



ThermoFluidProperties

**Property Library for
the Industrial Formulation
IAPWS-IF97
for Water and Steam**

**FluidEXL *Graphics*
with LibIF97IT
for Excel®**

Prof. Dr. Hans-Joachim Kretzschmar
Prof. Dr. Matthias Kunick
Dr. Sebastian Herrmann
M.Eng Martin Suender

**Software for the Calculation of the Properties
of the Industrial Formulation IAPWS-IF97 for Water and Steam
Including DLL and Add-In for Excel®
FluidEXL *Graphics*
LibIF97IT**

Contents

- 0. Package Contents
 - 0.1 Zip-files for 32-bit Office®
 - 0.2 Zip-files for 64-bit Office®
- 1. Property Functions
- 2. Application of FluidEXL in Excel®
 - 2.1 Installing FluidEXL
 - 2.2 Registering FluidEXL as Add-In in Excel®
 - 2.3 Licensing the LibIF97IT Property Library
 - 2.4 Example calculation
 - 2.5 Representation of Calculated Properties in Thermodynamic Diagrams
 - 2.6 The FluidEXL Help System
 - 2.7 Removing FluidEXL
- 3. Program Documentation
- 4. Property Libraries for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators
- 5. References
- 6. Satisfied Customers

© KCE-ThermoFluidProperties
Prof. Dr. Hans-Joachim Kretzschmar
Haager Weg 6, 92224 Amberg, Germany
Phone: +49-9621-1762047
Mobile: +49-172-7914607
Fax: +49-3222-1095810
Email: info@thermofluidprop.com
Internet: www.thermofluidprop.com

0 Package Contents

0.1 Zip files for 64-bit Office®

The following zip file has been delivered for your computer running a 64-bit Office® version:

CD_FluidEXL_Graphics_Eng_LibIF97IT_x64.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibIF97IT_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibIF97IT.dll

LibIF97IT.chm.

0.2 Zip files for 32-bit Office®

The following zip file has been delivered for your computer running a 32-bit Office® version:

CD_FluidEXL_Graphics_Eng_LibIF97IT.zip

including the following folders and files:

\FLUFT\

\Formulation97\

FluidEXL_Graphics_LibIF97IT_Docu_Eng.pdf

FluidEXL_Graphics_Eng.xla

LC.dll

LibIF97IT.dll

LibIF97IT.chm.

1. Program Functions

1.1 Range of Validity

The International Association for the Properties of Water and Steam IAPWS issued the

"Release on the IAPWS Industrial Formulation 1997

for the Thermodynamic Properties of Water and Steam IAPWS-IF97"

in September 1997 [1], [2], [3]. It will be abbreviated as IAPWS-IF97. This new industrial standard must be applied worldwide in acceptance and guarantees calculations of facilities and plants working with water or steam. The IAPWS-IF97 Formulation replaces the former Industrial Formulation IFC-67 [12].

Figure 1.1 shows the entire range of validity for the equation set of the new Industrial Formulation IAPWS-IF97. It includes temperatures from 0 °C to 800 °C at pressures from 0.00611 bar to 1000 bar and temperatures to 2000 °C for pressures to 500 bar.

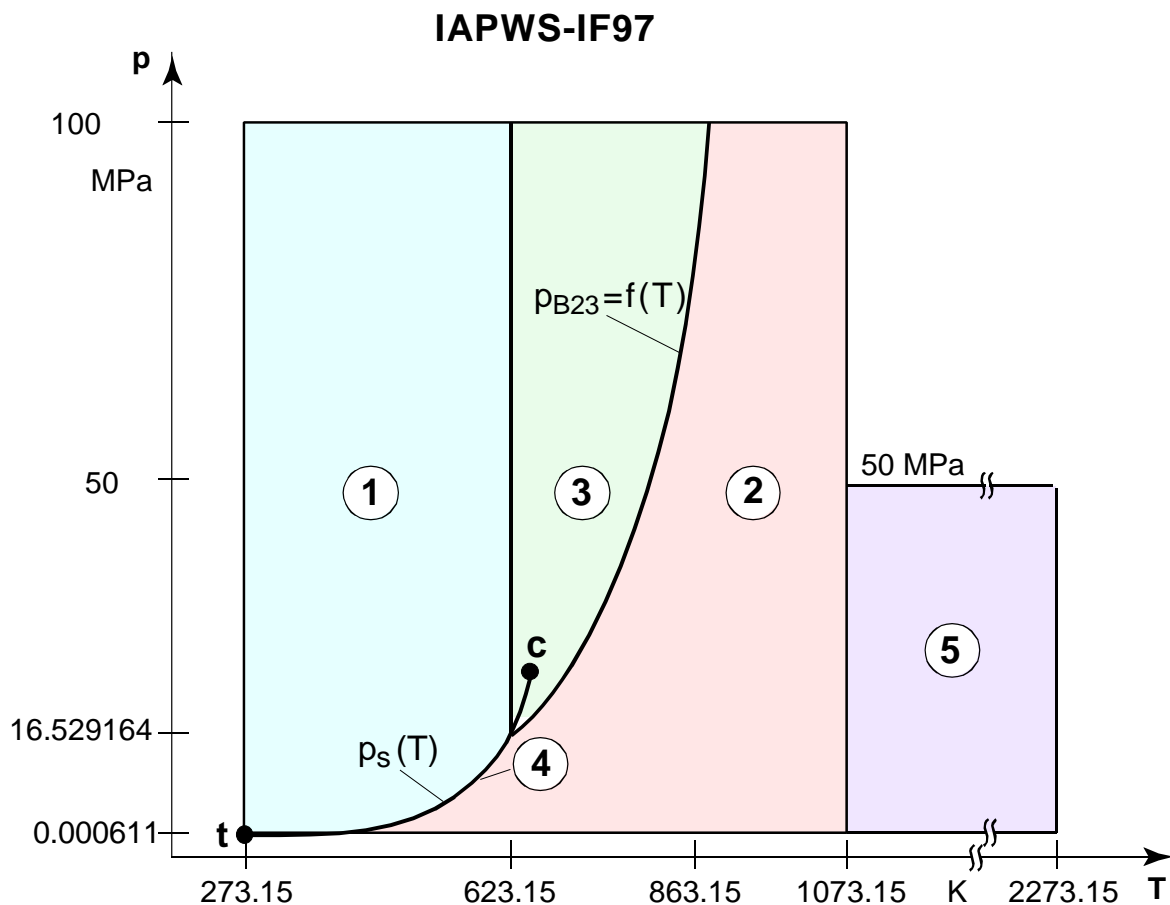


Figure 1.1 Entire Range of Validity of the IF97

The range of validity is divided into five calculation regions. Each of the calculation regions contains its own equations of state. They are described in detail in the official Release of the IAPWS [1] and in the publications by *Wagner et al.* [2] and [3].

