kg and for entropy of 1 kJ/(kg·K), both for the saturated liquid at 0 °C. Such values of h_{ref} and s_{ref} are informative only; different values, corresponding to different reference state conventions, are acceptable.

The heat capacity of the ideal gas state, $C_{p,id}$ may be represented as a function of temperature by the general form consisting of separate summations of polynomial (empirical) and exponential (theoretical) terms, as given in Formula (4):

$$\frac{C_{p,\mathrm{id}}}{R} = c_0 + \sum_k c_k T^{t_k} + \sum_k a_k \frac{u_k^2 \exp(u_k)}{[\exp(u_k) - 1]^2} \tag{4}$$

where

$$u_k = \frac{b_k}{T}; \tag{5}$$

c_k, a_k, b_k and t_k are numerical coefficients and exponents fitted to data or derived from theoretical calculations.

A second representation of the ideal-gas contribution is given directly in terms of the Helmholtz free energy, as shown in Formula (6):

$$\phi_{\mathrm{id}} = d_1 + d_2\tau + \ln\delta + d_3 \ln\tau + \sum_k d_k \tau^{t_k} + \sum_k a_k \ln[1 - \exp(-\tau\lambda_k)] \tag{6}$$

where

d_1 and d_2 are adjusted to yield the desired reference state values for the enthalpy and entropy;

d_3, d_k, a_k, λ_k and t_k are either empirical or theoretical parameters.

Formula (6) is functionally equivalent to Formulae (3) to (5), and an ideal-gas contribution in the form of Formula (6) may be converted to the heat capacity form as given by Formula (7):

$$\frac{C_{p,\mathrm{id}}}{R} = d_3 + 1 - \sum_k d_k t_k (t_k - 1)\left(\frac{T^*}{T}\right)^{t_k} + \sum_k a_k \frac{u_k^2 \exp(u_k)}{[\exp(u_k) - 1]^2} \tag{7}$$

where

$$u_k = \frac{\lambda_k T^*}{T} \tag{8}$$

The equations of state for certain fluids may also include special terms to represent the behaviour very close to the critical point. These are of the form of Formula (9):

$$\phi_{\mathrm{crit}} = \sum_k N_k \delta \Delta^{b_k} \Psi \tag{9}$$

where

$$\Delta = \theta^2 + B_k \left[(\delta - 1)^2\right]^{a_k} \tag{10}$$

$$\theta = (1 - \tau) + A_k \left[(\delta - 1)^2\right]^{1/(2\beta_k)} \tag{11}$$

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$$\Psi = \exp\left[-C_k(\delta-1)^2 - D_k(\tau-1)^2\right] \tag{12}$$

where N_k, A_k, B_k, C_k, D_k, α_k and β_k are adjustable parameters fitted to data.

Formula (9) is added to the normal terms in Formula (1). Among the fluids in this document, only the equation of state for R744 (carbon dioxide) includes these critical region terms.

Alternately, an equation of state may express pressure as an explicit function of temperature and molar density. One form is that of a modified Benedict-Webb-Rubin (MBWR) equation of state, as given in Formula (13):

$$p = \sum_{k=1}^{9} a_k \rho^k + \exp\left(-\rho^2/\rho_{\text{crit}}^2\right) \sum_{k=10}^{15} a_k \rho^{2k-17} \tag{13}$$

where the a_k are functions of temperature resulting in a total of 32 adjustable parameters that are fitted to the experimental data. For a complete description of the thermodynamic properties, the MBWR formula is combined with an expression for the ideal-gas heat capacity, such as Formula (4) or (5).

In this document, pressure-explicit equations of state [such as Formula (13)] are transformed into the Helmholtz-energy form to maintain a consistent representation. The pressure is related to the Helmholtz energy using the thermodynamic identity shown in Formula (14):

$$p = -\left(\frac{\partial A}{\partial V}\right)_T \tag{14}$$

Thus, the Helmholtz energy can be evaluated from the pressure by an integration over volume, V, , using Formula (15):

$$\frac{A_{\text{r}}(T,\rho)}{RT} = \phi_{\text{r}} = -\int_V^{\infty}\left(\frac{p}{RT} - \rho\right)\mathrm{d}V \tag{15}$$

Formula (15) is then combined with an ideal-gas contribution given by Formulae (3) to (5) to yield a complete description of the thermodynamic properties. Among the fluids in this document, the equations of state for R123 and R152a have been transformed in this manner.

An equation of state or the ideal-gas heat capacity may also be expressed in other forms, but the forms represented by Formulae (1) through (15) encompass all those specified in this document.

Methods for computing pure-fluid thermodynamic properties from an equation of state are given in Annex B.

4.3 Mixture equation of state

Thermodynamic properties of mixtures are calculated by applying mixing rules to the Helmholtz energy of the mixture components together with a separate mixture function. The reduced Helmholtz energy of the mixture is a sum of ideal-gas and residual contributions as given by Formula (16):

$$\phi_{\text{mix}} = \frac{A}{RT} = \phi_{\text{mix,id}} + \phi_{\text{mix,r}} \tag{16}$$

The ideal gas part is given by Formula (17):

$$\phi_{\text{mix,id}} = \sum_{i=1}^{n}\left[x_i\phi_{i,\text{id}} + x_i \ln x_i\right] + f_3 + f_4/T \tag{17}$$

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where

x_i is the mole fraction of component i in the n-component mixture;

$x_i \ln x_i$ are terms arising from the entropy of mixing of ideal gases.

The parameters f_3 and f_4 are used to shift the thermodynamic surface such that the reference state for enthalpy is 200 kJ/kg and entropy is 1 kJ/(kg·K) at the saturated liquid at 0 °C, similar to that done for the pure fluids. Setting the parameters f_3 and f_4 to zero corresponds to a reference state based solely on the constituents of the mixture.

The residual part is given by Formula (18):

$$\phi_{\text{mix,r}} = \sum_{i=1}^{n} x_i \phi_{i,\text{r}} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} x_i x_j \phi_{ij,\text{excess}} \tag{18}$$

The first summation in this formula represents the ideal solution; it consists of the real fluid terms for each of the pure fluids multiplied by their respective compositions. The double summation accounts for the "excess" Helmholtz energy or "departure" from ideal solution. The $\phi_{i,\text{r}}$ and $\phi_{ij,\text{excess}}$ functions in Formula (18) are not evaluated at the temperature, T_{mix}, and density, ρ_{mix}, of the mixture, but, rather, at a reduced temperature, τ, and density, δ. The mixing rules for the reducing parameters are given by Formulae (19) and (20):

$$\tau = \frac{T^*}{T_{\text{mix}}} \tag{19}$$

where

$$T^* = \sum_{i=1}^{n} x_i T_i^* + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} x_i x_j \zeta_{ij}$$

and

$$\delta = \frac{\rho_{\text{mix}}}{\rho^*} \tag{20}$$

where

$$\frac{1}{\rho^*} = \sum_{i=1}^{n} \frac{x_i}{\rho_i^*} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} x_i x_j \xi_{ij}$$

where

ζ_{ij} and ξ_{ij} are "interaction parameters";

T_i^* and ρ_i^* are the reducing parameters of the pure fluids.

The $\phi_{ij,\text{excess}}$ function is of the general form of Formula (21):

$$\phi_{ij,\text{excess}} = F_{ij} \sum_{k} N_k \delta^{d_k} \tau^{t_k} \exp\left(-\delta^{l_k}\right) \tag{21}$$

The $\phi_{ij,\text{excess}}$ function will, in general, vary from mixture to mixture (see Annex E), and the coefficients and exponents are tabulated in Clause 5 for the refrigerant blends included in this document. In all cases, the pure-component contributions are those defined in Clause 5 of this document.

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Methods for computing thermodynamic properties from a mixture equation of state are given in Annex C.

4.4 Implementation

An algorithm shall directly implement one or more of the equations of state specified in Clause 5 together with the methods of calculating the thermodynamic properties given in Annex B and is also demonstrate to reproduce, for the fluids implemented, the "verification values" given in Annex D.

4.5 Alternative implementation

An algorithm shall, by any method, reproduce the values of thermodynamic properties specified in this document for the fluids implemented. Such an algorithm is considered to be applicable to the full range of temperature, pressure, and density and to the full set of properties or to any subrange of conditions and/or subset of properties. Any algorithm shall state the fluids for which it is applicable and the applicable property(ies) and range(s). The allowable variations (tolerances) between the property values specified in this document and those of an alternative implementation vary from property to property and are defined in Annex A.

4.6 Testing implementations against requirements

Any computer program or other implementation of this document shall satisfy the requirements specified in Annex A before it can claim compliance with this document. These requirements shall be carried out by the developer of the particular implementation.

5 Specifications for individual refrigerants

5.1 General

The following subclauses specify the equations of state used to calculate the properties of each of the refrigerants covered by this document and also tabulate the properties along the liquid-vapour saturation boundary. In the tabulations of coefficients and exponents, any terms not listed are zero.

5.2 R744 — Carbon dioxide

5.2.1 Range of validity

The coefficients are valid within the following ranges:

T_{min} = 216,592 K, T_{max} = 1 100 K; p_{max} = 800 MPa; ρ_{max} = 37,24 mol/l (1 639 kg/m^3)

Coefficients and exponents of the ideal-gas part are listed in Table 1. Coefficients and exponents of the real-gas part are listed in Table 2. Coefficients and exponents of the critical region terms are listed in Table 3.

