

Refrigerant properties

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National foreword

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17584 was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 8, *Refrigerants and refrigeration lubricants*.

Introduction

This document, prepared by ISO/TC 86/SC 8/WG 7, is a new International Standard. It is consistent with and is intended to complement ISO 817. The purpose of this International Standard 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 International Standard represent those for which sufficient high-quality data were available. While the working group recognizes the desirability of including additional fluids, such as the hydrocarbons, and including the transport properties of viscosity and thermal conductivity, the data and models for these were judged insufficient at this time to be worthy of designation as an International Standard. Therefore, the working group decided to prepare the present International Standard, incomplete though it might be, in a timely fashion rather than delay it awaiting additional data. The working group is continuing its efforts to add additional fluids and additional properties to this International Standard. It is anticipated that this International Standard will undergo regular reviews and revisions.

For applications such as performance rating of refrigeration equipment, having all parties adopt a consistent set of properties is more important than absolute accuracy. But consensus is easiest to achieve when high-quality property data are available.

With this in mind, the Working Group has taken as its starting point the results of Annex 18 Thermophysical Properties of the Environmentally Acceptable Refrigerants of the Heat Pump Programme of the International Energy Agency (McLinden and Watanabe^[7]). Annex 18 reports the comprehensive evaluations of the available equations of state and recommended formulations for R123, R134a, R32, R125, and R143a. Wide participation was invited in this process, and anyone could submit an equation of state for evaluation. The formulations for R123, R134a, R32, and R143a adopted in this International Standard are the same as those recommended by Annex 18. (The recent equation of state for R125 adopted in this International Standard was shown to be more accurate than the older formulation recommended by Annex 18.)

A similar comparison of mixture models reported by Annex 18 facilitated the dissemination and adoption of a new mixture modelling approach. This model is based on Helmholtz energies for each of the mixture components, and it is the approach used in the NIST REFPROP refrigerant property database (Lemmon *et al.*^[5]) and in the extensive tabulation of properties published by the Japan Society of Refrigerating and Air Conditioning Engineers (Tillner-Roth *et al.*^[12]). The Lemmon and Jacobsen^[2] model (implemented in the REFPROP database) is simpler than the Tillner-Roth *et al.*^[12] model in that it avoids the ternary interactions terms required in the Tillner-Roth model, with practically the same representations of the experimental data. For these reasons, as well as the widespread use of REFPROP, the Lemmon and Jacobsen model was adopted as the basis for the mixture properties specified in this International Standard.

The one significant disadvantage of the formulations adopted here is their complexity. In recognition of this, this International Standard 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). This International Standard does not restrict the form of such alternative implementations, but it does impose requirements, in the form of allowable tolerances (deviations from the standard values), given in Annex A, which alternative implementations shall satisfy.

The question of allowable tolerances for alternative implementations generated the most controversy among the working group. In the working group discussions, some felt that the tolerances should be fairly large to encompass as many formulations in common use as possible. But others argued that this would defeat the very purpose of this International Standard, which was to harmonize the property values used across the industry. The concept of alternative implementations with their allowable tolerances was not intended to sanction the continued use of “incorrect” data but, rather, to provide for fast, application-specific equations that would be fitted to the properties specified in this International Standard. In the end, fairly strict tolerances were selected. The experiences and recommendations of the European Association of Compressor Manufacturers (ASERCOM) carried significant weight. They had experience with simplified property equations that were fitted

to, and closely matched, several of the same equations of state recommended in this International Standard. They recommended strict tolerances.

These tolerances do not necessarily represent the uncertainty of the original experimental data or of the equation of state in fitting the data. The allowable tolerances specified in Annex A were selected to result in “reasonable” differences in quantities derived from these properties, for example, a cycle efficiency or compressor rating. For example, the tolerances specified in Annex A result in an overall variation of approximately 2,5 % in the efficiency of an ideal refrigeration cycle operating between an evaporator temperature of $-15\text{ }^{\circ}\text{C}$ and a condenser temperature of $30\text{ }^{\circ}\text{C}$. By comparison, ISO 817 specifies that the primary energy balance for compressor tests agree with flow data within 4 %.

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. This scaling arose from a cycle analysis which revealed that a constant tolerance resulted in greatly differing sensitivities of the cycle efficiency depending on the enthalpy and entropy of vapourisation. 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 International Standard), 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 International Standard.

