



ThermoFluidProperties

Property Library for Standard Dry Air

LibRealAir

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Property Functions

Range of Validity

The LibRealAir property library uses the thermodynamic property formulation for standard dry air released by *LEMMON* et al. [1], [2]. Whereas the atmospheric air is a mixture of fluids including nitrogen, oxygen, argon, carbon dioxide, steam, and other trace elements. The standard air this formulation is based on is dry and contains no carbon dioxide or trace elements. Due to the fact that the caused change is less than the experimental error in the measurements, this assumption has been made [1]. The composition is given in Table 0.1.

Table 0.1: Composition of air with N₂, O₂ and Ar as constituents

Component name	Chemical symbol	Mole fraction
Nitrogen	N ₂	0.7812
Oxygen	O ₂	0.2096
Argon	Ar	0.0092

The LibRealAir property library is valid for liquid, steam and supercritical air. This includes temperatures from 59.75 K (-213.4 °C) at the solidification point on the saturated liquid line to 2000 K (1726.85 °C) and pressures from 0.00001 bar to 20000 bar. The range of validity of the LibRealAir property library is shown in Figure 0.1 and Figure 0.3. Values for the points marked on these Figures are listed in Table 0.2 and Table 0.3.

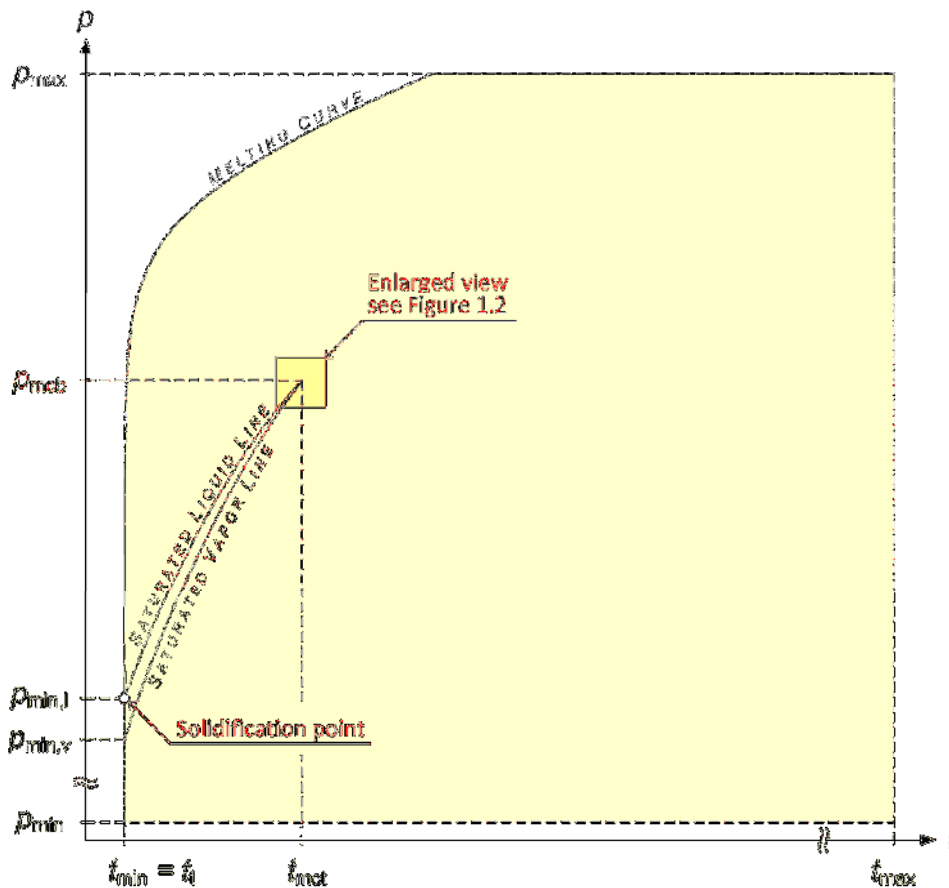


Figure 0.1: Entire range of validity in an $\lg p, \lg t$ - diagram (see Figure 1.2 for an enlarged view of the critical region phase boundaries)