Table 1 — Coefficients and exponents of the ideal-gas part [Formulae (3) to (5)]

k	a_k	b_k	c_k
0	—	—	3,5
1	1,994 270 42	958,499 56	—
2	0,621 052 475	1 858,801 15	—
3	0,411 952 928	2 061,101 14	—
4	1,040 289 22	3 443,899 08	—
5	0,083 276 775 3	8 238,200 35	—

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Table 2 — Coefficients and exponents of the real-gas part [Formula (2)]

k	N_k	t_k	d_k	l_k	α_k	m_k	β_k	γ_k	ε_k
1	0,388 568 232 032	0	1	0	0	—	—	—	—
2	$0{,}293\,854\,759\,427 \times 10^{1}$	0,75	1	0	0	—	—	—	—
3	$-0{,}558\,671\,885\,349 \times 10^{1}$	1	1	0	0	—	—	—	—
4	−0,767 531 995 925	2	1	0	0	—	—	—	—
5	0,317 290 055 804	0,75	2	0	0	—	—	—	—
6	0,548 033 158 978	2	2	0	0	—	—	—	—
7	0,122 794 112 203	0,75	3	0	0	—	—	—	—
8	$0{,}216\,589\,615\,432 \times 10^{1}$	1,5	1	1	1	—	—	—	—
9	$0{,}158\,417\,351\,097 \times 10^{1}$	1,5	2	1	1	—	—	—	—
10	−0,231 327 054 055	2,5	4	1	1	—	—	—	—
11	$0{,}581\,169\,164\,314 \times 10^{-1}$	0	5	1	1	—	—	—	—
12	−0,553 691 372 054	1,5	5	1	1	—	—	—	—
13	0,489 466 159 094	2	5	1	1	—	—	—	—
14	$-0{,}242\,757\,398\,435 \times 10^{-1}$	0	6	1	1	—	—	—	—
15	$0{,}624\,947\,905\,017 \times 10^{-1}$	1	6	1	1	—	—	—	—
16	−0,121 758 602 252	2	6	1	1	—	—	—	—
17	−0,370 556 852 701	3	1	2	1	—	—	—	—
18	$-0{,}167\,758\,797\,004 \times 10^{-1}$	6	1	2	1	—	—	—	—
19	−0,119 607 366 380	3	4	2	1	—	—	—	—
20	$-0{,}456\,193\,625\,088 \times 10^{-1}$	6	4	2	1	—	—	—	—
21	$0{,}356\,127\,892\,703 \times 10^{-1}$	8	4	2	1	—	—	—	—
22	$-0{,}744\,277\,271\,321 \times 10^{-2}$	6	7	2	1	—	—	—	—
23	$-0{,}173\,957\,049\,024 \times 10^{-2}$	0	8	2	1	—	—	—	—
24	$-0{,}218\,101\,212\,895 \times 10^{-1}$	7	2	3	1	—	—	—	—
25	$0{,}243\,321\,665\,592 \times 10^{-1}$	12	3	3	1	—	—	—	—
26	$-0{,}374\,401\,334\,235 \times 10^{-1}$	16	3	3	1	—	—	—	—
27	0,143 387 157 569	22	5	4	1	—	—	—	—
28	−0,134 919 690 833	24	5	4	1	—	—	—	—
29	$-0{,}231\,512\,250\,535 \times 10^{-1}$	16	6	4	1	—	—	—	—
30	$0{,}123\,631\,254\,929 \times 10^{-1}$	24	7	4	1	—	—	—	—
31	$0{,}210\,583\,219\,729 \times 10^{-2}$	8	8	4	1	—	—	—	—
32	$-0{,}339\,585\,190\,264 \times 10^{-3}$	2	10	4	1	—	—	—	—
33	$0{,}559\,936\,517\,716 \times 10^{-2}$	28	4	5	1	—	—	—	—
34	$-0{,}303\,351\,180\,556 \times 10^{-3}$	14	8	6	1	—	—	—	—
35	$-0{,}213\,654\,886\,883 \times 10^{3}$	1	2	2	25	2	325	1,16	1
36	$0{,}266\,415\,691\,493 \times 10^{5}$	0	2	2	25	2	300	1,19	1
37	$-0{,}240\,272\,122\,046 \times 10^{5}$	1	2	2	25	2	300	1,19	1
38	$-0{,}283\,416\,034\,240 \times 10^{3}$	3	3	2	15	2	275	1,25	1
39	$0{,}212\,472\,844\,002 \times 10^{3}$	3	3	2	20	2	275	1,22	1

Table 3 — Coefficients and exponents of the critical region terms [Formulae (9) to (12)]

k	N_k	a_k	b_k	β_k	A_k	B_k	C_k	D_k
40	−0,666 422 765 408	3,5	0,875	0,3	0,7	0,3	10	275

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Table 3 *(continued)*

k	N_k	a_k	b_k	β_k	A_k	B_k	C_k	D_k
41	0,726 086 323 499	3,5	0,925	0,3	0,7	0,3	10	275
42	$0{,}550\,686\,686\,128 \times 10^{-1}$	3	0,875	0,3	0,7	1	12,5	275

5.2.2 Reducing parameters, molar mass, and gas constant

T^* = 304,128 2 K, ρ^* = 10,624 906 3 mol/l, M = 44,009 8 g/mol, R = 8,314 51 J/(mol·K)

5.2.3 Reference state parameters

T_{ref} = 273,15 K, p_{ref} = 1,0 kPa, h_{ref} = 21 389,328 J/mol, s_{ref} = 155,741 4 J/(mol·K), f_1 = 5,805 551 35, f_2 = 1 555,797 10

R744 property values along the liquid-vapour saturation boundary are listed in Table 4.

Table 4 — R744 property values along the liquid-vapour saturation boundary

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−56,56[a]	0,518 0	1 178,5	79,60	80,04	0,521 3	0,974 7	1,953 2	975,8	−0,144 3
vapour			13,761	392,78	430,42	2,139 0	0,629 2	0,908 7	222,78	26,17
liquid	−55,00	0,554 0	1 172,9	82,62	83,09	0,535 2	0,972 4	1,956 9	964,6	−0,138 7
vapour			14,673	393,23	430,99	2,130 0	0,633 6	0,918 4	222,96	25,67
liquid	−50,00	0,682 3	1 154,6	92,35	92,94	0,579 4	0,965 5	1,971 2	928,5	−0,119 1
vapour			17,925	394,61	432,68	2,101 8	0,648 3	0,951 9	223,39	24,14
liquid	−45,00	0,831 8	1 135,8	102,14	102,87	0,622 8	0,959 0	1,989 2	892,4	−0,096 3
vapour			21,717	395,83	434,13	2,074 7	0,664 0	0,990 0	223,57	22,77
liquid	−40,00	1,004 5	1 116,4	112,00	112,90	0,665 6	0,952 9	2,011 7	856,3	−0,069 9
vapour			26,121	396,87	435,32	2,048 5	0,680 7	1,033 3	223,50	21,51
liquid	−35,00	1,202 4	1 096,4	121,95	123,05	0,707 9	0,947 3	2,039 3	819,9	−0,039 1
vapour			31,216	397,71	436,23	2,023 0	0,698 5	1,083 0	223,15	20,37
liquid	−30,00	1,427 8	1 075,7	132,01	133,34	0,749 8	0,942 2	2,073 1	783,2	−0,003 1
vapour			37,098	398,33	436,82	1,998 0	0,717 4	1,140 6	222,54	19,32
liquid	−25,00	1,682 7	1 054,2	142,20	143,79	0,791 4	0,937 9	2,114 5	745,8	0,039 4
vapour			43,880	398,71	437,06	1,973 2	0,737 9	1,208 3	221,63	18,35
liquid	−20,00	1,969 6	1 031,7	152,54	154,45	0,832 8	0,934 4	2,165 3	707,5	0,090 0
vapour			51,700	398,79	436,89	1,948 5	0,760 2	1,289 3	220,41	17,44
liquid	−15,00	2,290 8	1 008,0	163,07	165,34	0,874 2	0,932 4	2,228 3	667,8	0,150 9
vapour			60,728	398,55	436,27	1,923 7	0,784 7	1,387 7	218,85	16,58
liquid	−10,00	2,648 7	982,9	173,83	176,52	0,915 7	0,933 0	2,307 2	626,1	0,225 1
vapour			71,185	397,93	435,14	1,898 5	0,811 3	1,509 1	216,94	15,77
liquid	−5,00	3,045 9	956,2	184,86	188,05	0,957 6	0,937 1	2,408 5	582,2	0,316 8
vapour			83,359	396,84	433,38	1,872 5	0,840 3	1,662 8	214,68	14,99

[a] Triple point.

[b] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 4 *(continued)*

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	0,00	3,485 1	927,4	196,24	200,00	1,000 0	0,944 9	2,542 3	536,4	0,432 5
vapour			97,647	395,20	430,89	1,845 3	0,872 2	1,864 8	212,04	14,23
liquid	5,00	3,969 5	896,0	208,07	212,50	1,043 4	0,955 8	2,726 8	489,3	0,582 4
vapour			114,621	392,85	427,48	1,816 3	0,908 4	2,144 0	208,97	13,47
liquid	10,00	4,502 2	861,1	220,50	225,73	1,088 4	0,969 1	2,997 6	441,0	0,783 6
vapour			135,156	389,57	422,88	1,784 7	0,950 7	2,557 8	205,41	12,69
liquid	15,00	5,087 1	821,2	233,79	239,99	1,135 9	0,985 9	3,436 0	391,1	1,067 0
vapour			160,730	384,99	416,64	1,748 9	1,002 9	3,237 1	201,21	11,85
liquid	20,00	5,729 1	773,4	248,46	255,87	1,187 7	1,011 4	4,263 7	337,6	1,497 3
vapour			194,202	378,36	407,87	1,706 2	1,072 5	4,559 9	196,09	10,88
liquid	25,00	6,434 2	710,5	265,73	274,78	1,248 5	1,070 4	6,467 4	274,3	2,256 5
vapour			242,732	367,92	394,43	1,649 8	1,181 9	8,212 3	189,12	9,62
liquid	30,00	7,213 7	593,3	292,40	304,55	1,343 5	1,406 3	35,338 4	177,2	4,278 9
vapour			345,102	344,23	365,13	1,543 3	1,522 8	55,821 7	171,26	7,39
critical	30,98	7,377 3	467,6	316,47	332,25	1,433 6	[b]	[b]	[b]	5,866 5

[a] Triple point.

[b] The values of C_v, C_p, and w at the critical point are not included as part of this document.

5.3 R717 — Ammonia

5.3.1 Range of validity

The coefficients are valid within the following ranges:

T_{min} = 195,495 K, T_{max} = 725 K; p_{max} = 1 000 MPa; ρ_{max} = 52,43 mol/l (893 kg/m³)

5.3.2 Coefficients and exponents of the ideal-gas part [Formulae (3) to (5)]

Coefficients and exponents of the ideal-gas part are listed in Table 5 and Table 6. Coefficients and exponents of the real-gas part are listed in Table 7, Table 8 and Table 9.