The values of the gas constant, R , vary from fluid to fluid. Similarly, the number of significant figures given for the molecular mass, M , vary. The values for R and M are those from the original equation of state source from the literature. These values are adopted to maintain consistency with the original sources. 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 $8,314\,472\text{ J}/(\text{mol}\cdot\text{K})$ 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 figures are given for consistency with the tables of “verification values” given in Annex D.

This International Standard anticipates regular reviews (see Clause 6) and will be reviewed every five years. Any interested party requesting the inclusion of additional refrigerant(s) to this International Standard or requesting the revision of one or more fluids specified in this International Standard should petition the ISO/TC 86 secretariat.

Refrigerant properties

1 Scope

This International Standard specifies thermophysical properties of several commonly used refrigerants and refrigerant blends.

This International Standard is applicable to the refrigerants R12, R22, R32, R123, R125, R134a, R143a, R152a, R717 (ammonia), and R744 (carbon dioxide) 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.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 817, *Refrigerants — Designation system*

3 Terms and definitions

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

3.1

algorithm

procedure for the computation of refrigerant properties

NOTE 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 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.

3.4

equation of state

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

NOTE 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 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 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

all of the 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 International Standard specifies properties for the refrigerants listed in Clause 1. These properties are derived from experimental measurements. It is not practical, however, to directly reference the experimental data; they may not be available at all conditions of interest and some properties, such as entropy, cannot be measured directly. Furthermore, a simple tabulation, even for properties (such as vapour pressure) that are directly measurable, is not convenient for modern engineering use. Thus, some means to correlate the data is required to allow calculation of the properties at a desired thermodynamic state.

The properties enumerated in this International Standard are calculated from specified equations of state, although alternative algorithms are allowed. The properties themselves constitute this International Standard. The equations of state serve as a convenient means to represent and reproduce the properties. The properties enumerated in the tables in this International Standard thus represent only a subset of the properties specified by this International Standard; 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;
- 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 and density. The equation is composed of separate terms arising from ideal-gas behaviour (subscript “id”) and a “residual” or “real-fluid” (subscript “r”) contribution as given in Equation (1):

$$\phi = \frac{A}{RT} = \phi_{\text{id}} + \phi_{\text{r}} \quad (1)$$

where R is the gas constant. Equations of this form may be written on either a molar basis or a mass basis. For a consistent representation in this International Standard, 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 Equation (2):

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

where

τ	is the dimensionless temperature variable T^*/T ;
T^*	is the reducing parameter which is often equal to the critical parameter;
δ	is the dimensionless density variable ρ/ρ^* ;
ρ^*	is the reducing parameter which is often equal to the critical parameter;
N_k	are numerical coefficients fitted to experimental data;
$\alpha_k, \beta_k, \varepsilon_k$ 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 Equation (3):

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

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} .

In this International Standard, 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, $C_{p,\text{id}}$ 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 Equation (4):

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

where

$$u_k = \frac{b_k}{T}; \quad (5)$$

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 Equation (6):

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

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.

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

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

where

$$u_k = \frac{\lambda_k T^*}{T} \quad (8)$$

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 Equation (9):

$$\phi_{\text{crit}} = \sum_k N_k \delta \Delta^{b_k} \Psi \quad (9)$$

where

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

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

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

Equation (9) is added to the normal terms in Equation (1). The N_k , A_k , B_k , C_k , D_k , α_k and β_k are adjustable parameters fitted to data. Among the fluids in this International Standard, 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 Equation (13):

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

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 equation is combined with an expression for the ideal-gas heat capacity, such as Equation (4) or (5).

In this International Standard, pressure-explicit equations of state [such as Equation (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 Equation (14):

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

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

$$\frac{A_r(T, \rho)}{RT} = \phi_r = - \int_V^\infty \left(\frac{p}{RT} - \rho \right) dV \quad (15)$$

Equation (15) is then combined with an ideal-gas contribution given by Equations (3) to (5) to yield a complete description of the thermodynamic properties. Among the fluids in this International Standard, 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 Equations (1) through (15) encompass all those specified in this International Standard.