The sub-programs of the LibIF97IT DLL and the functions of the Add-In FluidEXL *Graphics* for Excel are listed in the following section.

All sub-programs and functions can be applied in the entire range of validity of the IF97. The call of the necessary equation of state for each calculation region will be realized within the program.

1.2 Functions

Functional Dependence	Function Name	Call as Function from DLL LibIF97IT	Property or Function	Unit of the Result
$a = f(p, t, x)$	a_ptx_97IT	= A_PTX_97IT(P, T, X)	Thermal diffusivity	m ² /s
$\alpha_p = f(p, t, x)$	alphap_ptx_97IT	= ALPHAP_PTX_97IT(P, T, X)	Relative pressure coefficient	K ⁻¹
$\alpha_v = f(p, t, x)$	alphav_ptx_97IT	= ALPHAV_PTX_97IT(P, T, X)	Isobaric cubic expansion coefficient	K ⁻¹
$b = f(p)$	b_p_97IT	= B_P_97IT(P)	Laplace coefficient	m
$b = f(t)$	b_t_97IT	= B_T_97IT(T)	Laplace coefficient	m
$\beta_p = f(p, t, x)$	betap_ptx_97IT	= BETAP_PTX_97IT(P, T, X)	Isothermal stress coefficient	kg/m ³
$c_p = f(p, t, x)$	cp_ptx_97IT	= CP_PTX_97IT(P, T, X)	Specific isobaric heat capacity	kJ/(kg · K)
$c_v = f(p, t, x)$	cv_ptx_97IT	= CV_PTX_97IT(P, T, X)	Specific isochoric heat capacity	kJ/(kg · K)
$\delta_T = f(p, t, x)$	deltat_ptx_97IT	= DELTAT_PTX_97IT(P, T, X)	Isothermal throttling coefficient	kJ/(kg · kPa ⁻¹)
$\left(\frac{\partial v}{\partial p}\right)_T = f(p, t, x)$	dv_dp_T_ptx_97IT	= DVDP_T_97IT(P, T, X)	Differential quotient $\left(\frac{\partial v}{\partial p}\right)_T(p, t, x)$	m ³ /(kg · kPa)
$\left(\frac{\partial v}{\partial T}\right)_p = f(p, t, x)$	dv_dT_p_ptx_97IT	= DVDT_P_97IT(P, T, X)	Differential quotient $\left(\frac{\partial v}{\partial T}\right)_p(p, t, x)$	m ³ /(kg · K)
$e = f(p, t, x, t_U)$	e_ptx_tu_97IT	= E_PTXTU_97IT(P, T, X, TU)	Specific exergy	kJ/kg
$\varepsilon = f(p, t, x)$	epsilon_ptx_97IT	= EPS_PTX_97IT(P, T, X)	Dielectric constant	-
$\eta = f(p, t, x)$	eta_ptx_97IT	= ETA_PTX_97IT(P, T, X)	Dynamic viscosity	Pa · s = kg/(m · s)
$f = f(p, t, x)$	f_ptx_97IT	= F_PTX_97IT(P, T, X)	Specific Helmholtz energy	kJ/kg
$f^* = f(p, t, x)$	fug_ptx_97IT	= FUG_PTX_97IT(P, T, X)	Fugacity	bar
$g = f(p, t, x)$	g_ptx_97IT	= G_PTX_97IT(P, T, X)	Specific Gibbs energy	kJ/kg
$h = f(p, s)$	h_ps_97IT	= H_PS_97IT(P, S)	Backward function: Specific enthalpy from pressure and entropy	kJ/kg

Functional Dependence	Function Name	Call as Function from DLL LibIF97IT	Property or Function	Unit of the Result
$h = f(p, t, x)$	h_ptx_97IT	= HPTX97IT(P, T, X)	Specific enthalpy	kJ/kg
$\kappa = f(p, t, x)$	kappa_ptx_97IT	= KAPPA_PTX_97IT(P, T, X)	Isentropic exponent	-
$\kappa_T = f(p, t, x)$	kappat_ptx_97IT	= KAPPAT_PTX_97IT(P, T, X)	Isothermal compressibility	kPa ⁻¹
$\lambda = f(p, t, x)$	lambda_ptx_97IT	= LAMBDA_PTX_97IT(P, T, X)	Heat conductivity	W/(m · K)
$\mu = f(p, t, x)$	my_ptx_97IT	= MY_PTX_97IT(P, T, X)	Joule-Thomson coefficient	K kPa ⁻¹
$n = f(p, t, x, wl)$	n_ptxwl_97IT	= N_PTXWL_97IT(P, T, X, WL)	Refractive index	-
$\nu = f(p, t, x)$	ny_ptx_97IT	= NY_PTX_97IT(P, T, X)	Kinematic viscosity	m ² /s
$p = f(h, s)$	p_hs_97IT	= P_HS_97IT(H, S)	Backward function: Pressure from enthalpy and entropy	bar
$p = f(t, h)$	p_th_97IT	= P_TH_97IT(T, H)	Backward function: Pressure from Temperature and enthalpie	bar
$p = f(t, v)$	p_tv_97IT	= P_TV_97IT(T, V)	Backward function: Pressure from Temperature and volume	bar
$p = f(v, h)$	p_vh_97IT	= P_VH_97IT(V, H)	Backward function: Pressure from volume and enthalpy	bar
$p = f(v, s)$	p_vs_97IT	= P_VS_97IT(V, S)	Backward function: Pressure from volume and entropie	bar
$p = f(v, u)$	p_vu_97IT	= P_VU_97IT(V, U)	Backward function: Pressure from volume and internal energy	bar
$Pr = f(p, t, x)$	Pr_ptx_97IT	= PR_PTX_97IT(P, T, X)	Prandtl-number	-
$p_s = f(h')$	ps_h1_97IT	= PS_H1_97IT(H)	Vapor pressure	bar
$p_s = f(t)$	ps_t_97IT	= PS_T_97IT(T)	Vapor pressure	bar
$\rho = f(p, t, x)$	rho_ptx_97IT	= RHO_PTX_97IT(P, T, X)	Density	kg/m ³
$s = f(p, h)$	s_ph_97IT	= S_PH_97IT(P, H)	Backward function: Specific entropy from pressure and enthalpy	kJ/(kg · K)