Table 5 — Coefficients and exponents for k =0

k	c_k
0	4,000

Table 6 — Coefficients and exponents for k = 1 up to 3

k	a_k	b_k
1	2,224	1 646
2	3,148	3 965
3	0,957 9	7 231

5.3.3 Coefficients and exponents of the real-gas part [Formula (2)]

Parameters not listed are zero.

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Table 7 — Coefficients and exponents for k = 1 up to 5

k	N_k	t_k	d_k
1	0,006 132 232	1,0	4
2	1,739 586 6	0,382	1
3	−2,226 179 2	1	1
4	−0,301 275 53	1	2
5	0,089 670 23	0,677	3

Table 8 — Coefficients and exponents for k = 6 up to 18

k	N_k	t_k	d_k	l_k	α_k	m_k	β_k	γ_k	ε_k
6	−0,076 387 037	2,915	3	2	1	1	0	1	0
7	−0,840 639 63	3,51	2	2	1	1	0	1	0
8	−0,270 263 27	1,063	3	1	1	1	0	1	0
9	6,212 578	0,655	1	2	−0,427 76	2	−1,708	1,036	−0,072 6
10	−5,784 435 7	1,3	1	2	−0,642 4	2	−1,486 5	1,277 7	−0,127 4
11	2,481 754 2	3,1	1	2	−0,817 5	2	−2,091 5	1,083	0,752 7
12	−2,373 916 8	1,439 5	2	2	−0,799 5	2	−2,43	1,290 6	0,57
13	0,014 936 97	1,623	2	2	−0,91	2	−0,488	0,928	2,2
14	−3,774 926 4	0,643	1	2	−0,357 4	2	−1,1	0,934	−0,243
15	0,000 625 435	1,13	3	2	−1,21	2	−0,85	0,919	2,96
16	−0,000 017 359	4,5	3	2	−4,14	2	−1,14	1,852	3,02
17	−0,134 620 33	1	1	2	−22,56	2	−945,64	1,058 97	0,957 4
18	0,077 490 728	4	1	2	−22,68	2	−993,85	1,052 77	0,957 6

For ammonia (R717), the final two terms in the summation of Formula (2) (i.e., k= 19,20) have a slightly different form, see Formula (22):

$$\phi_r = \sum_{k=19}^{20} N_k \tau^{t_k} \delta^{d_k} \exp\left[-\alpha_k (\delta - \varepsilon_k)^{l_k}\right] \exp\left[\frac{1}{\chi_k (\tau - \gamma_k)^{m_k} + b_k}\right] \tag{22}$$

Table 9 — Coefficients and exponents for k = 19 up to 20

k	N_k	t_k	d_k	l_k	α_k	m_k	χ_k	γ_k	ε_k	b_k
19	−1,690 985 8	4,331 5	1	2	−2,845 2	2	0,369 6	1,108	0,447 8	1,244
20	0,937 390 74	4,015	1	2	−2,834 2	2	0,296 2	1,313	0,446 89	0,682 6

5.3.4 Reducing parameters, molar mass, and gas constant

T^* = 405,56 K, ρ^* = 13,696 mol/l, M = 17,030 52 g/mol, R = 8,314 459 8 J/(mol·K)

5.3.5 Reference state parameters

T_{ref} = 273,15 K, p_{ref} = 1,0 kPa, h_{ref} = 28 044,796 J/mol, s_{ref} = 156,239 4 J/(mol·K)

R717 property values along the liquid-vapour saturation boundary are listed in Table 10.

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Table 10 — R717 property values along the liquid-vapour saturation boundary

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−77,66[a]	0,006 05	733,9	−145,67	−145,67	−0,483 5	2,967 5	4,305 3	2 011,3	−0,219 6
vapour			0,063 7	1 248,25	1 343,27	7,132 9	1,516 2	2,022 9	355,26	180,96
liquid	−75,00	0,007 47	730,8	−134,21	−134,20	−0,425 3	2,968 7	4,312 3	1 994,6	−0,218 4
vapour			0,077 6	1 251,91	1 348,16	7,055 7	1,522 5	2,031 9	357,48	169,43
liquid	−70,00	0,010 9	725	−112,62	−112,60	−0,317 6	2,970 1	4,327 7	1 963,4	−0,215 8
vapour			0,111	1 258,72	1 357,25	6,917 7	1,535 6	2,050 7	361,55	150,11
liquid	−65,00	0,015 6	719,3	−90,94	−90,92	−0,212 2	2,969 9	4,345 1	1 932,3	−0,212 8
vapour			0,155	1 265,41	1 366,19	6,788 1	1,550 5	2,072 6	365,49	133,43
liquid	−60,00	0,021 8	713,5	−69,17	−69,14	−0,108 9	2,967 7	4,363 6	1 901,4	−0,209 5
vapour			0,212	1 271,99	1 374,98	6,666 3	1,567 5	2,097 5	369,29	118,99
liquid	−55,00	0,030 1	707,6	−47,31	−47,27	−0,007 5	2,963 3	4,382 7	1 870,6	−0,205 8
vapour			0,286	1 278,43	1 383,58	6,551 5	1,586 5	2,125 9	372,93	106,44
liquid	−50,00	0,040 8	701,7	−25,35	−25,29	0,092	2,956 7	4,401 9	1 839,7	−0,201 8
vapour			0,38	1 284,72	1 391,98	6,443 3	1,607 7	2,157 8	376,41	95,48
liquid	−45,00	0,054 4	695,8	−3,30	−3,23	0,189 8	2,948	4,421	1 808,8	−0,197 5
vapour			0,498	1 290,86	1 400,17	6,341	1,631 1	2,193 4	379,73	85,9
liquid	−40,00	0,071 6	689,8	18,84	18,94	0,285 8	2,937 6	4,44	1 777,6	−0,192 9
vapour			0,644	1 296,83	1 408,14	6,244 1	1,656 7	2,232 8	382,86	77,48
liquid	−35,00	0,093	683,7	41,07	41,21	0,380 1	2,925 7	4,458 9	1 746,3	−0,187 9
vapour			0,822	1 302,63	1 415,86	6,152 3	1,684 4	2,276 1	385,81	70,08
liquid	−33,32[b]	0,101 3	681,6	48,58	48,73	0,411 5	2,921 4	4,465 3	1 735,6	−0,186 1
vapour			0,89	1 304,55	1 418,4	6,122 4	1,694 2	2,291 6	386,76	67,78
liquid	−30,00	0,119 4	677,5	63,4	63,57	0,472 9	2,912 7	4,478	1 714,6	−0,182 6
vapour			1,037	1 308,25	1 423,32	6,065 1	1,714 3	2,323 5	388,57	63,55
liquid	−25,00	0,151 4	671,3	85,81	86,04	0,564 1	2,899 1	4,497 4	1 682,5	−0,176 8
vapour			1,296	1 313,68	1 430,51	5,982 1	1,746 1	2,374 9	391,12	57,78
liquid	−20,00	0,19	665	108,32	108,6	0,654	2,885 2	4,517 3	1 650	−0,170 6
vapour			1,604	1 318,9	1 437,41	5,903	1,779 8	2,430 5	393,47	52,68
liquid	−15,00	0,236 1	658,5	130,92	131,28	0,742 4	2,871 2	4,538 2	1 617,1	−0,163 9
vapour			1,966	1 323,91	1 444	5,827 5	1,815 2	2,490 2	395,61	48,17
liquid	−10,00	0,290 6	652	153,62	154,06	0,829 5	2,857 4	4,560 4	1 583,7	−0,156 7
vapour			2,391	1 328,7	1 450,27	5,755 2	1,852 3	2,554 3	397,53	44,16
liquid	−5,00	0,354 7	645,4	176,42	176,97	0,915 3	2,844 1	4,584 1	1 549,9	−0,148 9
vapour			2,885	1 333,26	1 456,2	5,685 9	1,890 7	2,622 9	399,23	40,61
liquid	0	0,429 2	638,6	199,33	200	1	2,831 4	4,609 7	1 515,6	−0,140 4
vapour			3,456	1 337,57	1 461,77	5,619 3	1,930 4	2,696 2	400,7	37,44
liquid	5	0,515 6	631,8	222,36	223,17	1,083 6	2,819 4	4,637 6	1 480,8	−0,131 1
vapour			4,113	1 341,62	1 466,96	5,555 2	1,971 4	2,774 5	401,94	34,61
liquid	10	0,614 8	624,8	245,51	246,49	1,166 1	2,808 3	4,668 2	1 445,5	−0,120 9
vapour			4,866	1 345,38	1 471,73	5,493 3	2,013 4	2,858 3	402,95	32,09
liquid	15	0,728 2	617,7	268,8	269,98	1,247 7	2,798	4,701 8	1 409,8	−0,109 8

