# INTERNATIONAL STANDARD

# ISO
# 17584

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## Refrigerant properties

*Propriétés des fluides frigorigènes*

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# Foreword

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

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# 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 recommend 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 $-15\,°C$ and a condenser temperature of 30 °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 $5 \times 10^{-6}$ (equal to parts per million, a deprecated unit) from the currently accepted value of 8,314 472 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 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):

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

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):

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

where

$\tau$              is the dimensionless temperature variable $T^*/T$;

$T^*$            is the reducing parameter which is often equal to the critical parameter;

$\delta$              is the dimensionless density variable $\rho/\rho^*$;

$\rho^*$            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 $\gamma_k$    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):

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

where

$h_{\text{ref}}$  is the arbitrary reference enthalpy for the ideal gas at the reference state specified by $T_{\text{ref}}$;

$s_{\text{ref}}$  is the arbitrary reference entropy for the ideal gas at the reference state specified by $T_{\text{ref}}$ and $p_{\text{ref}}$.

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, $C_{p,id}$ 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):

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

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 Equation (6):

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

where

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

$d_3$, $d_k$, $a_k$, $\lambda_k$ 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):

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

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 Equation (9):

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

where

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

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

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

Equation (9) is added to the normal terms in Equation (1). The $N_k$, $A_k$, $B_k$, $C_k$, $D_k$, $\alpha_k$ and $\beta_k$ 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):

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

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 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):

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

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

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

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):

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

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

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

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):

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

The first summation in this 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 $\phi_{i,\text{r}}$ and $\phi_{ij,\text{excess}}$ functions in Equation (18) are not evaluated at the temperature, $T_{\text{mix}}$, and density, $\rho_{\text{mix}}$, of the mixture, but, rather, at a reduced temperature, $\tau$, and density, $\delta$. The mixing rules for the reducing parameters are given by Equations (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

$\zeta_{ij}$ and $\xi_{ij}$      are "interaction parameters";

$T_i^*$ and $\rho_i^*$      are the reducing parameters of the pure fluids.

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

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

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:

$T_{\min} = 216{,}592$ K, $T_{\max} = 1\,100$ K; $p_{\max} = 800$ MPa; $\rho_{\max} = 37{,}24$ mol/l (1 639 kg/m³)

**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)]

| $k$ | $N_k$ | $t_k$ | $d_k$ | $l_k$ | $\alpha_k$ | $m_k$ | $\beta_k$ | $\gamma_k$ | $\varepsilon_k$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0,388 568 232 032 | 0 | 1 | 0 | 0 | — | — | — | — |
| 2 | 0,293 854 759 427 × 10$^1$ | 0,75 | 1 | 0 | 0 | — | — | — | — |
| 3 | − 0,558 671 885 349 × 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 × 10$^1$ | 1,5 | 1 | 1 | 1 | — | — | — | — |
| 9 | 0,158 417 351 097 × 10$^1$ | 1,5 | 2 | 1 | 1 | — | — | — | — |
| 10 | − 0,231 327 054 055 | 2,5 | 4 | 1 | 1 | — | — | — | — |
| 11 | 0,581 169 164 314 × 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 × 10$^{-1}$ | 0 | 6 | 1 | 1 | — | — | — | — |
| 15 | 0,624 947 905 017 × 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 × 10$^{-1}$ | 6 | 1 | 2 | 1 | — | — | — | — |
| 19 | − 0,119 607 366 380 | 3 | 4 | 2 | 1 | — | — | — | — |
| 20 | − 0,456 193 625 088 × 10$^{-1}$ | 6 | 4 | 2 | 1 | — | — | — | — |
| 21 | 0,356 127 892 703 × 10$^{-1}$ | 8 | 4 | 2 | 1 | — | — | — | — |
| 22 | − 0,744 277 271 321 × 10$^{-2}$ | 6 | 7 | 2 | 1 | — | — | — | — |
| 23 | − 0,173 957 049 024 × 10$^{-2}$ | 0 | 8 | 2 | 1 | — | — | — | — |
| 24 | − 0,218 101 212 895 × 10$^{-1}$ | 7 | 2 | 3 | 1 | — | — | — | — |
| 25 | 0,243 321 665 592 × 10$^{-1}$ | 12 | 3 | 3 | 1 | — | — | — | — |
| 26 | − 0,374 401 334 235 × 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 × 10$^{-1}$ | 16 | 6 | 4 | 1 | — | — | — | — |
| 30 | 0,123 631 254 929 × 10$^{-1}$ | 24 | 7 | 4 | 1 | — | — | — | — |
| 31 | 0,210 583 219 729 × 10$^{-2}$ | 8 | 8 | 4 | 1 | — | — | — | — |
| 32 | − 0,339 585 190 264 × 10$^{-3}$ | 2 | 10 | 4 | 1 | — | — | — | — |
| 33 | 0,559 936 517 716 × 10$^{-2}$ | 28 | 4 | 5 | 1 | — | — | — | — |
| 34 | − 0,303 351 180 556 × 10$^{-3}$ | 14 | 8 | 6 | 1 | — | — | — | — |
| 35 | − 0,213 654 886 883 × 10$^3$ | 1 | 2 | 2 | 25 | 2 | 325 | 1,16 | 1 |
| 36 | 0,266 415 691 493 × 10$^5$ | 0 | 2 | 2 | 25 | 2 | 300 | 1,19 | 1 |
| 37 | − 0,240 272 122 046 × 10$^5$ | 1 | 2 | 2 | 25 | 2 | 300 | 1,19 | 1 |
| 38 | − 0,283 416 034 240 × 10$^3$ | 3 | 3 | 2 | 15 | 2 | 275 | 1,25 | 1 |
| 39 | 0,212 472 844 002 × 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)]

| $k$ | $N_k$ | $a_k$ | $b_k$ | $\beta_k$ | $A_k$ | $B_k$ | $C_k$ | $D_k$ |
|---|---|---|---|---|---|---|---|---|
| 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 × $10^{-1}$ | 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, $\rho^* = 10{,}624\,906\,3$ mol/l, $M = 44{,}009\,8$ g/mol, $R = 8{,}314\,51$ J/(mol·K)

### 5.2.3 Reference state parameters

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

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