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 Equation (16):

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

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

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

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 Equation (18):

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

The first summation in this equation 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 $\phi_{i,r}$ and $\phi_{ij,\text{excess}}$ functions in Equation (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 Equations (19) and (20):

$$\tau = \frac{T^*}{T_{\text{mix}}} \quad (19)$$

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

$$\delta = \frac{\rho_{\text{mix}}}{\rho^*} \quad (20)$$

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 Equation (21):

$$\phi_{ij,\text{excess}} = F_{ij} \sum_k N_k \delta^{d_k} \tau^{t_k} \exp(-\delta^{l_k}) \quad (21)$$

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

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

4.4 Implementation

An algorithm is conforming to this International Standard if it directly implements 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 demonstrated to reproduce, for the fluids implemented, the “verification values” given in Annex D.

4.5 Alternative implementation

An algorithm is conforming to this International Standard if, by any method, it reproduces the values of thermodynamic properties specified in this International Standard for the fluids implemented. An algorithm claiming compliance under this section can 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 must 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 International Standard and those of an alternative implementation vary from property to property and are defined in Annex A.

4.6 Certification of conformance

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

5 Specifications for individual refrigerants

5.1 General

The following sections specify the equations of state used to calculate the properties of each of the refrigerants covered by this International Standard 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:

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

Table 1 — Coefficients and exponents of the ideal-gas part [Equations (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	—

Table 2 — Coefficients and exponents of the real-gas part [Equation (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 [Equations (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
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

$$T^* = 304,128\,2\text{ K}, \rho^* = 10,624\,906\,3\text{ mol/l}, M = 44,009\,8\text{ g/mol}, R = 8,314\,51\text{ J/(mol}\cdot\text{K)}$$

5.2.3 Reference state parameters

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

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

	Temp. °C	Pressure MPa	Density kg/m ³	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	–56,56 ^a	0,518 0	1178,5	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	1172,9	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	1154,6	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	1135,8	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	1116,4	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	1096,4	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	1075,7	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	1054,2	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	1031,7	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	1008,0	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
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 International Standard.

5.3 R717 — Ammonia

5.3.1 Range of validity

The coefficients are valid within the following ranges:

$$T_{\min} = 195,495 \text{ K}, T_{\max} = 700 \text{ K}; p_{\max} = 1\,000 \text{ MPa}; \rho_{\max} = 52,915 \text{ mol/l (901 kg/m}^3\text{)}$$

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

k	c_k	t_k
1	$1,887\,164\,1 \times 10^1$	$-0,333\,333\,333\,333$
2	$5,954\,993\,4 \times 10^{-4}$	1,5
3	$-7,498\,313\,1 \times 10^{-5}$	1,75

Table 6 — Coefficients and exponents of the real-gas part [Equation (2)]

k	N_k	t_k	d_k	l_k	α_k
1	$-1,858\,814$	1,5	1	0	0
2	$0,0455\,443\,1$	$-0,5$	2	0	0
3	$0,723\,854\,8$	0,5	1	0	0
4	$0,012\,294\,7$	1	4	0	0
5	$2,141\,882 \times 10^{-11}$	3	15	0	0
6	$-0,014\,300\,2$	0	3	1	1
7	$0,344\,132\,4$	3	3	1	1
8	$-0,287\,357\,1$	4	1	1	1
9	$0,000\,023\,525\,89$	4	8	1	1
10	$-0,034\,971\,11$	5	2	1	1
11	$0,0018\,311\,17$	5	8	2	1
12	$0,023\,978\,52$	3	1	2	1
13	$-0,040\,853\,75$	6	1	2	1
14	$0,237\,927\,5$	8	2	2	1
15	$-0,035\,489\,72$	8	3	2	1
16	$-0,182\,372\,9$	10	2	2	1
17	$0,022\,815\,56$	10	4	2	1
18	$-0,006\,663\,444$	5	3	3	1
19	$-0,008\,847\,486$	7,5	1	3	1
20	$0,002\,272\,635$	15	2	3	1
21	$-0,000\,558\,865\,5$	30	4	3	1

5.3.2 Reducing parameters, molar mass, and gas constant

$$T^* = 405,4 \text{ K}, \rho^* = 13,211\,777\,15 \text{ mol/l}, M = 17,030\,26 \text{ g/mol}, R = 8,314\,471 \text{ J/(mol}\cdot\text{K)}$$

5.3.3 Reference state parameters

$$T_{\text{ref}} = 273,15 \text{ K}, p_{\text{ref}} = 1,0 \text{ kPa}, h_{\text{ref}} = 25\,558,797 \text{ J/mol}, s_{\text{ref}} = 147,991\,0 \text{ J/(mol}\cdot\text{K)}, f_1 = -24,401, \\ f_2 = 1\,725,271\,55$$