Functional Dependence	Function Name	Call as Function from DLL LibIF97IT	Property or Function	Unit of the Result
$s = f(p, t, x)$	s_ptx_97IT	= S_PTX_97IT(P,T,X)	Specific entropy	kJ/(kg · K)
$\sigma = f(p)$	sigma_p_97IT	= SIGMA_P_97IT(P)	Surface tension from pressure	mN/m = mPa · m
$\sigma = f(t)$	sigma_t_97IT	= SIGMA_T_97IT(T)	Surface tension from temperature	mN/m = mPa · m
$t = f(h, s)$	t_hs_97IT	= T_HS_97IT(H,S)	Backward function: Temperature from enthalpy and entropy	°C
$t = f(p, h)$	t_ph_97IT	= T_PH_97IT(P,H)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p, s)$	t_ps_97IT	= T_PS_97IT(P,S)	Backward function: Temperature from pressure and entropy	°C
$t = f(p, v)$	t_pv_97IT	= T_PV_97IT(P,S)	Backward function: Temperature from Temperature and volume	°C
$t = f(v, h)$	t_vh_97IT	= T_VH_97IT(P,H)	Backward function: Temperature from volume and enthalpy	°C
$t = f(v, s)$	t_vs_97IT	= T_VS_97IT(P,S)	Backward function: Temperature from volume and entropie	°C
$t = f(v, u)$	t_vu_97IT	= T_VU_97IT(P,H)	Backward function: Temperature from volume and internal energy	°C
$t_s = f(p)$	ts_p_97IT	= TS_P_97IT(P)	Saturation temperature	°C
$u = f(p, t, x)$	u_ptx_97IT	= U_PTX_97IT(P,T,X)	Specific internal energy	kJ/kg
$v = f(h, s)$	v_hs_97IT	= V_HS_97IT(H,S)	Backward function: Specific volume from enthalpy an entropie	m ³ /kg
$v = f(p, h)$	v_ph_97IT	= V_PH_97IT(P,S)	Backward function: Specific volume from pressure and enthalpy	m ³ /kg
$v = f(p, s)$	v_ps_97IT	= V_PS_97IT(P,S)	Backward function: Specific volume from pressure and entropy	m ³ /kg
$v = f(p, t, x)$	v_ptx_97IT	= V_PTX_97IT(P,T,X)	Specific volume	m ³ /kg
$v = f(t, h)$	v_th_97IT	= V_TH_97IT(T,H)	Backward function: Spec. volume from Temperature and enthalpie	bar
$w = f(p, t, x)$	w_ptx_97IT	= W_PTX_97IT(P,T,X)	Isentropic speed of sound	m/s

$x = f(h, s)$	x_hs_97IT	= X_HS_97IT(H,S)	Backward function: Vapor fraction from enthalpy and entropy	kg/kg
$x = f(p, h)$	x_ph_97IT	= X_PH_97IT(P,H)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p, s)$	x_ps_97IT	= X_PS_97IT(P,S)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$x = f(p, v)$	x_pv_97IT	= X_PV_97IT(P,V)	Backward function: Vapor fraction from pressure and volume	kg/kg
$x = f(t, h)$	x_th_97IT	= X_TH_97IT(T,H)	Backward function: Vapor fraction from Temperature and enthalpie	bar
$x = f(t, v)$	x_tv_97IT	= X_TV_97IT(P,H)	Backward function: Vapor fraction from temperature and volume	kg/kg
$x = f(v, h)$	x_vh_97IT	= X_VH_97IT(P,H)	Backward function: Vapor fraction from volume and enthalpy	kg/kg
$x = f(v, s)$	x_vs_97IT	= X_VS_97IT(P,S)	Backward function: Vapor fraction from volume and entropie	kg/kg
$x = f(v, u)$	x_vu_97IT	= X_VU_97IT(P,H)	Backward function: Vapor fraction from volume and internal energy	kg/kg
$z = f(p, t, x)$	z_ptx_97IT	= Z_PTX_97IT(P,T,X)	Compression factor	-

Units: t in °C p in bar x in kg saturated steam/kg wet steam

Range of validity of IAPWS-IF97

Temperature:	from 0 °C to 800 °C
Pressure:	from 0.00611 bar to 1000 bar
High temperature region:	to 2000 °C for pressures less than 500 bar
	Exception to 900°C for the functions for a , η , λ , v , Pr

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

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered. In this case, the backward functions result in the appropriate value between 0 and 1 for x . When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve. If this is not the case the calculation for the property of the chosen function results in -1 .

[Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$ (c – critical point)]

Note.