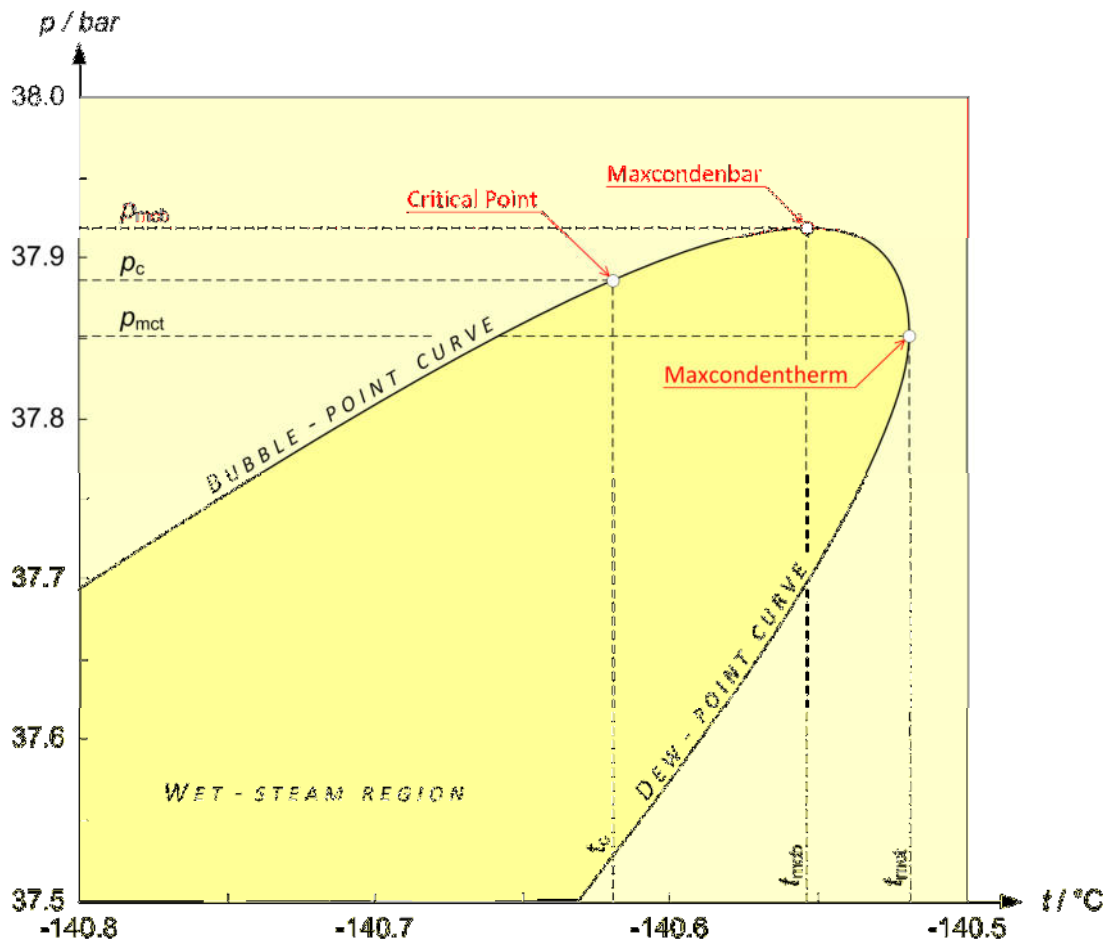


Figure 0.2: Enlarged view of the critical region phase boundaries in an p, t -diagram

Owing to the different boiling point temperatures of the mixture components in the p, T -diagram the saturation lines (liquid and vapor) of air do not overlap. In addition to the critical point a state point of maximum temperature (maxcondentherm) and a state point of maximum pressure (maxcondenbar) were determined on the saturation line. The maxcondentherm, maxcondenbar and critical point properties of air are shown in Table 0.3.