[a] Triple point

[b] Normal boiling point

[*] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 10 *(continued)*

	Temp. °C	Pressure MPa	Density kg/m³	Internal energy kJ/kg	Enthalpy kJ/kg	Entropy kJ/(kg·K)	C_v kJ/(kg·K)	C_p kJ/(kg·K)	Sound speed m/s	J-T coefficient K/MPa
vapour			5,724	1 348,84	1 476,07	5,433 3	2,056 5	2,948 1	403,7	29,82
liquid	20	0,857	610,4	292,24	293,64	1,328 4	2,788 6	4,738 9	1 373,6	−0,097 6
vapour			6,698	1 351,99	1 479,94	5,375 1	2,100 6	3,044 5	404,21	27,79
liquid	25	1,002 7	603	315,84	317,5	1,408 3	2,780 2	4,78	1 336,9	−0,084 2
vapour			7,801	1 354,78	1 483,32	5,318 4	2,145 8	3,148 6	404,46	25,96
liquid	30	1,166 5	595,4	339,61	341,57	1,487 4	2,772 7	4,825 7	1 299,7	−0,069 4
vapour			9,046	1 357,2	1 486,16	5,263 1	2,192 2	3,261 1	404,44	24,3
liquid	35	1,35	587,6	363,58	365,88	1,565 9	2,766 1	4,876 5	1 262,1	−0,052 9
vapour			10,448	1 359,22	1 488,44	5,208 8	2,239 6	3,383 6	404,15	22,79
liquid	40	1,554 5	579,6	387,76	390,45	1,643 9	2,760 4	4,933 3	1 223,9	−0,034 6
vapour			12,024	1 360,81	1 490,1	5,155 5	2,288 4	3,517 4	403,57	21,42
liquid	45	1,781 7	571,4	412,18	415,3	1,721 4	2,755 7	4,997	1 185,2	−0,014 2
vapour			13,792	1 361,93	1 491,11	5,102 8	2,338 5	3,664 6	402,68	20,16
liquid	50	2,033	563	436,85	440,46	1,798 5	2,752	5,068 8	1 146	0,008 7
vapour			15,775	1 362,54	1 491,41	5,050 7	2,390 2	3,827 4	401,49	19,01
liquid	55	2,31	554,3	461,81	465,97	1,875 3	2,749 2	5,149 9	1 106,1	0,034 4
vapour			17,996	1 362,59	1 490,95	4,998 8	2,443 6	4,008 8	399,96	17,95
liquid	60	2,614 5	545,3	487,08	491,87	1,951 9	2,747 5	5,242 4	1 065,6	0,063 6
vapour			20,484	1 362,04	1 489,67	4,947	2,498 9	4,212 6	398,09	16,97
liquid	65	2,948 1	536	512,7	518,2	2,028 5	2,747	5,348 6	1 024,4	0,096 8
vapour			23,274	1 360,81	1 487,48	4,895	2,556 2	4,443 4	395,84	16,06
liquid	70	3,312 5	526,3	538,72	545,02	2,105 2	2,747 9	5,471 6	982,4	0,135
vapour			26,404	1 358,86	1 484,31	4,842 5	2,615 9	4,707 4	393,21	15,21
liquid	75	3,709 6	516,3	565,19	572,38	2,182 2	2,750 2	5,615 7	939,5	0,179 1
vapour			29,924	1 356,08	1 480,05	4,789 3	2,678 1	5,013	390,16	14,41
liquid	80	4,141 3	505,7	592,18	600,37	2,259 6	2,754 3	5,787	895,6	0,230 7
vapour			33,892	1 352,38	1 474,57	4,735 1	2,743 1	5,371 4	386,66	13,66
liquid	85	4,609 5	494,6	619,77	629,08	2,337 7	2,760 5	5,993 8	850,5	0,291 6
vapour			38,384	1 347,63	1 467,72	4,679 3	2,811 2	5,798 4	382,67	12,95
liquid	90	5,116 4	482,8	648,06	658,65	2,416 8	2,769 4	6,248 9	804,2	0,364 5
vapour			43,493	1 341,68	1 459,32	4,621 6	2,882 8	6,317	378,14	12,27
liquid	95	5,664 1	470,3	677,19	689,24	2,497 3	2,781 7	6,571 6	756,3	0,453 2
vapour			49,346	1 334,32	1 449,1	4,561 3	2,958 3	6,962	373,02	11,62
liquid	100	6,255 1	456,8	707,37	721,07	2,579 8	2,798 3	6,993 3	706,7	0,563 1
vapour			56,112	1 325,26	1 436,74	4,497 7	3,038 3	7,788 8	367,24	10,99
liquid	105	6,891 9	442,1	738,88	754,47	2,664 9	2,820 8	7,568 6	654,9	0,702 7
vapour			64,035	1 314,12	1 421,74	4,429 5	3,122 9	8,892 4	360,7	10,38
liquid	110	7,577 5	425,7	772,13	789,93	2,753 9	2,851 5	8,4	600,8	0,885 1
vapour			73,481	1 300,29	1 403,41	4,355 1	3,212 8	10,454 7	353,3	9,77
liquid	115	8,315 1	407,1	807,81	828,23	2,848 6	2,894 4	9,706 7	543,8	1,132 6
vapour			85,052	1 282,79	1 380,55	4,271 6	3,312 7	12,884 2	344,87	9,15

[a] Triple point

[b] Normal boiling point

[*] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 10 *(continued)*

	Temp. °C	Pressure MPa	Density kg/m³	Internal energy kJ/kg	Enthalpy kJ/kg	Entropy kJ/(kg·K)	C_v kJ/(kg·K)	C_p kJ/(kg·K)	Sound speed m/s	J-T coefficient K/MPa
liquid	120	9,108 8	385,1	847,17	870,82	2,952 5	2,957 5	12,060 4	483	1,487 5
vapour			99,866	1 259,78	1 350,99	4,173 8	3,441 6	17,313	334,87	8,47
liquid	125	9,963 8	357,1	893,01	920,91	3,073 3	3,072 6	17,636 5	414,5	2,051 1
vapour			120,494	1 227,07	1 309,76	4,049 9	3,667 7	28,268 5	321,42	7,64
liquid	130	10,888 3	313,4	955,79	990,53	3,240 1	3,557 2	50,546 8	313	3,245
vapour			156,733	1 168,91	1 238,38	3,854 9	4,384 7	96,671	294,02	6,36
critical	132,41	11,363 4	233,3	1 053,41	1 102,13	3,511 7	*	*	*	4,950 6

[a] Triple point

[b] Normal boiling point

* The values of C_v, C_p, and w at the critical point are not included as part of this document.

5.4 R12 — Dichlorodifluoromethane

5.4.1 Range of validity

The coefficients are valid within the following ranges:

T_{min} = 116,099 K, T_{max} = 525 K; p_{max} = 200 MPa; ρ_{max} = 15,13 mol/l (1 829 kg/m³)

Coefficients and exponents of the ideal-gas part are listed in Table 11. Coefficients and exponents of the real-gas part are listed in Table 12.

Table 11 — Coefficients and exponents of the ideal-gas part [Formulae (3) to (5)]

k	c_k	a_k	b_k
0	4,003 638 529	—	—
1	—	3,160 638 395	1 433,434 2
2	—	0,371 259 877 4	2 430,049 8
3	—	3,562 277 099	685,659 52
4	—	2,121 533 311	412,415 79

Table 12 — Coefficients and exponents of the real-gas part [Formula (2)]

k	N_k	t_k	d_k	l_k	α_k
1	$0{,}207\,534\,340\,2 \times 10^{1}$	0,5	1	0	0
2	$-0{,}296\,252\,599\,6 \times 10^{1}$	1	1	0	0
3	$0{,}100\,158\,961\,6 \times 10^{-1}$	2	1	0	0
4	$0{,}178\,134\,761\,2 \times 10^{-1}$	2,5	2	0	0
5	$0{,}255\,692\,915\,7 \times 10^{-1}$	−0,5	4	0	0
6	$0{,}235\,214\,263\,7 \times 10^{-2}$	0	6	0	0
7	$-0{,}849\,555\,331\,4 \times 10^{-4}$	0	8	0	0
8	$-0{,}153\,594\,559\,9 \times 10^{-1}$	−0,5	1	1	1
9	−0,210 881 677 6	1,5	1	1	1
10	$-0{,}165\,422\,880\,6 \times 10^{-1}$	2,5	5	1	1
11	$-0{,}118\,131\,613\,0 \times 10^{-1}$	−0,5	7	1	1
12	$-0{,}416\,029\,583\,0 \times 10^{-4}$	0	12	1	1

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Table 12 *(continued)*

k	N_k	t_k	d_k	l_k	α_k
13	$0{,}278\,486\,166\,4 \times 10^{-4}$	0,5	12	1	1
14	$0{,}161\,868\,643\,3 \times 10^{-5}$	−0,5	14	1	1
15	−0,106 461 468 6	4	1	2	1
16	$0{,}936\,966\,520\,7 \times 10^{-3}$	4	9	2	1
17	$0{,}259\,009\,544\,7 \times 10^{-1}$	2	1	3	1
18	$-0{,}434\,702\,502\,5 \times 10^{-1}$	4	1	3	1
19	0,101 230 844 9	12	3	3	1
20	−0,110 000 343 8	14	3	3	1
21	$-0{,}336\,101\,200\,9 \times 10^{-2}$	0	5	3	1
22	$0{,}378\,919\,000\,8 \times 10^{-3}$	14	9	4	1

5.4.2 Reducing parameters, molar mass, and gas constant

T^* = 385,12 K, ρ^* = 4,672 781 mol/l, M = 120,913 g/mol, R = 8,314 471 J/(mol·K)

5.4.3 Reference state parameters

T_{ref} = 273,15 K, p_{ref} = 1,0 kPa, h_{ref} = 43 261,068 J/mol, s_{ref} = 237,753 2 J/(mol·K), f_1 = 1,622 697 55, f_2 = 3 621,284 29

R12 property values along the liquid-vapour saturation boundary are listed in Table 13.

Table 13 — R12 property values along the liquid-vapour saturation boundary

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−157,05[a]	$2{,}426\times10^{-7}$	1 828,8	66,33	66,33	0,278 0	0,572 5	0,856 1	1 310,0	−0,530 5
vapour			$3{,}038 \times 10^{-5}$	275,23	283,21	2,146 1	0,286 0	0,354 8	99,51	532,60
liquid	−155,00	$3{,}883\times10^{-7}$	1 823,4	68,08	68,08	0,293 0	0,567 4	0,851 0	1 299,6	−0,533 3
vapour			$4{,}779 \times 10^{-5}$	275,82	283,94	2,120 0	0,289 4	0,358 2	100,27	495,55
liquid	−150,00	$1{,}135\times10^{-6}$	1 810,1	72,31	72,31	0,328 0	0,556 7	0,840 4	1 274,4	−0,538 9
vapour			$1{,}340 \times 10^{-4}$	277,29	285,75	2,061 2	0,297 8	0,366 5	102,10	418,14
liquid	−145,00	$3{,}019\times10^{-6}$	1 796,9	76,49	76,49	0,361 3	0,548 2	0,832 1	1 249,5	−0,543 0
vapour			$3{,}426 \times 10^{-4}$	278,80	287,61	2,008 7	0,306 2	0,374 9	103,88	355,64
liquid	−140,00	$7{,}387\times10^{-6}$	1 783,7	80,63	80,63	0,393 0	0,541 5	0,825 7	1 224,8	−0,545 8
vapour			$8{,}068 \times 10^{-4}$	280,35	289,50	1,961 7	0,314 6	0,383 3	105,63	304,78
liquid	−135,00	$1{,}680\times10^{-5}$	1 770,6	84,75	84,75	0,423 4	0,536 3	0,821 0	1 200,3	−0,547 3
vapour			$1{,}768 \times 10^{-3}$	281,94	291,44	1,919 5	0,322 9	0,391 7	107,34	263,05
liquid	−130,00	$3{,}577\times10^{-5}$	1 757,5	88,85	88,85	0,452 5	0,532 4	0,817 7	1 176,0	−0,547 6
vapour			$3{,}635 \times 10^{-3}$	283,57	293,42	1,881 6	0,331 3	0,400 1	109,02	228,57
liquid	−125,00	$7{,}189\times10^{-5}$	1 744,5	92,93	92,93	0,480 5	0,529 6	0,815 7	1 152,0	−0,546 9
vapour			$7{,}058 \times 10^{-3}$	285,25	295,44	1,847 4	0,339 6	0,408 4	110,67	199,86
liquid	−120,00	0,000 137	1 731,4	97,01	97,01	0,507 6	0,527 7	0,814 6	1 128,1	−0,545 3