Table 7 — R717 property values along the liquid-vapour saturation boundary

	Temp. °C	Pressure MPa	Density kg/m ³	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 vapour	−77,65 ^a	0,00609	732,9 0,0641	−143,15 1246,20	−143,15 1341,23	−0,4716 7,1213	2,9343 1,5566	4,2022 2,0628	2124,2 354,12	−0,2336 171,13
liquid vapour	−75,00	0,00751	730,1 0,0780	−131,98 1249,97	−131,97 1346,24	−0,4148 7,0452	2,9297 1,5613	4,2167 2,0700	2097,8 356,37	−0,2310 159,84
liquid vapour	−70,00	0,0109	724,7 0,111	−110,83 1257,00	−110,81 1355,55	−0,3094 6,9088	2,9206 1,5715	4,2450 2,0856	2051,3 360,50	−0,2260 141,14
liquid vapour	−65,00	0,0156	719,2 0,155	−89,53 1263,92	−89,51 1364,73	−0,2058 6,7807	2,9113 1,5836	4,2740 2,1040	2008,0 364,50	−0,2208 125,27
liquid vapour	−60,00	0,0219	713,6 0,213	−68,09 1270,71	−68,06 1373,73	−0,1040 6,6602	2,9019 1,5975	4,3031 2,1254	1967,1 368,35	−0,2155 111,72
liquid vapour	−55,00	0,0301	707,9 0,287	−46,51 1277,37	−46,47 1382,56	−0,0040 6,5467	2,8928 1,6133	4,3318 2,1500	1927,9 372,05	−0,2101 100,10
liquid vapour	−50,00	0,0408	702,1 0,381	−24,79 1283,88	−24,73 1391,19	0,0945 6,4396	2,8837 1,6310	4,3599 2,1778	1889,9 375,60	−0,2047 90,06
liquid vapour	−45,00	0,0545	696,2 0,498	−2,93 1290,23	−2,85 1399,59	0,1914 6,3384	2,8749 1,6507	4,3872 2,2092	1852,7 378,98	−0,1992 81,36
liquid vapour	−40,00	0,0717	690,2 0,644	19,07 1296,41	19,17 1407,76	0,2867 6,2425	2,8662 1,6724	4,4137 2,2441	1816,2 382,19	−0,1936 73,77
liquid vapour	−35,00	0,0931	684,0 0,822	41,18 1302,40	41,32 1415,68	0,3806 6,1516	2,8577 1,6961	4,4394 2,2830	1780,2 385,23	−0,1878 67,11
liquid vapour	−33,33 ^b	0,1013	682,0 0,890	48,62 1304,36	48,76 1418,26	0,4117 6,1221	2,8548 1,7045	4,4479 2,2969	1768,2 386,20	−0,1858 65,06
liquid vapour	−30,00	0,1194	677,8 1,037	63,43 1308,19	63,60 1423,31	0,4730 6,0651	2,8492 1,7218	4,4645 2,3259	1744,4 388,08	−0,1818 61,24
liquid vapour	−25,00	0,1515	671,5 1,296	85,79 1313,77	86,01 1430,65	0,5641 5,9827	2,8408 1,7495	4,4892 2,3730	1708,8 390,73	−0,1756 56,05
liquid vapour	−20,00	0,1901	665,1 1,603	108,26 1319,12	108,55 1437,68	0,6538 5,9041	2,8325 1,7793	4,5138 2,4245	1673,2 393,18	−0,1691 51,43
liquid vapour	−15,00	0,2362	658,6 1,966	130,86 1324,23	131,22 1444,37	0,7421 5,8289	2,8243 1,8110	4,5385 2,4807	1637,7 395,42	−0,1623 47,32
liquid vapour	−10,00	0,2907	652,1 2,391	153,56 1329,10	154,01 1450,70	0,8293 5,7569	2,8162 1,8446	4,5636 2,5419	1602,1 397,45	−0,1550 43,63
liquid vapour	−5,00	0,3548	645,4 2,885	176,39 1333,70	176,94 1456,67	0,9152 5,6877	2,8082 1,8802	4,5895 2,6082	1566,4 399,25	−0,1472 40,32
liquid vapour	0,00	0,4294	638,6 3,457	199,33 1338,02	200,00 1462,24	1,0000 5,6210	2,8003 1,9176	4,6165 2,6799	1530,5 400,82	−0,1388 37,33
liquid vapour	5,00	0,5157	631,7 4,115	222,39 1342,05	223,21 1467,39	1,0837 5,5568	2,7926 1,9569	4,6451 2,7575	1494,4 402,16	−0,1297 34,63
liquid vapour	10,00	0,6150	624,6 4,868	245,58 1345,77	246,57 1472,11	1,1664 5,4946	2,7851 1,9979	4,6757 2,8413	1458,1 403,24	−0,1198 32,19
liquid vapour	15,00	0,7285	617,5 5,727	268,91 1349,17	270,09 1476,38	1,2481 5,4344	2,7780 2,0406	4,7088 2,9318	1421,5 404,07	−0,1090 29,97
liquid vapour	20,00	0,8575	610,2 6,703	292,38 1352,22	293,78 1480,16	1,3289 5,3759	2,7711 2,0849	4,7448 3,0296	1384,5 404,63	−0,0971 27,96
liquid vapour	25,00	1,0032	602,8 7,807	316,00 1354,92	317,67 1483,43	1,4088 5,3188	2,7647 2,1308	4,7844 3,1353	1347,1 404,92	−0,0840 26,13
liquid vapour	30,00	1,1672	595,2 9,053	339,80 1357,24	341,76 1486,17	1,4881 5,2631	2,7587 2,1782	4,8282 3,2500	1309,3 404,92	−0,0695 24,45