Table 0.2: Range of validity

Pressure	Abbreviations	Values in bar
Minimum pressure	p_{\min}	$1 \cdot 10^{-5}$
Minimum pressure on the dew-point curve	$p_{\min, l}$	0.024316
Minimum pressure on the bubble-point curve	$p_{\min, v}$	0.052646
Maximum pressure	p_{\max}	20000
Temperature	Abbreviations	Values in °C
Minimum temperature eq. triple point temperature	$t_{\min} = t_t$	-213.4
Maximum temperature	t_{\max}	1726.85
Specific Volume	Abbreviations	Values in m ³ /kg
Minimum specific volume	v_{\min}	0.00071991
Minimum specific volume on the bubble point curve	$v_{\min, l}$	0.00104112
Maximum specific volume on the dew-point curve	$v_{\max, v}$	7.037519
Maximum specific volume	v_{\max}	574234.252

Table 0.3: Maxcondentherm, maxcondenbar and critical point of air (calculated with the formulation by LEMMON et al.)

Condition	Pressure in bar	Temperature in °C	Spec. volume in m ³ /kg
Maxcondentherm (mct)	37.8502	-140.5188	0.003323
Maxcondenbar (mcb)	37.9195	-140.5539	0.003018
Critical point (c)	37.8869	-140.6194	0.002853

Figure 0.3 shows the entire range of validity for the equation in an p, v -diagram. An enlarged view of the critical region phase boundaries in an p, v -diagram is shown in Figure 0.4.