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 13 *(continued)*

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
vapour			0,013 03	286,96	297,49	1,816 7	0,347 8	0,416 6	112,29	175,81
liquid	−115,00	0,000 250	1 718,4	101,08	101,08	0,533 8	0,526 6	0,814 5	1 104,5	−0,542 8
vapour			0,022 97	288,72	299,59	1,789 0	0,355 9	0,424 8	113,89	155,54
liquid	−110,00	0,000 436	1 705,3	105,15	105,15	0,559 1	0,526 3	0,815 2	1 081,1	−0,539 5
vapour			0,038 87	290,51	301,72	1,764 0	0,364 0	0,433 0	115,45	138,34
liquid	−105,00	0,000 732	1 692,2	109,23	109,23	0,583 8	0,526 5	0,816 6	1 058,0	−0,535 5
vapour			0,063 39	292,34	303,89	1,741 4	0,371 9	0,441 0	116,99	123,68
liquid	−100,00	0,001 19	1 679,1	113,32	113,32	0,607 7	0,527 2	0,818 6	1 035,0	−0,530 8
vapour			0,100 0	294,20	306,09	1,721 0	0,379 8	0,449 1	118,49	111,11
liquid	−95,00	0,001 87	1 666,0	117,42	117,42	0,631 0	0,528 3	0,821 1	1 012,2	−0,525 4
vapour			0,152 9	296,10	308,32	1,702 6	0,387 6	0,457 1	119,96	100,28
liquid	−90,00	0,002 86	1 652,8	121,53	121,53	0,653 8	0,529 8	0,824 1	989,7	−0,519 4
vapour			0,227 5	298,03	310,59	1,686 1	0,395 3	0,465 0	121,39	90,92
liquid	−85,00	0,004 26	1 639,6	125,66	125,66	0,676 1	0,531 6	0,827 5	967,3	−0,512 8
vapour			0,330 2	299,98	312,87	1,671 1	0,403 0	0,473 0	122,79	82,78
liquid	−80,00	0,006 19	1 626,3	129,80	129,81	0,697 8	0,533 7	0,831 3	945,2	−0,505 5
vapour			0,468 3	301,97	315,19	1,657 6	0,410 5	0,481 0	124,14	75,69
liquid	−75,00	0,008 81	1 612,9	133,97	133,98	0,719 1	0,536 1	0,835 5	923,3	−0,497 7
vapour			0,650 3	303,98	317,52	1,645 4	0,418 1	0,489 0	125,45	69,49
liquid	−70,00	0,012 3	1 599,5	138,16	138,17	0,740 0	0,538 6	0,840 0	901,5	−0,489 2
vapour			0,886	306,01	319,87	1,634 4	0,425 5	0,497 1	126,71	64,05
liquid	−65,00	0,016 8	1 586,0	142,37	142,38	0,760 4	0,541 3	0,844 8	879,9	−0,480 1
vapour			1,186	308,07	322,24	1,624 5	0,433 0	0,505 2	127,91	59,26
liquid	−60,00	0,022 6	1 572,3	146,60	146,62	0,780 6	0,544 2	0,849 9	858,5	−0,470 3
vapour			1,563	310,14	324,61	1,615 6	0,440 3	0,513 4	129,06	55,03
liquid	−55,00	0,030 0	1 558,6	150,87	150,88	0,800 3	0,547 2	0,855 3	837,3	−0,459 8
vapour			2,029	312,23	327,00	1,607 6	0,447 7	0,521 8	130,15	51,29
liquid	−50,00	0,039 1	1 544,7	155,15	155,18	0,819 7	0,550 3	0,860 9	816,2	−0,448 6
vapour			2,598	314,34	329,39	1,600 4	0,455 0	0,530 2	131,17	47,97
liquid	−45,00	0,050 4	1 530,7	159,47	159,50	0,838 9	0,553 5	0,866 8	795,3	−0,436 6
vapour			3,286	316,45	331,79	1,594 0	0,462 4	0,538 9	132,11	45,01
liquid	−40,00	0,064 1	1 516,5	163,81	163,86	0,857 7	0,556 8	0,873 0	774,5	−0,423 7
vapour			4,108	318,58	334,18	1,588 2	0,469 7	0,547 7	132,99	42,38
liquid	−35,00	0,080 6	1 502,2	168,19	168,24	0,876 3	0,560 2	0,879 5	753,8	−0,409 9
vapour			5,083	320,71	336,56	1,583 1	0,477 0	0,556 8	133,78	40,02
liquid	−30,00	0,100 3	1 487,7	172,60	172,67	0,894 6	0,563 6	0,886 3	733,3	−0,395 1
vapour			6,228	322,84	338,94	1,578 4	0,484 3	0,566 1	134,49	37,90
liquid	−29,75[b]	0,101 3	1 487,0	172,82	172,89	0,895 5	0,563 7	0,886 6	732,3	−0,394 3
vapour			6,289	322,95	339,06	1,578 2	0,484 7	0,566 6	134,52	37,81
liquid	−25,00	0,123 5	1 473,0	177,04	177,12	0,912 7	0,567 0	0,893 4	712,9	−0,379 2
vapour			7,563	324,98	341,30	1,574 3	0,491 7	0,575 7	135,10	36,00

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 13 *(continued)*

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m^3	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−20,00	0,150 7	1 458,1	181,51	181,62	0,930 5	0,570 5	0,900 7	692,5	−0,362 0
vapour			9,109	327,11	343,65	1,570 6	0,499 0	0,585 7	135,63	34,29
liquid	−15,00	0,182 3	1 443,0	186,02	186,15	0,948 2	0,574 1	0,908 5	672,3	−0,343 4
vapour			10,889	329,24	345,98	1,567 3	0,506 4	0,596 0	136,05	32,75
liquid	−10,00	0,218 8	1 427,6	190,57	190,72	0,965 6	0,577 6	0,916 6	652,1	−0,323 3
vapour			12,925	331,36	348,29	1,564 4	0,513 9	0,606 8	136,38	31,35
liquid	−5,00	0,260 6	1 412,0	195,15	195,34	0,982 9	0,581 2	0,925 1	632,0	−0,301 5
vapour			15,244	333,47	350,56	1,561 8	0,521 3	0,618 0	136,59	30,09
liquid	0,00	0,308 1	1 396,1	199,78	200,00	1,000 0	0,584 9	0,934 1	611,9	−0,277 7
vapour			17,873	335,56	352,81	1,559 4	0,528 9	0,629 8	136,69	28,94
liquid	5,00	0,362 0	1 379,8	204,45	204,71	1,016 9	0,588 5	0,943 6	591,9	−0,251 6
vapour			20,842	337,64	355,01	1,557 3	0,536 5	0,642 3	136,68	27,91
liquid	10,00	0,422 7	1 363,2	209,15	209,46	1,033 7	0,592 2	0,953 7	571,8	−0,223 0
vapour			24,184	339,70	357,18	1,555 4	0,544 1	0,655 5	136,54	26,97
liquid	15,00	0,490 6	1 346,3	213,91	214,27	1,050 4	0,596 0	0,964 5	551,8	−0,191 5
vapour			27,935	341,73	359,30	1,553 7	0,551 9	0,669 6	136,28	26,11
liquid	20,00	0,566 4	1 328,9	218,71	219,14	1,066 9	0,599 7	0,976 1	531,7	−0,156 5
vapour			32,135	343,73	361,36	1,552 1	0,559 7	0,684 6	135,88	25,34
liquid	25,00	0,650 6	1 311,0	223,56	224,06	1,083 4	0,603 6	0,988 5	511,5	−0,117 6
vapour			36,828	345,70	363,37	1,550 6	0,567 6	0,700 8	135,34	24,65
liquid	30,00	0,743 7	1 292,7	228,47	229,04	1,099 7	0,607 5	1,002 1	491,3	−0,074 0
vapour			42,066	347,63	365,31	1,549 2	0,575 7	0,718 4	134,65	24,02
liquid	35,00	0,846 2	1 273,8	233,43	234,10	1,116 0	0,611 4	1,016 9	471,0	−0,024 8
vapour			47,906	349,51	367,18	1,547 8	0,583 8	0,737 7	133,82	23,46
liquid	40,00	0,958 8	1 254,3	238,46	239,22	1,132 2	0,615 5	1,033 2	450,5	0,031 1
vapour			54,416	351,34	368,96	1,546 5	0,592 1	0,758 9	132,82	22,96
liquid	45,00	1,082 1	1 234,0	243,55	244,42	1,148 4	0,619 7	1,051 4	429,7	0,095 0
vapour			61,673	353,11	370,66	1,545 1	0,600 6	0,782 7	131,65	22,52
liquid	50,00	1,216 6	1 213,0	248,71	249,71	1,164 5	0,624 2	1,071 9	408,8	0,168 8
vapour			69,771	354,81	372,24	1,543 7	0,609 3	0,809 5	130,30	22,14
liquid	55,00	1,363 0	1 191,1	253,95	255,10	1,180 7	0,628 8	1,095 3	387,5	0,254 9
vapour			78,823	356,42	373,72	1,542 1	0,618 2	0,840 4	128,76	21,81
liquid	60,00	1,521 9	1 168,1	259,28	260,58	1,196 9	0,633 8	1,122 5	365,9	0,356 5
vapour			88,966	357,94	375,05	1,540 4	0,627 4	0,876 3	127,02	21,54
liquid	65,00	1,694 1	1 144,0	264,71	266,19	1,213 1	0,639 1	1,154 5	343,9	0,478 3
vapour			100,375	359,35	376,23	1,538 5	0,637 0	0,919 1	125,07	21,31
liquid	70,00	1,880 2	1 118,3	270,26	271,94	1,229 5	0,645 0	1,193 1	321,3	0,626 4
vapour			113,272	360,62	377,22	1,536 3	0,647 1	0,971 4	122,88	21,14
liquid	75,00	2,081 1	1 090,9	275,94	277,84	1,246 1	0,651 7	1,241 0	298,1	0,810 3
vapour			127,952	361,72	377,99	1,533 7	0,657 8	1,037 0	120,44	21,01
liquid	80,00	2,297 5	1 061,4	281,78	283,94	1,262 9	0,659 4	1,302 4	274,1	1,043 9