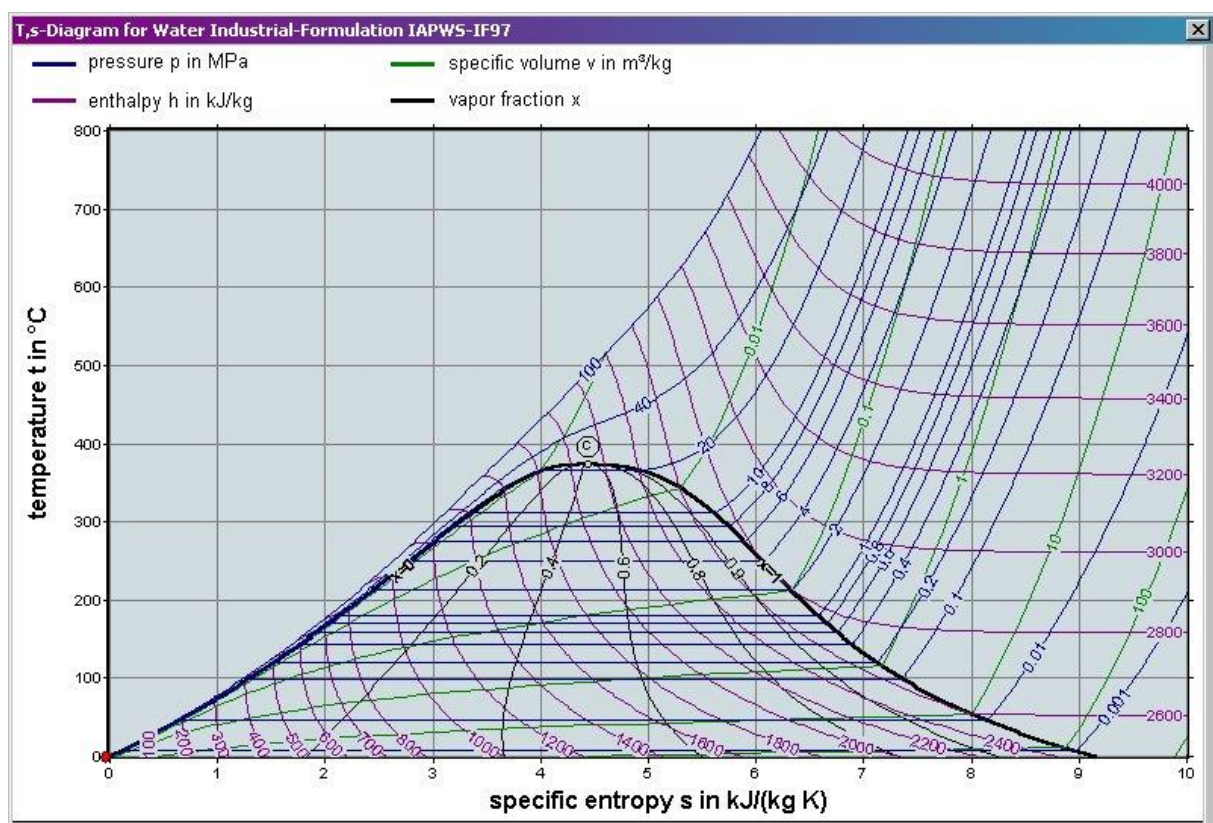
If the calculation results in $-1E16$, the values entered represent a state point beyond the range of validity of IAPWS-IF97. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.