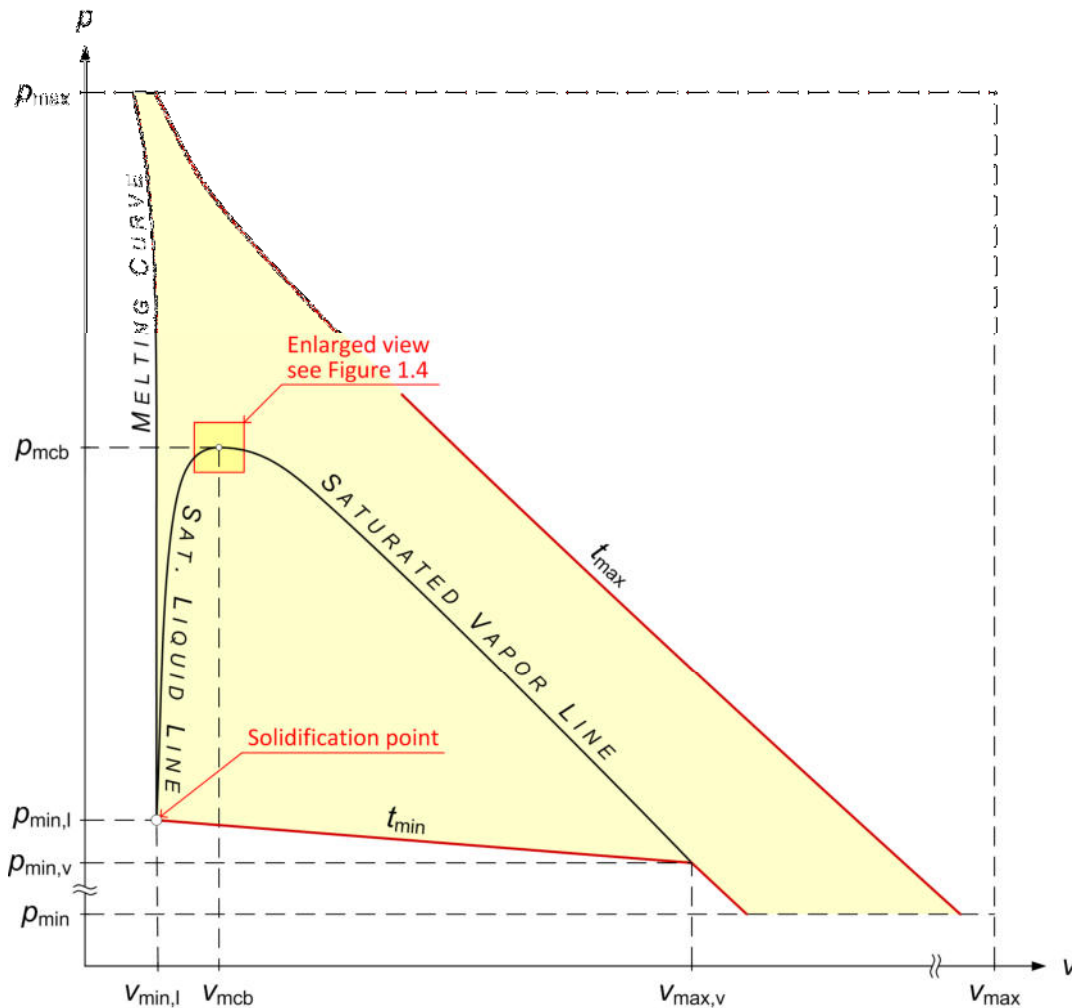


Figure 0.3: Entire range of validity in an $\lg p, \lg v$ - diagram

All sub-programs and functions can be applied in the entire range of validity of the LibRealAir. The call of the equation of state for each calculation region will be carried out within the program. The sub-programs of the LibRealAir DLL and the functions of the Add-In are listed in the following section.