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 13 *(continued)*

	Temp. °C	Pressure MPa	Density kg/m³	Internal energy kJ/kg	Enthalpy kJ/kg	Entropy kJ/(kg·K)	C_v kJ/(kg·K)	C_p kJ/(kg·K)	Sound speed m/s	J-T coefficient K/MPa
vapour			144,822	362,62	378,48	1,530 6	0,669 3	1,122 5	117,73	20,92
liquid	85,00	2,530 4	1 029,1	287,82	290,27	1,280 1	0,668 4	1,384 4	249,4	1,349 5
vapour			164,464	363,26	378,64	1,526 8	0,681 9	1,239 4	114,73	20,85
liquid	90,00	2,780 8	993,2	294,11	296,91	1,297 8	0,679 5	1,500 6	223,6	1,763 6
vapour			187,766	363,54	378,35	1,522 0	0,696 1	1,410 1	111,41	20,79
liquid	95,00	3,050 1	952,2	300,75	303,95	1,316 3	0,693 6	1,679 4	196,9	2,351 8
vapour			216,208	363,34	377,45	1,515 9	0,712 7	1,683 5	107,75	20,68
liquid	100,00	3,339 9	903,8	307,89	311,58	1,336 0	0,712 2	1,996 3	169,0	3,247 0
vapour			252,577	362,38	375,60	1,507 6	0,733 2	2,192 4	103,73	20,41
liquid	105,00	3,652 5	842,2	315,90	320,24	1,358 1	0,738 7	2,753 9	139,3	4,787 2
vapour			303,473	360,05	372,08	1,495 2	0,761 0	3,457 9	99,28	19,71
liquid	110,00	3,992 4	742,7	326,44	331,82	1,387 4	0,787 0	7,806 1	105,3	8,291 6
vapour			396,337	353,88	363,95	1,471 2	0,808 9	11,440 0	93,96	17,60
critical	111,97	4,136 1	565,0	340,44	347,76	1,428 3	c	c	c	13,369 4

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

5.5 R22 — Chlorodifluoromethane

5.5.1 Range of validity

The coefficients are valid within the following ranges:

T_{min} = 115,73 K, T_{max} = 550 K; p_{max} = 60 MPa; ρ_{max} = 19,91 mol/l (1 722 kg/m³)

Coefficients and exponents of the ideal-gas part are listed in Table 14. Coefficients and exponents of the real-gas part are listed in Table 15.

Table 14 — Coefficients and exponents of the ideal-gas part [Formulae (3) to (5)]

k	c_k	t_k	a_k	b_k
0	4,005 261 404 46	—	—	—
1	0,000 120 662 553	1	—	—
2	—	—	1,0	4 352,309 5
3	—	—	1,0	1 935,159 1
4	—	—	1,0	1 887,679 36
5	—	—	1,0	1 694,882 84
6	—	—	1,0	1 605,678 48
7	—	—	1,0	1 162,534 24
8	—	—	1,0	857,512 88
9	—	—	1,0	605,726 38
10	—	—	1,0	530,909 82

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Table 15 — Coefficients and exponents of the real-gas part [Formula (2)]

k	N_k	t_k	d_k	l_k	α_k
1	$0{,}695\,645\,445\,236 \times 10^{-1}$	−1	1	0	0
2	$0{,}252\,275\,419\,999 \times 10^{2}$	1,75	1	0	0
3	$-0{,}202\,351\,148\,311 \times 10^{3}$	2,25	1	0	0
4	$0{,}350\,063\,090\,302 \times 10^{3}$	2,5	1	0	0
5	$-0{,}223\,134\,648\,863 \times 10^{3}$	2,75	1	0	0
6	$0{,}488\,345\,904\,592 \times 10^{2}$	3	1	0	0
7	$0{,}108\,874\,958\,556 \times 10^{-1}$	5,5	1	0	0
8	0,590 315 073 614	1,5	2	0	0
9	−0,689 043 767 432	1,75	2	0	0
10	0,284 224 445 844	3,5	2	0	0
11	0,125 436 457 897	1	3	0	0
12	$-0{,}113\,338\,666\,416 \times 10^{-1}$	4,5	3	0	0
13	$-0{,}631\,388\,959\,17 \times 10^{-1}$	1,5	4	0	0
14	$0{,}974\,021\,015\,232 \times 10^{-2}$	0,5	5	0	0
15	$-0{,}408\,406\,844\,722 \times 10^{-3}$	4,5	6	0	0
16	$0{,}741\,948\,773\,570 \times 10^{-3}$	1	7	0	0
17	$0{,}315\,912\,525\,922 \times 10^{-3}$	4	7	0	0
18	$0{,}876\,009\,723\,338 \times 10^{-5}$	5	7	0	0
19	$-0{,}110\,343\,340\,301 \times 10^{-3}$	−0,5	8	0	0
20	$-0{,}705\,323\,356\,879 \times 10^{-4}$	3,5	8	0	0
21	0,235 850 731 510	5	2	2	1
22	−0,192 640 494 729	7	2	2	1
23	$0{,}375\,218\,008\,557 \times 10^{-2}$	12	2	2	1
24	$-0{,}448\,926\,036\,678 \times 10^{-4}$	15	2	2	1
25	$0{,}198\,120\,520\,635 \times 10^{-1}$	3,5	3	3	1
26	$-0{,}356\,958\,425\,255 \times 10^{-1}$	3,5	4	2	1
27	$0{,}319\,594\,161\,562 \times 10^{-1}$	8	4	2	1
28	$0{,}260\,284\,291\,078 \times 10^{-5}$	15	4	2	1
29	$-0{,}897\,629\,021\,967 \times 10^{-2}$	25	4	4	1
30	$0{,}345\,482\,791\,645 \times 10^{-1}$	3	6	2	1
31	$-0{,}411\,831\,711\,251 \times 10^{-2}$	9	6	2	1
32	$0{,}567\,428\,536\,529 \times 10^{-2}$	19	6	4	1
33	$-0{,}563\,368\,989\,908 \times 10^{-2}$	2	8	2	1
34	$0{,}191\,384\,919\,423 \times 10^{-2}$	7	8	2	1
35	$-0{,}178\,930\,036\,389 \times 10^{-2}$	13	8	4	1

5.5.2 Reducing parameters, molar mass, and gas constant

$T^* = 369{,}295$ K, $\rho^* = 6{,}058\,22$ mol/l, $M = 86{,}468$ g/mol, $R = 8{,}314\,51$ J/(mol·K)

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5.5.3 Reference state parameters

T_{ref} = 273,15 K, p_{ref} = 1,0 kPa, h_{ref} = 35 874,594 J/mol, s_{ref} = 205,291 5 J/(mol·K), f_1 = 4,111 053 69, f_2 = 2 986,449 88

R22 property values along the liquid-vapour saturation boundary are listed in Table 16.