Table 7 (continued)

	Temp. °C	Pressure MPa	Density kg/m ³	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 vapour	35,00	1,3508	587,4 10,457	363,77 1359,16	366,07 1488,34	1,5666 5,2086	2,7532 2,2272	4,8771 3,3745	1271,0 404,63	−0,0534 22,92
liquid vapour	40,00	1,5554	579,4 12,034	387,95 1360,65	390,64 1489,91	1,6446 5,1549	2,7484 2,2776	4,9318 3,5104	1232,1 404,03	−0,0353 21,52
liquid vapour	45,00	1,7827	571,3 13,803	412,35 1361,68	415,48 1490,83	1,7220 5,1020	2,7443 2,3294	4,9935 3,6593	1192,7 403,12	−0,0152 20,24
liquid vapour	50,00	2,0340	562,9 15,785	437,01 1362,22	440,62 1491,07	1,7990 5,0497	2,7411 2,3828	5,0635 3,8233	1152,6 401,88	0,0076 19,06
liquid vapour	55,00	2,3111	554,2 18,006	461,93 1362,22	466,10 1490,57	1,8758 4,9977	2,7389 2,4377	5,1434 4,0051	1111,7 400,29	0,0333 17,98
liquid vapour	60,00	2,6156	545,2 20,493	487,17 1361,63	491,97 1489,27	1,9523 4,9458	2,7379 2,4942	5,2351 4,2084	1070,2 398,34	0,0626 16,98
liquid vapour	65,00	2,9491	536,0 23,280	512,76 1360,41	518,26 1487,09	2,0288 4,8939	2,7382 2,5525	5,3411 4,4376	1027,7 396,01	0,0960 16,05
liquid vapour	70,00	3,3135	526,3 26,407	538,75 1358,46	545,04 1483,94	2,1054 4,8415	2,7402 2,6126	5,4648 4,6990	984,4 393,29	0,1346 15,19
liquid vapour	75,00	3,7105	516,2 29,923	565,19 1355,73	572,37 1479,72	2,1823 4,7885	2,7441 2,6748	5,6103 5,0009	940,0 390,14	0,1793 14,39
liquid vapour	80,00	4,1420	505,7 33,888	592,15 1352,08	600,34 1474,31	2,2596 4,7344	2,7503 2,7393	5,7837 5,3546	894,7 386,54	0,2317 13,65
liquid vapour	85,00	4,6100	494,5 38,376	619,72 1347,40	629,04 1467,53	2,3377 4,6789	2,7594 2,8066	5,9930 5,7766	848,1 382,47	0,2935 12,94
liquid vapour	90,00	5,1167	482,8 43,484	648,01 1341,52	658,61 1459,19	2,4168 4,6213	2,7719 2,8770	6,2501 6,2907	800,4 377,88	0,3674 12,27
liquid vapour	95,00	5,6643	470,2 49,340	677,14 1334,20	689,19 1449,01	2,4973 4,5612	2,7886 2,9511	6,5731 6,9332	751,3 372,74	0,4569 11,63
liquid vapour	100,00	6,2553	456,6 56,117	707,30 1325,16	721,00 1436,63	2,5797 4,4975	2,8108 3,0297	6,9912 7,7622	700,7 366,99	0,5673 11,01
liquid vapour	105,00	6,8923	441,9 64,063	738,75 1313,98	754,35 1421,57	2,6647 4,4291	2,8400 3,1139	7,5551 8,8773	648,5 360,54	0,7063 10,40
liquid vapour	110,00	7,5783	425,6 73,550	771,88 1300,04	789,68 1403,08	2,7533 4,3542	2,8787 3,2049	8,3621 10,4630	594,4 353,29	0,8869 9,78
liquid vapour	115,00	8,3170	407,2 85,182	807,31 1282,36	827,74 1379,99	2,8474 4,2702	2,9307 3,3047	9,6278 12,9091	537,7 345,04	1,1313 9,15
liquid vapour	120,00	9,1125	385,5 100,068	846,28 1259,17	869,92 1350,23	2,9502 4,1719	3,0037 3,4163	11,9405 17,2119	477,4 335,41	1,4834 8,47
liquid vapour	125,00	9,9702	357,8 120,728	891,82 1226,54	919,68 1309,12	3,0702 4,0483	3,1159 3,5447	17,6583 26,9963	411,4 323,57	2,0455 7,69
liquid vapour	130,00	10,8977	312,3 156,766	957,12 1169,80	992,02 1239,32	3,2437 3,8571	3,3450 3,7014	54,2103 76,4902	333,6 306,58	3,1689 6,62
critical	132,25	11,3330	225,0	1068,82	1119,22	3,5542	c	c	c	5,0513
^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 International Standard.										