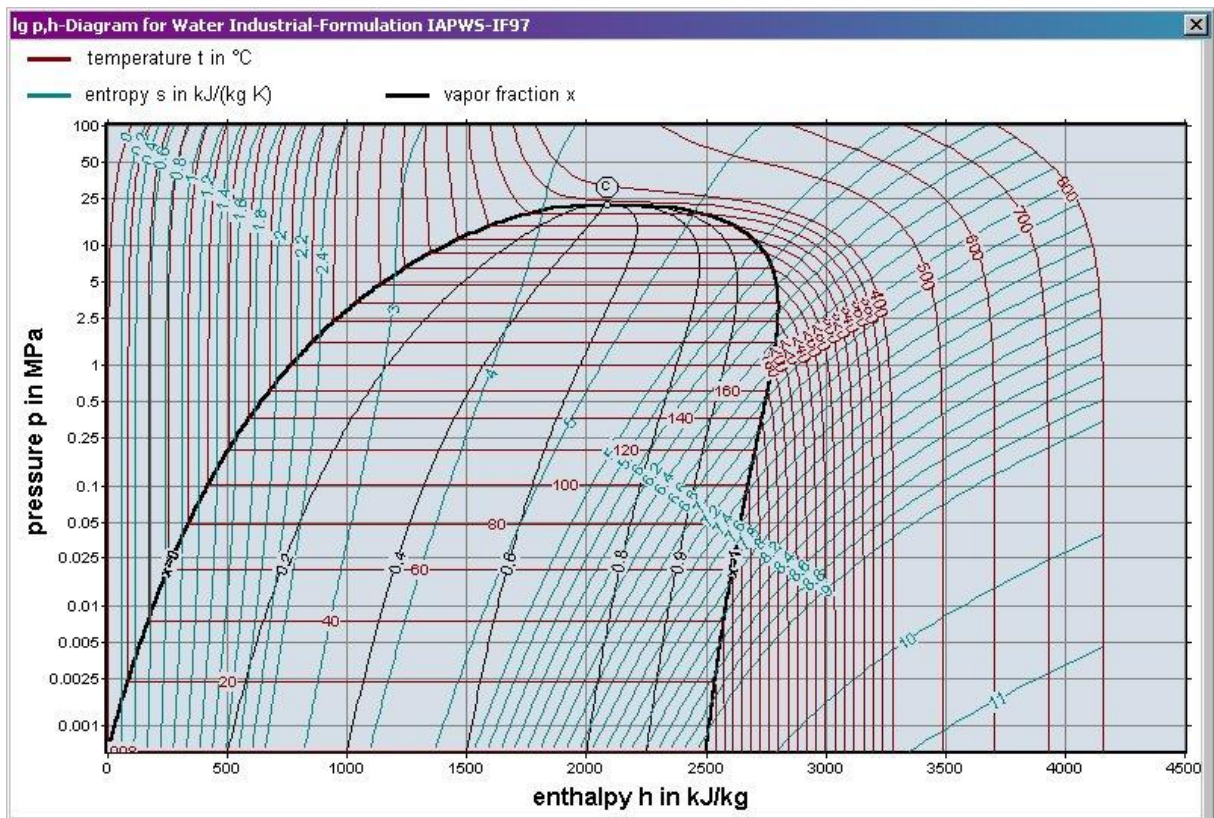
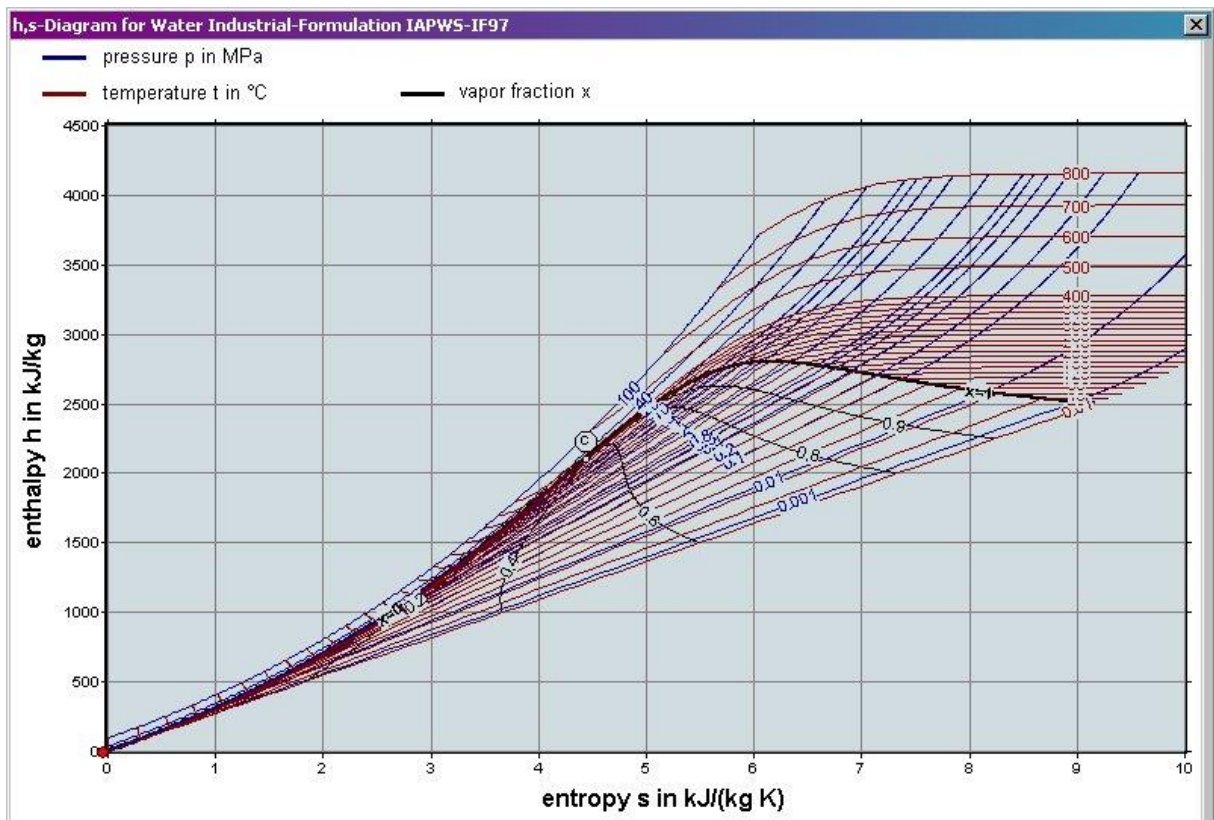
1.3 Thermodynamic Diagrams