Table 16 — R22 property values along the liquid-vapour saturation boundary

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−157,42[a]	$3{,}795 \times 10^{-7}$	1 721,3	29,60	29,60	0,076 1	0,716 1	1,075 3	1 410,9	−0,444 6
vapour			$3{,}410 \times 10^{-5}$	321,58	332,71	2,695 2	0,329 2	0,425 3	119,91	398,80
liquid	−155,00	$6{,}620 \times 10^{-7}$	1 714,9	32,20	32,20	0,098 3	0,713 9	1,073 5	1 398,2	−0,445 0
vapour			$5{,}827 \times 10^{-5}$	322,38	333,74	2,650 5	0,331 8	0,428 0	121,05	380,74
liquid	−150,00	$1{,}934 \times 10^{-6}$	1 701,8	37,56	37,56	0,142 8	0,708 6	1,069 6	1 371,9	−0,445 6
vapour			$1{,}633 \times 10^{-4}$	324,05	335,90	2,565 3	0,337 5	0,433 6	123,35	344,75
liquid	−145,00	$5{,}141 \times 10^{-6}$	1 688,8	42,90	42,90	0,185 3	0,702 7	1,066 3	1 346,3	−0,445 6
vapour			$4{,}172 \times 10^{-4}$	325,76	338,08	2,488 7	0,343 3	0,439 4	125,60	311,19
liquid	−140,00	$1{,}258 \times 10^{-5}$	1 675,8	48,22	48,22	0,226 0	0,697 2	1,064 1	1 321,4	−0,444 9
vapour			$9{,}826 \times 10^{-4}$	327,49	340,29	2,419 5	0,349 2	0,445 4	127,78	280,46
liquid	−135,00	$2{,}860 \times 10^{-5}$	1 662,8	53,54	53,54	0,265 2	0,692 3	1,062 8	1 296,8	−0,443 6
vapour			$2{,}153 \times 10^{-3}$	329,25	342,53	2,357 1	0,355 2	0,451 4	129,92	252,63
liquid	−130,00	$6{,}091 \times 10^{-5}$	1 649,8	58,85	58,85	0,303 0	0,688 2	1,062 2	1 272,4	−0,441 7
vapour			$4{,}426 \times 10^{-3}$	331,04	344,80	2,300 5	0,361 4	0,457 6	132,01	227,61
liquid	−125,00	0,000 122	1 636,8	64,16	64,16	0,339 5	0,684 7	1,062 0	1 248,0	−0,439 6
vapour			0,008 59	332,85	347,10	2,249 2	0,367 6	0,463 9	134,05	205,23
liquid	−120,00	0,000 233	1 623,7	69,47	69,47	0,374 7	0,681 5	1,061 9	1 223,7	−0,437 2
vapour			0,015 85	334,70	349,42	2,202 7	0,373 9	0,470 3	136,04	185,26
liquid	−115,00	0,000 424	1 610,7	74,78	74,78	0,408 8	0,678 6	1,061 8	1 199,5	−0,434 6
vapour			0,027 92	336,57	351,77	2,160 3	0,380 3	0,476 8	137,99	167,49
liquid	−110,00	0,000 740	1 597,6	80,09	80,09	0,441 9	0,675 9	1,061 6	1 175,4	−0,431 9
vapour			0,047 19	338,48	354,15	2,121 7	0,386 8	0,483 4	139,90	151,69
liquid	−105,00	0,001 24	1 584,5	85,40	85,40	0,473 9	0,673 2	1,061 4	1 151,4	−0,428 9
vapour			0,076 8	340,40	356,55	2,086 5	0,393 4	0,490 2	141,76	137,65
liquid	−100,00	0,002 01	1 571,3	90,70	90,71	0,505 0	0,670 6	1,061 2	1 127,5	−0,425 7
vapour			0,121 0	342,35	358,97	2,054 3	0,400 0	0,497 2	143,57	125,17
liquid	−95,00	0,003 16	1 558,1	96,01	96,01	0,535 2	0,668 0	1,061 1	1 103,7	−0,422 1
vapour			0,184 7	344,32	361,40	2,024 9	0,406 7	0,504 4	145,34	114,07
liquid	−90,00	0,004 81	1 544,9	101,31	101,32	0,564 6	0,665 5	1,061 2	1 080,1	−0,418 0
vapour			0,274 4	346,31	363,85	1,998 0	0,413 6	0,511 8	147,05	104,20
liquid	−85,00	0,007 15	1 531,6	106,62	106,63	0,593 2	0,663 2	1,061 6	1 056,6	−0,413 4
vapour			0,397 3	348,31	366,31	1,973 4	0,420 6	0,519 5	148,70	95,41
liquid	−80,00	0,010 4	1 518,2	111,93	111,94	0,621 0	0,661 1	1,062 4	1 033,1	−0,408 2
vapour			0,562	350,33	368,77	1,950 8	0,427 7	0,527 6	150,29	87,58
liquid	−75,00	0,014 7	1 504,7	117,24	117,25	0,648 2	0,659 2	1,063 7	1 009,8	−0,402 3
vapour			0,779	352,36	371,24	1,930 0	0,435 0	0,535 9	151,82	80,60
liquid	−70,00	0,020 5	1 491,2	122,56	122,58	0,674 7	0,657 5	1,065 5	986,4	−0,395 6

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 16 *(continued)*

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
vapour			1,060	354,39	373,70	1,910 8	0,442 5	0,544 7	153,28	74,36
liquid	−65,00	0,027 9	1 477,5	127,90	127,91	0,700 6	0,656 2	1,067 9	963,2	−0,388 1
vapour			1,416	356,42	376,15	1,893 2	0,450 2	0,553 9	154,66	68,78
liquid	−60,00	0,037 5	1 463,7	133,24	133,27	0,726 0	0,655 2	1,071 0	939,9	−0,379 6
vapour			1,863	358,46	378,59	1,877 0	0,458 1	0,563 7	155,97	63,78
liquid	−55,00	0,049 6	1 449,7	138,60	138,63	0,750 9	0,654 6	1,074 8	916,6	−0,370 2
vapour			2,414	360,49	381,02	1,861 9	0,466 2	0,573 9	157,18	59,29
liquid	−50,00	0,064 5	1 435,6	143,98	144,03	0,775 2	0,654 3	1,079 3	893,4	−0,359 7
vapour			3,088	362,52	383,42	1,848 0	0,474 5	0,584 7	158,31	55,26
liquid	−45,00	0,082 9	1 421,3	149,38	149,44	0,799 2	0,654 4	1,084 5	870,1	−0,348 1
vapour			3,901	364,53	385,79	1,835 1	0,483 1	0,596 2	159,33	51,63
liquid	−40,81[b]	0,101 3	1 409,2	153,93	154,00	0,818 9	0,654 8	1,089 5	850,6	−0,337 5
vapour			4,704	366,21	387,75	1,825 0	0,490 4	0,606 3	160,11	48,85
liquid	−40,00	0,105 2	1 406,8	154,81	154,89	0,822 7	0,654 9	1,090 5	846,9	−0,335 3
vapour			4,873	366,53	388,13	1,823 1	0,491 9	0,608 3	160,26	48,34
liquid	−30,00	0,163 9	1 377,2	165,76	165,88	0,868 7	0,657 0	1,104 9	800,3	−0,305 7
vapour			7,379	370,48	392,69	1,801 5	0,510 3	0,634 9	161,78	42,68
liquid	−25,00	0,201 4	1 362,0	171,29	171,44	0,891 2	0,658 5	1,113 4	777,0	−0,288 7
vapour			8,958	372,42	394,90	1,791 8	0,519 9	0,649 5	162,36	40,24
liquid	−20,00	0,245 3	1 346,5	176,86	177,04	0,913 5	0,660 4	1,122 7	753,6	−0,270 0
vapour			10,790	374,33	397,06	1,782 6	0,529 9	0,665 0	162,82	38,01
liquid	−15,00	0,296 2	1 330,8	182,47	182,70	0,935 4	0,662 6	1,132 8	730,2	−0,249 5
vapour			12,901	376,20	399,16	1,774 0	0,540 0	0,681 6	163,15	35,98
liquid	−10,00	0,354 8	1 314,7	188,13	188,40	0,957 2	0,665 1	1,143 9	706,8	−0,227 0
vapour			15,322	378,04	401,20	1,765 8	0,550 5	0,699 4	163,35	34,13
liquid	−5,00	0,421 8	1 298,3	193,85	194,17	0,978 7	0,668 0	1,156 1	683,4	−0,202 3
vapour			18,086	379,84	403,16	1,758 1	0,561 3	0,718 4	163,40	32,44
liquid	0,00	0,498 0	1 281,5	199,61	200,00	1,000 0	0,671 1	1,169 2	659,9	−0,175 0
vapour			21,229	381,59	405,05	1,750 7	0,572 3	0,739 0	163,31	30,89
liquid	5,00	0,584 1	1 264,3	205,44	205,90	1,021 2	0,674 5	1,183 6	636,3	−0,144 8
vapour			24,792	383,29	406,85	1,743 6	0,583 6	0,761 1	163,06	29,48
liquid	10,00	0,680 9	1 246,7	211,32	211,87	1,042 2	0,678 2	1,199 3	612,7	−0,111 2
vapour			28,820	384,93	408,56	1,736 8	0,595 3	0,785 2	162,65	28,18
liquid	15,00	0,789 3	1 228,6	217,28	217,92	1,063 0	0,682 2	1,216 6	588,9	−0,073 7
vapour			33,362	386,51	410,16	1,730 2	0,607 2	0,811 5	162,07	26,99
liquid	20,00	0,910 0	1 209,9	223,31	224,06	1,083 8	0,686 4	1,235 6	565,1	−0,031 6
vapour			38,477	388,01	411,66	1,723 8	0,619 5	0,840 4	161,32	25,90
liquid	25,00	1,043 9	1 190,7	229,41	230,29	1,104 5	0,690 9	1,256 8	541,1	0,016 1
vapour			44,232	389,43	413,03	1,717 4	0,632 1	0,872 4	160,38	24,90
liquid	30,00	1,191 9	1 170,7	235,61	236,62	1,125 2	0,695 6	1,280 7	516,8	0,070 4
vapour			50,705	390,76	414,26	1,711 1	0,645 0	0,908 1	159,25	23,98
liquid	35,00	1,354 8	1 150,1	241,89	243,07	1,145 8	0,700 6	1,307 7	492,4	0,133 1
vapour			57,988	391,98	415,34	1,704 8	0,658 4	0,948 5	157,91	23,14
liquid	40,00	1,533 6	1 128,5	248,29	249,65	1,166 5	0,705 9	1,338 9	467,6	0,206 0

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 16 *(continued)*

	Temp. °C	Pressure MPa	Density kg/m³	Internal energy kJ/kg	Enthalpy kJ/kg	Entropy kJ/(kg·K)	C_v kJ/(kg·K)	C_p kJ/(kg·K)	Sound speed m/s	J-T coefficient K/MPa
vapour			66,193	393,08	416,25	1,698 5	0,672 2	0,994 8	156,36	22,37
liquid	45,00	1,729 2	1 106,0	254,80	256,36	1,187 2	0,711 6	1,375 5	442,5	0,291 9
vapour			75,457	394,04	416,95	1,691 9	0,686 5	1,048 7	154,58	21,66
liquid	50,00	1,942 7	1 082,3	261,45	263,25	1,208 0	0,717 6	1,419 1	417,0	0,394 5
vapour			85,952	394,83	417,44	1,685 2	0,701 4	1,112 6	152,56	21,01
liquid	55,00	2,175 1	1 057,2	268,26	270,32	1,229 1	0,724 0	1,472 4	390,9	0,519 0
vapour			97,899	395,43	417,65	1,678 1	0,717 0	1,190 2	150,28	20,41
liquid	60,00	2,427 5	1 030,4	275,26	277,61	1,250 4	0,730 8	1,539 2	364,3	0,673 0
vapour			111,591	395,80	417,55	1,670 5	0,733 5	1,287 2	147,72	19,85
liquid	65,00	2,701 2	1 001,4	282,49	285,18	1,272 2	0,738 4	1,625 9	337,0	0,867 4
vapour			127,430	395,87	417,06	1,662 2	0,751 1	1,412 8	144,85	19,32
liquid	70,00	2,997 4	969,7	290,01	293,10	1,294 5	0,746 7	1,743 4	308,8	1,119 9
vapour			145,991	395,56	416,09	1,652 9	0,770 2	1,583 7	141,66	18,81
liquid	75,00	3,317 7	934,4	297,91	301,46	1,317 7	0,756 3	1,912 7	279,6	1,459 8
vapour			168,158	394,76	414,49	1,642 4	0,791 4	1,832 2	138,11	18,28
liquid	80,00	3,663 8	893,7	306,34	310,44	1,342 3	0,768 0	2,181 4	248,8	1,942 0
vapour			195,404	393,26	412,01	1,629 9	0,815 7	2,230 8	134,15	17,70
liquid	85,00	4,037 8	844,8	315,60	320,38	1,369 0	0,784 0	2,682 1	215,3	2,684 3
vapour			230,560	390,67	408,19	1,614 2	0,845 0	2,984 1	129,71	16,98
liquid	90,00	4,442 3	780,1	326,39	332,09	1,400 1	0,811 5	3,981 1	177,0	4,000 6
vapour			280,625	386,04	401,87	1,592 2	0,884 3	4,974 9	124,64	15,90
liquid	95,00	4,882 4	662,9	342,19	349,56	1,446 2	0,891 8	17,312 0	128,0	7,285 5
vapour			382,037	374,50	387,28	1,548 6	0,956 6	25,286 3	117,96	13,40
critical	96,15	4,990 0	523,8	357,37	366,90	1,492 7	c	c	c	10,366 1

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

5.6 R32 — Difluoromethane

5.6.1 Range of validity

The coefficients are valid within the following ranges:

T_{min} = 136,34 K, T_{max} = 435 K; p_{max} = 70 MPa; ρ_{max} = 27,473 4 mol/l (1 429 kg/m³)

Coefficients and exponents of the ideal-gas part are listed in Table 17. Coefficients and exponents of the real-gas part are listed in Table 18.