5.4 R12 — Dichlorodifluoromethane

5.4.1 Range of validity

The coefficients are valid within the following ranges:

$$T_{\min} = 116,099 \text{ K}, T_{\max} = 525 \text{ K}; p_{\max} = 200 \text{ MPa}; \rho_{\max} = 15,13 \text{ mol/l (1 829 kg/m}^3\text{)}$$

Table 8 — Coefficients and exponents of the ideal-gas part [Equations (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 9 — Coefficients and exponents of the real-gas part [Equation (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
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

$$T^* = 385,12 \text{ K}, \rho^* = 4,672\,781 \text{ mol/l}, M = 120,913 \text{ g/mol}, R = 8,314\,471 \text{ J/(mol}\cdot\text{K)}$$

5.4.3 Reference state parameters

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

Table 10 — R12 property values along the liquid-vapour saturation boundary

	Temp. °C	Pressure MPa	Density kg/m ³	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 vapour	−157,05 ^a	2,426×10 ^{−7}	1828,8 3,038×10 ^{−5}	66,33 275,23	66,33 283,21	0,2780 2,1461	0,5725 0,2860	0,8561 0,3548	1310,0 99,51	−0,5305 532,60
liquid vapour	−155,00	3,883×10 ^{−7}	1823,4 4,779×10 ^{−5}	68,08 275,82	68,08 283,94	0,2930 2,1200	0,5674 0,2894	0,8510 0,3582	1299,6 100,27	−0,5333 495,55
liquid vapour	−150,00	1,135×10 ^{−6}	1810,1 1,340×10 ^{−4}	72,31 277,29	72,31 285,75	0,3280 2,0612	0,5567 0,2978	0,8404 0,3665	1274,4 102,10	−0,5389 418,14
liquid vapour	−145,00	3,019×10 ^{−6}	1796,9 3,426×10 ^{−4}	76,49 278,80	76,49 287,61	0,3613 2,0087	0,5482 0,3062	0,8321 0,3749	1249,5 103,88	−0,5430 355,64
liquid vapour	−140,00	7,387×10 ^{−6}	1783,7 8,068×10 ^{−4}	80,63 280,35	80,63 289,50	0,3930 1,9617	0,5415 0,3146	0,8257 0,3833	1224,8 105,63	−0,5458 304,78
liquid vapour	−135,00	1,680×10 ^{−5}	1770,6 1,768×10 ^{−3}	84,75 281,94	84,75 291,44	0,4234 1,9195	0,5363 0,3229	0,8210 0,3917	1200,3 107,34	−0,5473 263,05