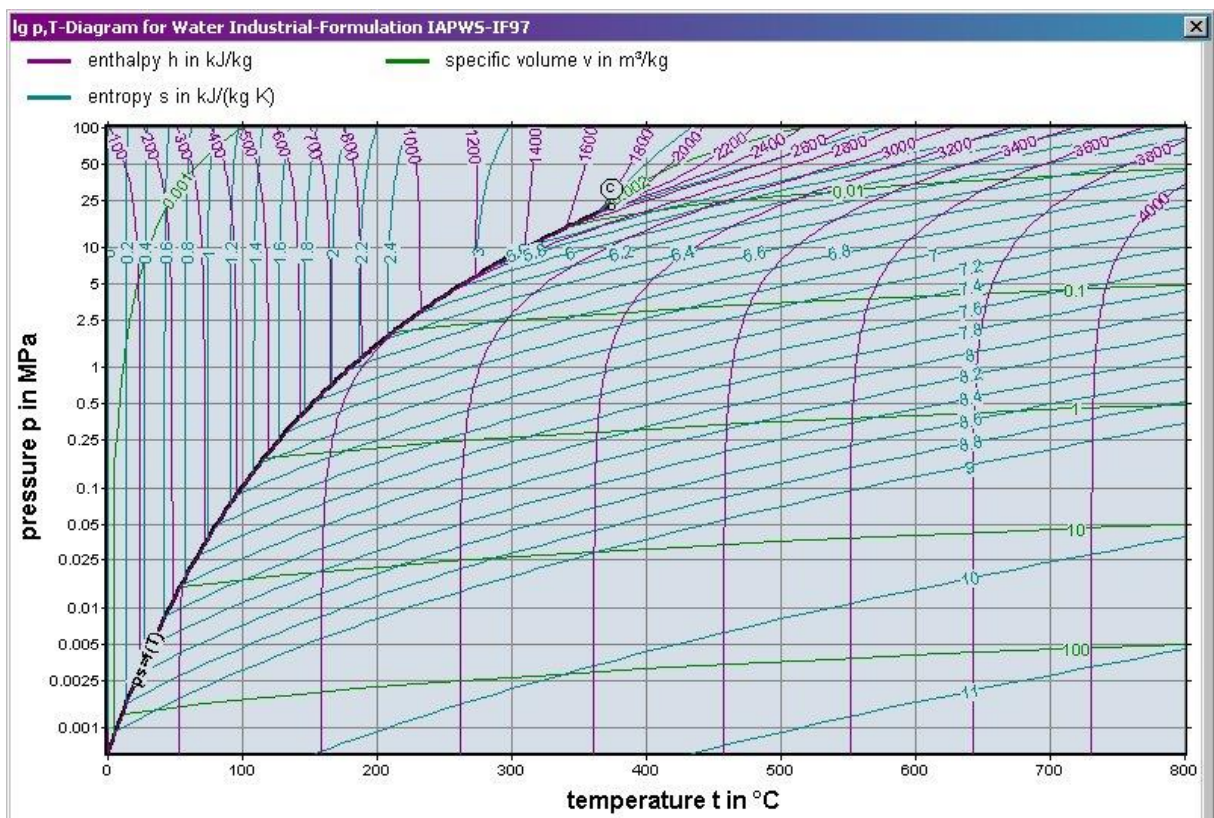
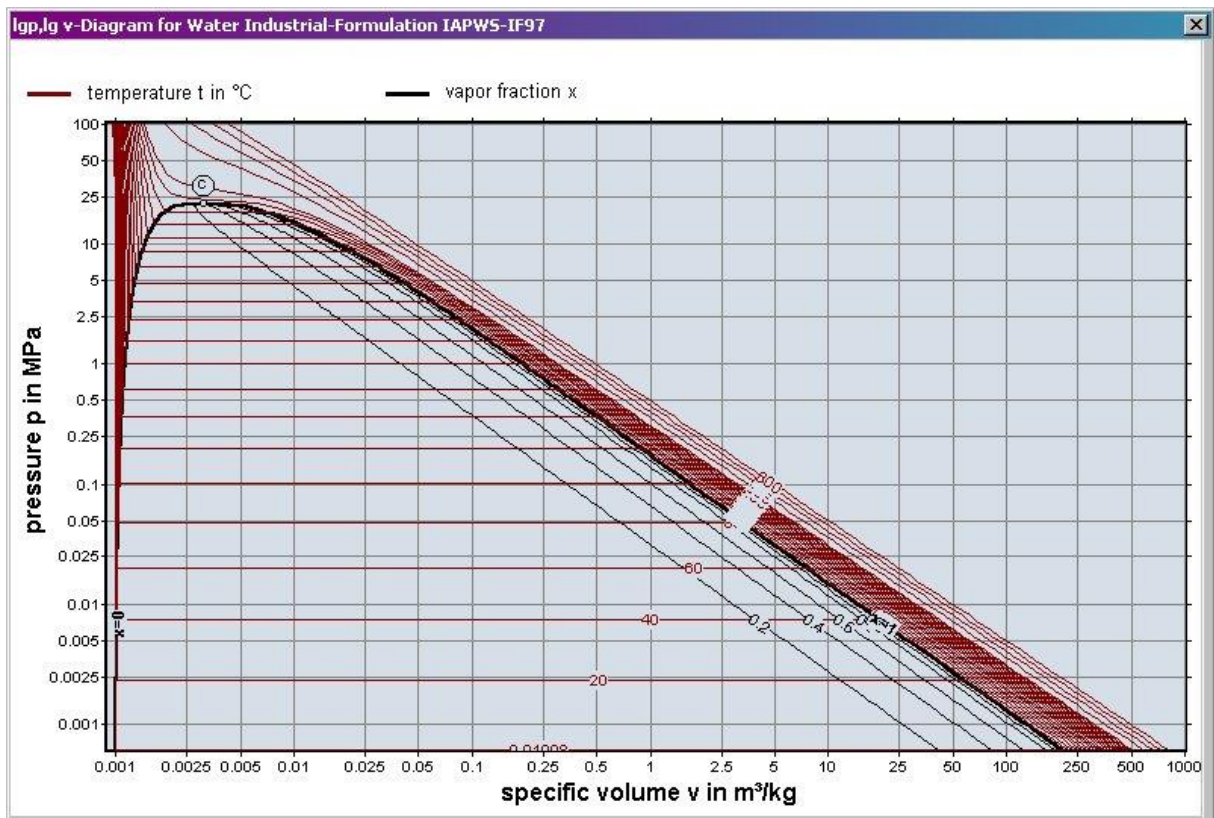
FluidEXL *Graphics* enables the user to represent the calculated properties in the following thermodynamic diagrams:

