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## Refrigerant properties

*Propriétés des fluides frigorigènes*

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CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

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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](http://www.iso.org/directives)).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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](http://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.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## 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  $5 \times 10^{-6}$  (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](#).





# 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.

**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;

- 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 \(1\)](#):

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

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 \(2\)](#):

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

where

$\tau$	is the dimensionless temperature variable $T^*/T$ ;
$T^*$	is the reducing parameter that is often equal to the critical temperature;
$\delta$	is the dimensionless density variable $\rho/\rho^*$ ;
$\rho^*$	is the reducing parameter that is often equal to the critical density;
$N_k$	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 [Formula \(3\)](#):

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

where

$h_{\text{ref}}$	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 document, the  $h_{\text{ref}}$  and  $s_{\text{ref}}$  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  $h_{\text{ref}}$  and  $s_{\text{ref}}$  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 [Formula \(4\)](#):

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

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 [Formula \(6\)](#):

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

where

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

$d_3$ ,  $d_k$ ,  $a_k$ ,  $\lambda_k$  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 \(7\)](#):

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

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 [Formula \(9\)](#):

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

where

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

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

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

where  $N_k, A_k, B_k, C_k, D_k, \alpha_k$  and  $\beta_k$  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 \(13\)](#):

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

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 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 \(14\)](#):

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

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

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

[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 \(16\)](#):

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

The ideal gas part is given by [Formula \(17\)](#):

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

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 [Formula \(18\)](#):

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

The first summation in this 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  $\phi_{i,r}$  and  $\phi_{ij,\text{excess}}$  functions in [Formula \(18\)](#) 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 [Formulae \(19\)](#) 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

$\zeta_{ij}$  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 [Formula \(21\)](#):

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

The  $\phi_{ij,\text{excess}}$  function will, in general, vary from mixture to mixture (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.

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:

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

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	—