liquid vapour	−130,00	3,577×10 ^{−5}	1757,5 3,635×10 ^{−3}	88,85 283,57	88,85 293,42	0,4525 1,8816	0,5324 0,3313	0,8177 0,4001	1176,0 109,02	−0,5476 228,57
liquid vapour	−125,00	7,189×10 ^{−5}	1744,5 7,058×10 ^{−3}	92,93 285,25	92,93 295,44	0,4805 1,8474	0,5296 0,3396	0,8157 0,4084	1152,0 110,67	−0,5469 199,86
liquid vapour	−120,00	0,000137	1731,4 0,01303	97,01 286,96	97,01 297,49	0,5076 1,8167	0,5277 0,3478	0,8146 0,4166	1128,1 112,29	−0,5453 175,81
liquid vapour	−115,00	0,000250	1718,4 0,02297	101,08 288,72	101,08 299,59	0,5338 1,7890	0,5266 0,3559	0,8145 0,4248	1104,5 113,89	−0,5428 155,54
liquid vapour	−110,00	0,000436	1705,3 0,03887	105,15 290,51	105,15 301,72	0,5591 1,7640	0,5263 0,3640	0,8152 0,4330	1081,1 115,45	−0,5395 138,34
liquid vapour	−105,00	0,000732	1692,2 0,06339	109,23 292,34	109,23 303,89	0,5838 1,7414	0,5265 0,3719	0,8166 0,4410	1058,0 116,99	−0,5355 123,68
liquid vapour	−100,00	0,00119	1679,1 0,1000	113,32 294,20	113,32 306,09	0,6077 1,7210	0,5272 0,3798	0,8186 0,4491	1035,0 118,49	−0,5308 111,11
liquid vapour	−95,00	0,00187	1666,0 0,1529	117,42 296,10	117,42 308,32	0,6310 1,7026	0,5283 0,3876	0,8211 0,4571	1012,2 119,96	−0,5254 100,28
liquid vapour	−90,00	0,00286	1652,8 0,2275	121,53 298,03	121,53 310,59	0,6538 1,6861	0,5298 0,3953	0,8241 0,4650	989,7 121,39	−0,5194 90,92
liquid vapour	−85,00	0,00426	1639,6 0,3302	125,66 299,98	125,66 312,87	0,6761 1,6711	0,5316 0,4030	0,8275 0,4730	967,3 122,79	−0,5128 82,78
liquid vapour	−80,00	0,00619	1626,3 0,4683	129,80 301,97	129,81 315,19	0,6978 1,6576	0,5337 0,4105	0,8313 0,4810	945,2 124,14	−0,5055 75,69
liquid vapour	−75,00	0,00881	1612,9 0,6503	133,97 303,98	133,98 317,52	0,7191 1,6454	0,5361 0,4181	0,8355 0,4890	923,3 125,45	−0,4977 69,49
liquid vapour	−70,00	0,0123	1599,5 0,886	138,16 306,01	138,17 319,87	0,7400 1,6344	0,5386 0,4255	0,8400 0,4971	901,5 126,71	−0,4892 64,05
liquid vapour	−65,00	0,0168	1586,0 1,186	142,37 308,07	142,38 322,24	0,7604 1,6245	0,5413 0,4330	0,8448 0,5052	879,9 127,91	−0,4801 59,26

Table 10 (continued)