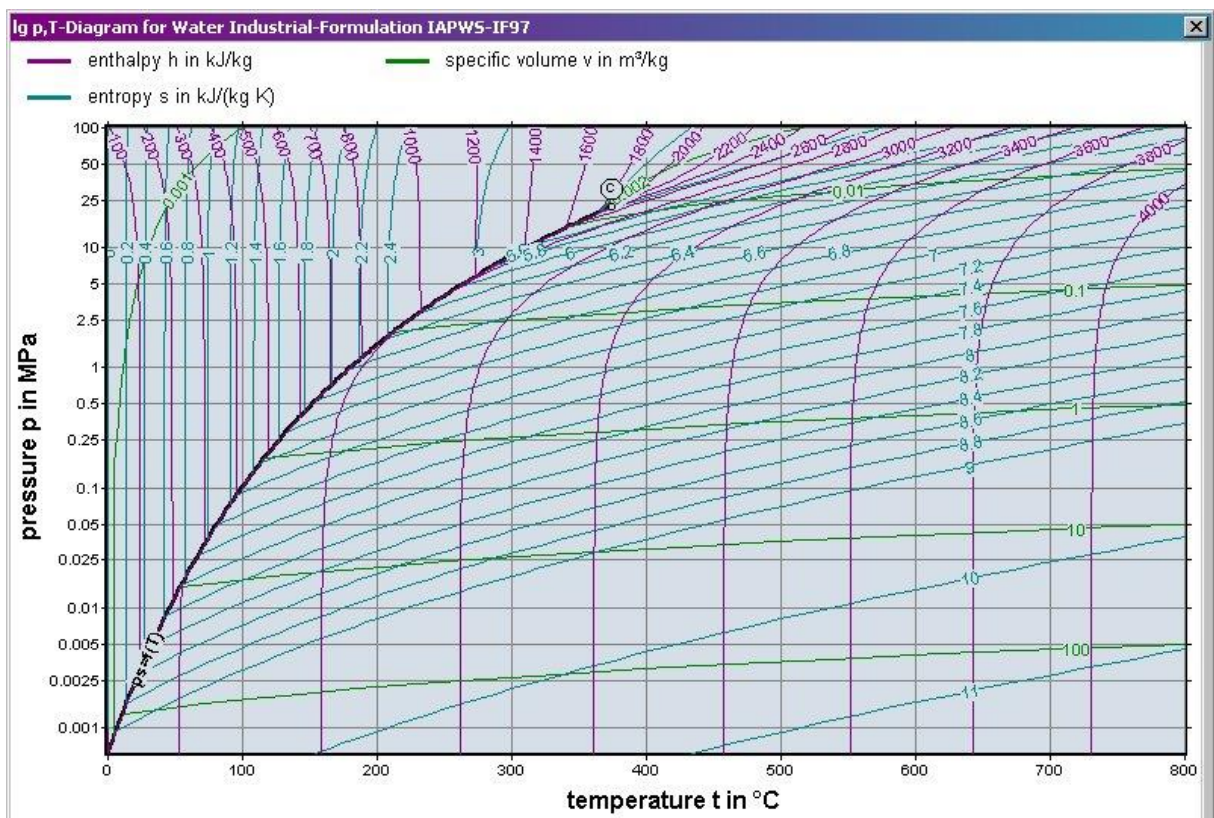
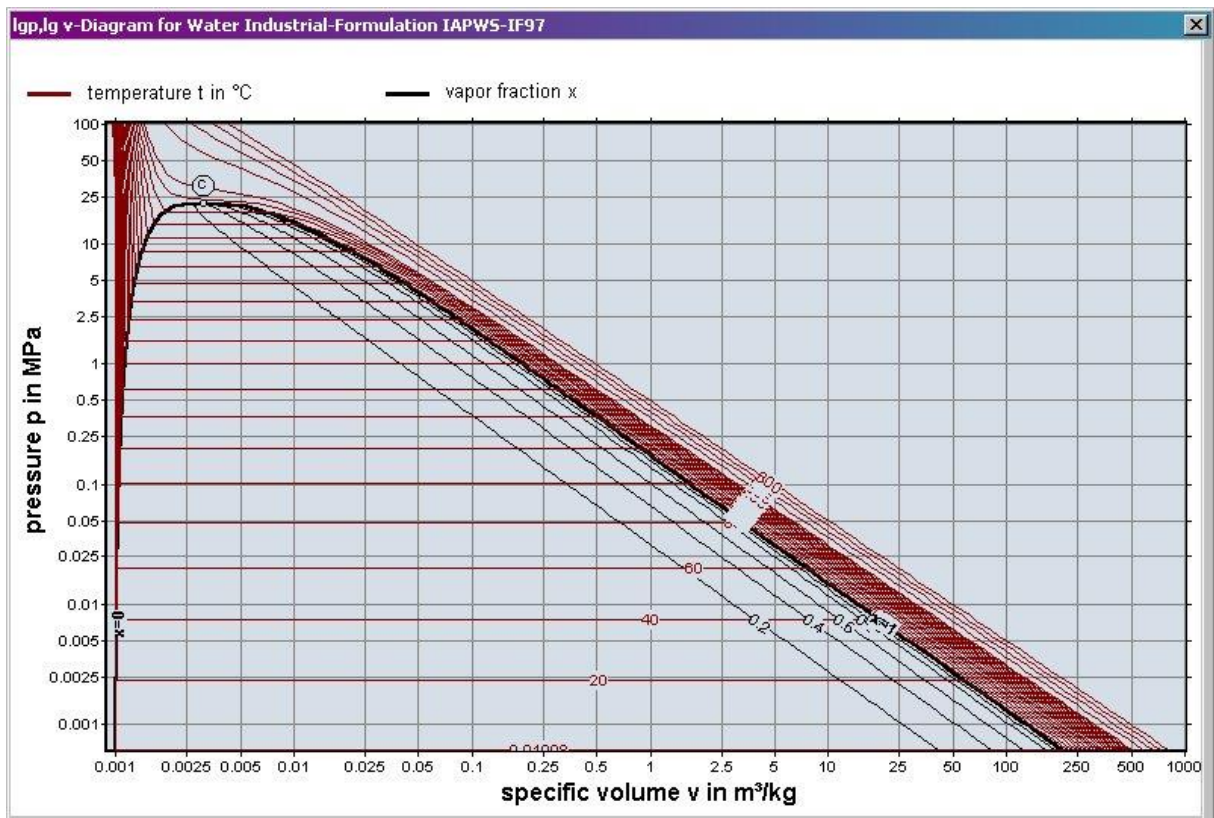
- T - s diagram
- T - h diagram
- h - s diagram
- T - $lg\ v$ diagram
- $lg\ p$ - h diagram
- $lg\ p$ - s diagram
- $lg\ p$ - $lg\ v$ diagram
- h - $lg\ v$ diagram
- $lg\ p$ - T diagram
- s - $lg\ v$ -diagram
- p - T diagram