Table 17 — Coefficients and exponents of the ideal-gas part [Formulae (3) to (5)]

k	c_k	a_k	b_k
0	4,004 486	—	—
1	—	1,160 761	798
2	—	2,645 151	4 185
3	—	5,794 987	1 806
4	—	1,129 475	11 510

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Table 18 — Coefficients and exponents of the real-gas part [Formula (2)]

k	N_k	t_k	d_k	l_k	α_k
1	1,046 634	0,25	1	0	0
2	−0,545 116 5	1	2	0	0
3	−0,002 448 595	−0,25	5	0	0
4	−0,048 770 02	−1	1	0	0
5	0,035 201 58	2	1	0	0
6	0,001 622 75	2	3	0	0
7	0,000 023 772 25	0,75	8	0	0
8	0,029 149	0,25	4	0	0
9	0,003 386 203	18	4	4	1
10	−0,004 202 444	26	4	3	1
11	0,000 478 202 5	−1	8	1	1
12	−0,005 504 323	25	3	4	1
13	−0,024 183 96	1,75	5	1	1
14	0,420 903 4	4	1	2	1
15	−0,461 653 7	5	1	2	1
16	−1,200 513	1	3	1	1
17	−2,591 55	1,5	1	1	1
18	−1,400 145	1	2	1	1
19	0,826 301 7	0,5	3	1	1

5.6.2 Reducing parameters, molar mass, and gas constant

T^* = 351,255 K, ρ^* = 8,150 084 6 mol/l, M = 52,024 g/mol, R = 8,314 471 J/(mol·K)

5.6.3 Reference state parameters

T_{ref} = 273,15 K, p_{ref} = 1,0 kPa, h_{ref} = 28 204,341 J/mol, s_{ref} = 171,691 3 J/(mol·K), f_1 = 7,254 707 84, f_2 = 2 231,557 35

R32 property values along the liquid-vapour saturation boundary are listed in Table 19.

Table 19 — R32 property values along the liquid-vapour saturation boundary

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−136,81[a]	4,800×10⁻⁵	1 429,3	−19,07	−19,07	−0,105 0	1,065 8	1,592 5	1 414,4	−0,337 6
vapour			2,203×10⁻³	422,52	444,31	3,293 7	0,499 5	0,659 7	169,60	881,12
liquid	−135,00	6,339×10⁻⁵	1 424,9	−16,19	−16,19	−0,084 0	1,061 3	1,590 0	1 404,9	−0,337 5
vapour			2,872×10⁻³	423,42	445,49	3,257 9	0,500 7	0,660 9	170,67	823,35
liquid	−130,00	0,000 131	1 412,7	−8,26	−8,26	−0,027 6	1,049 4	1,583 5	1 378,4	−0,336 9
vapour			0,005 74	425,90	448,77	3,165 1	0,504 1	0,664 6	173,59	686,24
liquid	−125,00	0,000 257	1 400,6	−0,36	−0,36	0,026 7	1,038 0	1,577 7	1 352,1	−0,335 9
vapour			0,010 85	428,39	452,05	3,080 4	0,508 0	0,668 9	176,44	576,21

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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Table 19 *(continued)*

	Temp.	Pressure	Density	Internal energy	Enthalpy	Entropy	C_v	C_p	Sound speed	J-T coefficient
	°C	MPa	kg/m³	kJ/kg	kJ/kg	kJ/(kg·K)	kJ/(kg·K)	kJ/(kg·K)	m/s	K/MPa
liquid	−120,00	0,000 478	1 388,4	7,52	7,52	0,079 0	1,027 4	1,572 6	1 325,8	−0,334 5
vapour			0,019 54	430,88	455,33	3,003 0	0,512 3	0,673 8	179,21	487,31
liquid	−115,00	0,000 850	1 376,1	15,37	15,37	0,129 4	1,017 3	1,568 2	1 299,5	−0,332 7
vapour			0,033 69	433,37	458,60	2,932 0	0,517 3	0,679 6	181,91	415,01
liquid	−110,00	0,001 45	1 363,8	23,20	23,20	0,178 2	1,007 9	1,564 7	1 273,4	−0,330 4
vapour			0,055 8	435,85	461,86	2,866 8	0,522 9	0,686 3	184,52	355,78
liquid	−105,00	0,002 39	1 351,5	31,02	31,02	0,225 4	0,999 1	1,561 9	1 247,3	−0,327 7
vapour			0,089 4	438,32	465,10	2,806 8	0,529 3	0,694 0	187,05	306,92
liquid	−100,00	0,003 81	1 339,0	38,82	38,83	0,271 1	0,991 0	1,560 0	1 221,2	−0,324 4
vapour			0,138 5	440,77	468,31	2,751 5	0,536 5	0,703 0	189,50	266,28
liquid	−95,00	0,005 90	1 326,5	46,62	46,62	0,315 5	0,983 4	1,558 8	1 195,3	−0,320 5
vapour			0,208 4	443,20	471,48	2,700 3	0,544 6	0,713 4	191,84	232,23
liquid	−90,00	0,008 87	1 313,9	54,41	54,42	0,358 6	0,976 4	1,558 6	1 169,3	−0,316 0
vapour			0,305 6	445,59	474,61	2,652 9	0,553 8	0,725 4	194,09	203,45
liquid	−85,00	0,013 0	1 301,2	62,20	62,21	0,400 6	0,970 0	1,559 2	1 143,4	−0,310 9
vapour			0,438	447,96	477,70	2,608 9	0,564 1	0,739 0	196,24	178,95
liquid	−80,00	0,018 7	1 288,4	70,00	70,02	0,441 5	0,964 1	1,560 6	1 117,5	−0,305 1
vapour			0,613	450,29	480,72	2,567 9	0,575 5	0,754 3	198,26	157,95
liquid	−75,00	0,026 2	1 275,4	77,81	77,83	0,481 4	0,958 8	1,563 0	1 091,7	−0,298 6
vapour			0,842	452,57	483,68	2,529 6	0,588 0	0,771 4	200,18	139,85
liquid	−70,00	0,036 1	1 262,4	85,63	85,66	0,520 4	0,954 0	1,566 3	1 065,8	−0,291 3
vapour			1,135	454,81	486,57	2,493 9	0,601 5	0,790 3	201,96	124,19
liquid	−65,00	0,048 8	1 249,1	93,46	93,50	0,558 5	0,949 7	1,570 6	1 039,9	−0,283 1
vapour			1,507	456,99	489,38	2,460 4	0,616 0	0,811 0	203,62	110,58
liquid	−60,00	0,065 0	1 235,7	101,32	101,38	0,595 8	0,946 0	1,575 8	1 014,1	−0,274 0
vapour			1,969	459,12	492,11	2,428 9	0,631 5	0,833 5	205,14	98,73
liquid	−55,00	0,085 2	1 222,1	109,21	109,28	0,632 4	0,942 7	1,582 1	988,2	−0,264 0
vapour			2,538	461,19	494,74	2,399 3	0,647 7	0,857 6	206,52	88,40
liquid	−50,00	0,110 1	1 208,4	117,13	117,22	0,668 3	0,940 0	1,589 5	962,2	−0,252 8
vapour			3,232	463,19	497,27	2,371 4	0,664 6	0,883 5	207,75	79,39
liquid	−51,65[b]	0,101 3	1 212,9	114,51	114,59	0,656 5	0,940 8	1,586 9	970,8	−0,256 6
vapour			2,988	462,54	496,45	2,380 5	0,658 9	0,874 8	207,36	82,23
liquid	−45,00	0,140 6	1 194,4	125,08	125,20	0,703 5	0,937 7	1,598 0	936,3	−0,240 4
vapour			4,067	465,13	499,70	2,345 0	0,682 0	0,911 0	208,83	71,52
liquid	−40,00	0,177 4	1 180,2	133,08	133,23	0,738 2	0,935 9	1,607 7	910,2	−0,226 7
vapour			5,065	466,99	502,02	2,320 0	0,699 8	0,940 1	209,74	64,65
liquid	−35,00	0,221 4	1 165,7	141,12	141,31	0,772 3	0,934 6	1,618 7	884,0	−0,211 5
vapour			6,248	468,78	504,21	2,296 2	0,718 0	0,970 9	210,49	58,63
liquid	−30,00	0,273 4	1 151,0	149,21	149,45	0,806 0	0,933 8	1,631 1	857,8	−0,194 7
vapour			7,639	470,48	506,27	2,273 5	0,736 5	1,003 5	211,07	53,37
liquid	−25,00	0,334 6	1 135,9	157,36	157,66	0,839 2	0,933 4	1,645 1	831,4	−0,176 1

[a] Triple point.

[b] Normal boiling point.

[c] The values of C_v, C_p, and w at the critical point are not included as part of this document.

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