	Temp. °C	Pressure MPa	Density kg/m ³	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 vapour	−60,00	0,0226	1572,3 1,563	146,60 310,14	146,62 324,61	0,7806 1,6156	0,5442 0,4403	0,8499 0,5134	858,5 129,06	−0,4703 55,03
liquid vapour	−55,00	0,0300	1558,6 2,029	150,87 312,23	150,88 327,00	0,8003 1,6076	0,5472 0,4477	0,8553 0,5218	837,3 130,15	−0,4598 51,29
liquid vapour	−50,00	0,0391	1544,7 2,598	155,15 314,34	155,18 329,39	0,8197 1,6004	0,5503 0,4550	0,8609 0,5302	816,2 131,17	−0,4486 47,97
liquid vapour	−45,00	0,0504	1530,7 3,286	159,47 316,45	159,50 331,79	0,8389 1,5940	0,5535 0,4624	0,8668 0,5389	795,3 132,11	−0,4366 45,01
liquid vapour	−40,00	0,0641	1516,5 4,108	163,81 318,58	163,86 334,18	0,8577 1,5882	0,5568 0,4697	0,8730 0,5477	774,5 132,99	−0,4237 42,38
liquid vapour	−35,00	0,0806	1502,2 5,083	168,19 320,71	168,24 336,56	0,8763 1,5831	0,5602 0,4770	0,8795 0,5568	753,8 133,78	−0,4099 40,02
liquid vapour	−30,00	0,1003	1487,7 6,228	172,60 322,84	172,67 338,94	0,8946 1,5784	0,5636 0,4843	0,8863 0,5661	733,3 134,49	−0,3951 37,90
liquid vapour	−29,75 ^b	0,1013	1487,0 6,289	172,82 322,95	172,89 339,06	0,8955 1,5782	0,5637 0,4847	0,8866 0,5666	732,3 134,52	−0,3943 37,81
liquid vapour	−25,00	0,1235	1473,0 7,563	177,04 324,98	177,12 341,30	0,9127 1,5743	0,5670 0,4917	0,8934 0,5757	712,9 135,10	−0,3792 36,00
liquid vapour	−20,00	0,1507	1458,1 9,109	181,51 327,11	181,62 343,65	0,9305 1,5706	0,5705 0,4990	0,9007 0,5857	692,5 135,63	−0,3620 34,29
liquid vapour	−15,00	0,1823	1443,0 10,889	186,02 329,24	186,15 345,98	0,9482 1,5673	0,5741 0,5064	0,9085 0,5960	672,3 136,05	−0,3434 32,75
liquid vapour	−10,00	0,2188	1427,6 12,925	190,57 331,36	190,72 348,29	0,9656 1,5644	0,5776 0,5139	0,9166 0,6068	652,1 136,38	−0,3233 31,35
liquid vapour	−5,00	0,2606	1412,0 15,244	195,15 333,47	195,34 350,56	0,9829 1,5618	0,5812 0,5213	0,9251 0,6180	632,0 136,59	−0,3015 30,09
liquid vapour	0,00	0,3081	1396,1 17,873	199,78 335,56	200,00 352,81	1,0000 1,5594	0,5849 0,5289	0,9341 0,6298	611,9 136,69	−0,2777 28,94
liquid vapour	5,00	0,3620	1379,8 20,842	204,45 337,64	204,71 355,01	1,0169 1,5573	0,5885 0,5365	0,9436 0,6423	591,9 136,68	−0,2516 27,91
liquid vapour	10,00	0,4227	1363,2 24,184	209,15 339,70	209,46 357,18	1,0337 1,5554	0,5922 0,5441	0,9537 0,6555	571,8 136,54	−0,2230 26,97
liquid vapour	15,00	0,4906	1346,3 27,935	213,91 341,73	214,27 359,30	1,0504 1,5537	0,5960 0,5519	0,9645 0,6696	551,8 136,28	−0,1915 26,11
liquid vapour	20,00	0,5664	1328,9 32,135	218,71 343,73	219,14 361,36	1,0669 1,5521	0,5997 0,5597	0,9761 0,6846	531,7 135,88	−0,1565 25,34
liquid vapour	25,00	0,6506	1311,0 36,828	223,56 345,70	224,06 363,37	1,0834 1,5506	0,6036 0,5676	0,9885 0,7008	511,5 135,34	−0,1176 24,65
liquid vapour	30,00	0,7437	1292,7 42,066	228,47 347,63	229,04 365,31	1,0997 1,5492	0,6075 0,5757	1,0021 0,7184	491,3 134,65	−0,0740 24,02
liquid vapour	35,00	0,8462	1273,8 47,906	233,43 349,51	234,10 367,18	1,1160 1,5478	0,6114 0,5838	1,0169 0,7377	471,0 133,82	−0,0248 23,46
liquid vapour	40,00	0,9588	1254,3 54,416	238,46 351,34	239,22 368,96	1,1322 1,5465	0,6155 0,5921	1,0332 0,7589	450,5 132,82	0,0311 22,96
liquid vapour	45,00	1,0821	1234,0 61,673	243,55 353,11	244,42 370,66	1,1484 1,5451	0,6197 0,6006	1,0514 0,7827	429,7 131,65	0,0950 22,52
liquid vapour	50,00	1,2166	1213,0 69,771	248,71 354,81	249,71 372,24	1,1645 1,5437	0,6242 0,6093	1,0719 0,8095	408,8 130,30	0,1688 22,14