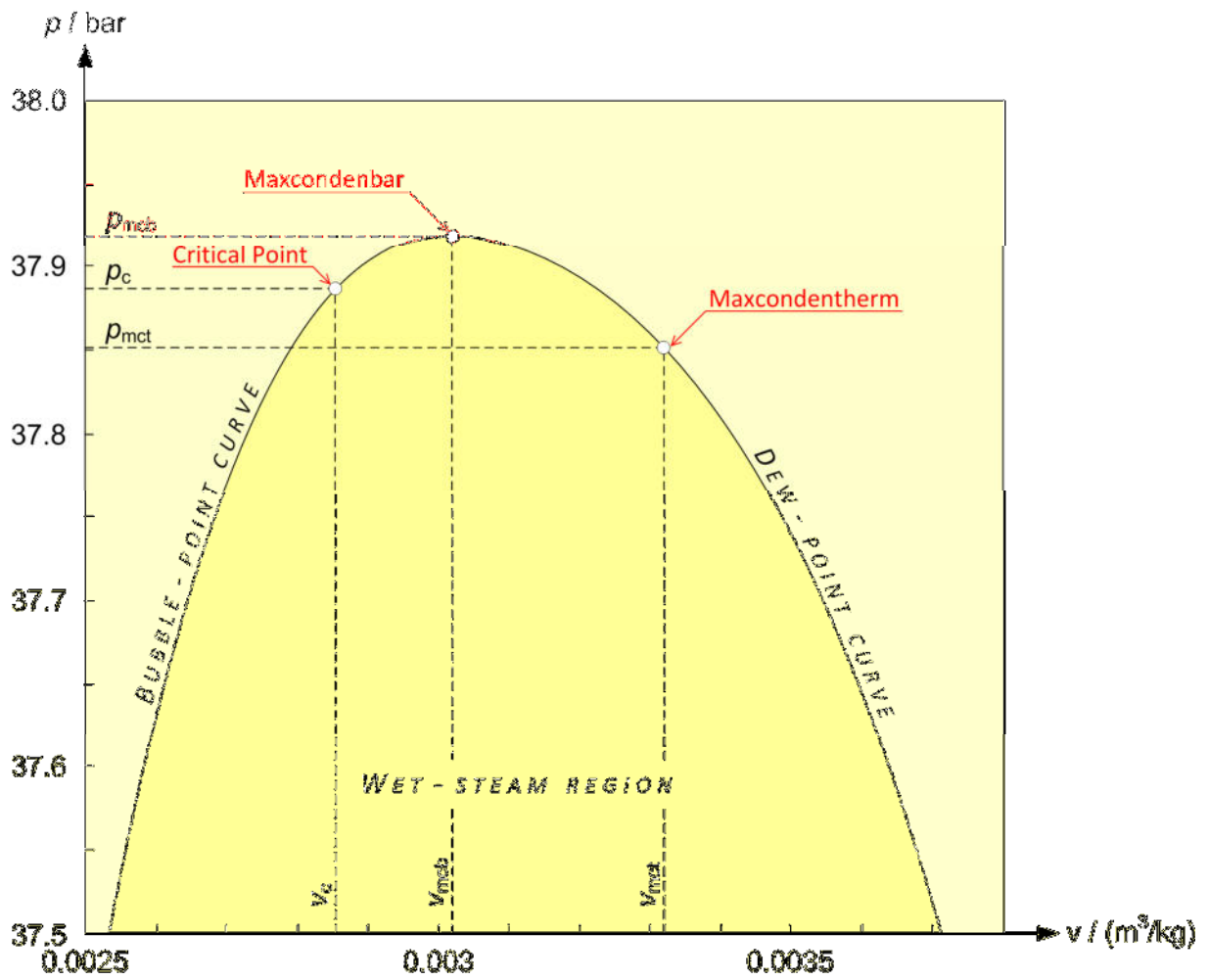


Figure 0.4: Enlarged view of the critical region phase boundaries in an p, v -diagram

Functions

Functional dependence	Function Name	Call from DLL LibRealAir, Result as Parameter	Property or Function	Unit of the Result
$a = f(p, t, x)$	a_ptx_air	= APTXAIR(P,T,X)	Thermal diffusivity	m ² /s
$\alpha_p = f(p, t, x)$	alphap_ptx_air	= ALPHAPPTXAIR(P,T,X)	Relative pressure coefficient	1/K
$\alpha_v = f(p, t, x)$	alphav_ptx_air	= ALPHAVPTXAIR(P,T,X)	Isobaric cubic expansion coefficient	1/K
$\beta_p = f(p, t, x)$	betap_ptx_air	= BETAPPTXAIR(P,T,X)	Isothermal stress coefficient	kg/m ³
$c_p = f(p, t, x)$	cp_ptx_air	= CPPTXAIR(P,T,X)	Specific isobaric heat capacity	kJ/(kg·K)
$c_v = f(p, t, x)$	cv_ptx_air	= CVPTXAIR(P,T,X)	Specific isochoric heat capacity	kJ/(kg·K)
$\eta = f(p, t, x)$	eta_ptx_air	= ETAPTXAIR(P,T,X)	Dynamic viscosity	Pa·s
$h = f(p, t, x)$	h_ptx_air	= HPTXAIR(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_air	= KAPPAPTXAIR(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p, t, x)$	kappat_ptx_air	= KAPPATPTXAIR(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p, t, x)$	lambda_ptx_air	= LAMBDAPTXAIR(P,T,X)	Thermal conductivity	W/(m·K)
$\nu = f(p, t, x)$	nu_ptx_air	= NUPTXAIR(P,T,X)	Kinematic viscosity	m ² /s
$p_{\text{mel}} = f(t)$	pmel_t_air	= PMELTAIR(T)	Pressure on the melting curve	bar
$Pr = f(p, t, x)$	prandtl_ptx_air	= PRANDTLPTXAIR(P,T,X)	Prandtl number	-
$p_{\text{sl}} = f(t)$	psl_t_air	= PSLTAIR(T)	Pressure on the saturated liquid line	bar
$p_{\text{sv}} = f(t)$	psv_t_air	= PSVTAIR(T)	Pressure on the saturated vapor line	bar
$\rho = f(p, t, x)$	rho_ptx_air	= RHOPTXAIR(P,T,X)	Density	kg/m ³
$s = f(p, t, x)$	s_ptx_air	= SPTXAIR(P,T,X)	Specific entropy	kJ/(kg·K)
$t_{\text{mel}} = f(p)$	tmel_p_air	= TMELPAIR(P)	Temperature on the melting curve	°C
$t = f(p, h)$	t_ph_air	= TPHAIR(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_air	= TPSAIR(P,S)	Backward function: Temperature from pressure and entropy	°C
$t_{\text{sl}} = f(p)$	tsl_p_air	= TSLPAIR(P)	Temperature on the saturated liquid line	°C
$t_{\text{sv}} = f(p)$	tsv_p_air	= TSVPAIR(P)	Temperature on the saturated vapor line	°C
$u = f(p, t, x)$	u_ptx_air	= UPTXAIR(P,T,X)	Specific internal energy	kJ/kg
$v = f(p, t, x)$	v_ptx_air	= VPTXAIR(P,T,X)	Specific volume	m ³ /kg
$w = f(p, t, x)$	w_ptx_air	= WPTXAIR(P,T,X)	Speed of sound	m/s
$x = f(p, h)$	x_ph_air	= XPHAIR(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x_ps_air	= XPSAIR(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg

Units:

Temperature	t in °C
Pressure	p in bar
Vapor fraction	x in kg saturated steam/kg wet steam

Range of validity of LibRealAir:

Temperature: from -213.4 °C (59.75 K) to 1726.85 °C (2000 K)
Pressure: from 0.00001 bar to 20000 bar

Details on the vapor fraction x and on the calculation of wet steam:

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction x are to be considered:

Single phase region

If the state point to be calculated is located in the single-phase region (liquid or superheated steam) $x = -1$ must be entered as a pro-forma value.

Wet steam region

When calculating wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. It is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. When p and t and x are entered as given values, the program will consider whether p and t fit together. If it is not the case the calculation for the property of the chosen function to be calculated results in -1000 . In this case, the backward functions result in the appropriate value between 0 and 1 for x .

Boundaries for wet steam region

The boundaries for the wet steam region are

$$t_t = -213.4 \text{ °C}; \quad p_{\min,l} = 0.052646 \text{ bar}; \quad p_{\min,v} = 0.024316 \text{ bar}$$

$$t_{\text{mct}} = -140.5188 \text{ °C}; \quad p_{\text{mcb}} = 37.9195 \text{ bar}.$$

They are illustrated in Figure 0.1 and Figure 0.2 and listed in Table 0.2 and Table 0.3.

Note:

If the calculation results in -1000 , the values entered represent a state point beyond the range of validity. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

Thermodynamic Diagrams

The next pages provide the following thermodynamic diagrams showing the properties of standard dry air.

- **lg p,h -diagram** from
 $p = 0.01 \text{ bar}$ to $p = 5000 \text{ bar}$,
 $t = -213.4 \text{ °C}$ to $t = 0 \text{ °C}$ and
 $\Delta h = 450 \text{ kJ/kg}$
- **T,s -diagram** from
 $t = -213.4 \text{ °C}$ to $t = 60 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 4.8 \text{ kJ/(kg}\cdot\text{K)}$
- **T,s -diagram** from
 $t = -50 \text{ °C}$ to $t = 1000 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 3.6 \text{ kJ/(kg}\cdot\text{K)}$
- **h,s -diagram** from
 $t = -40 \text{ °C}$ to $t = 1000 \text{ °C}$,
 $p = 0.01 \text{ bar}$ to $p = 1000 \text{ bar}$ and
 $\Delta s = 3.6 \text{ kJ/(kg}\cdot\text{K)}$