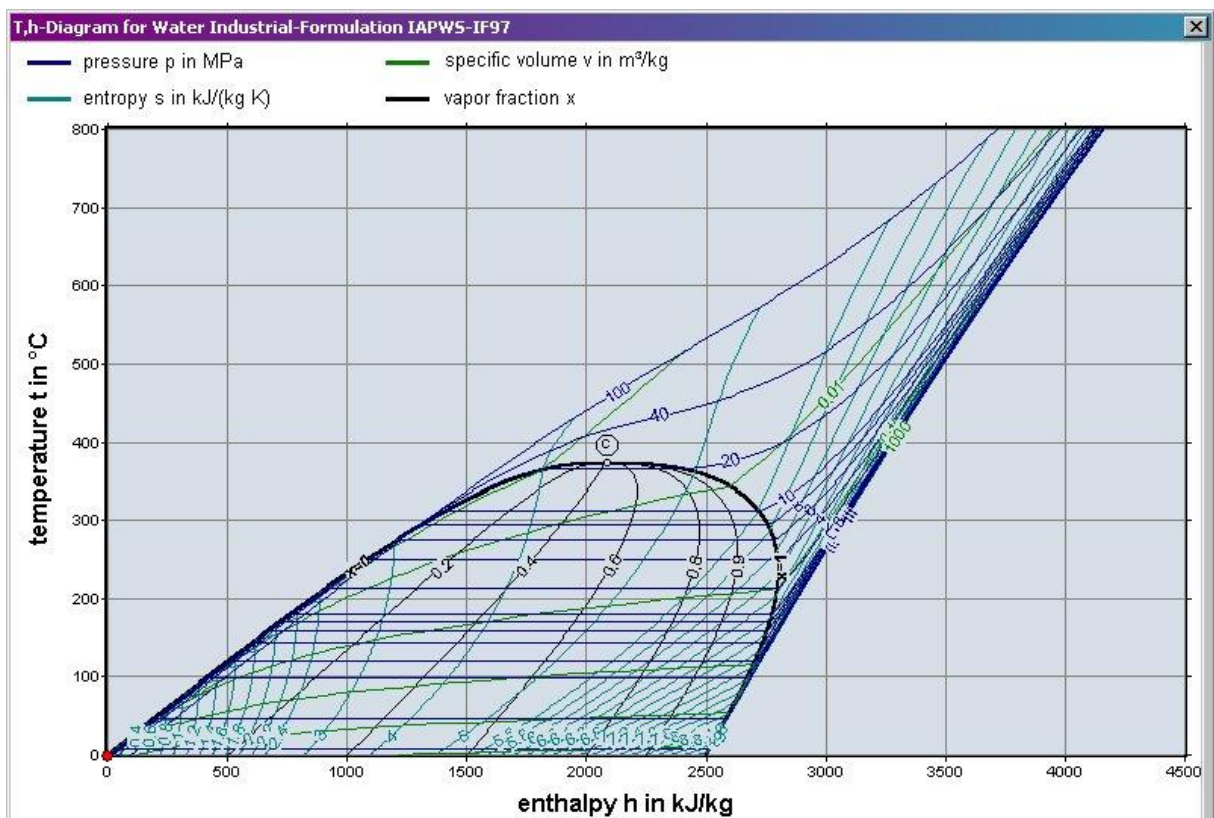
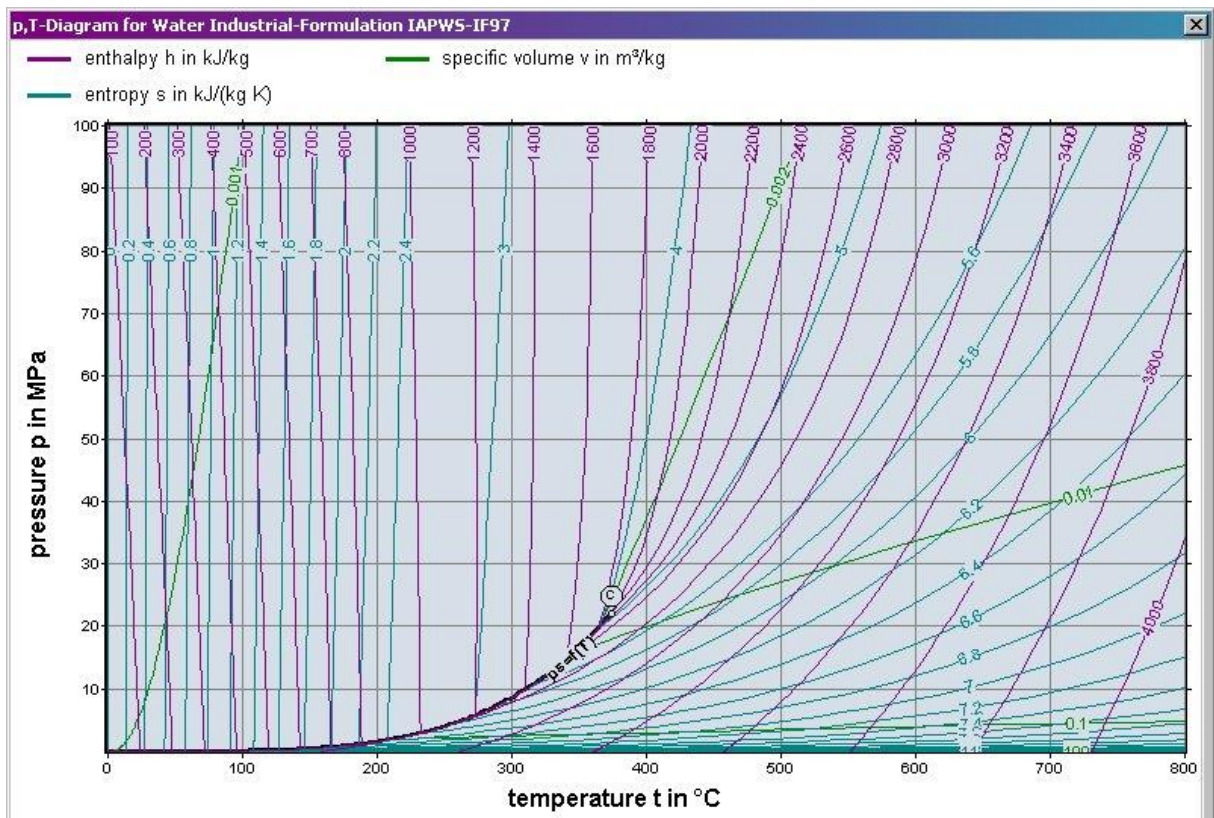
The diagrams, in which the calculated state point will be displayed, are shown on the following pages.

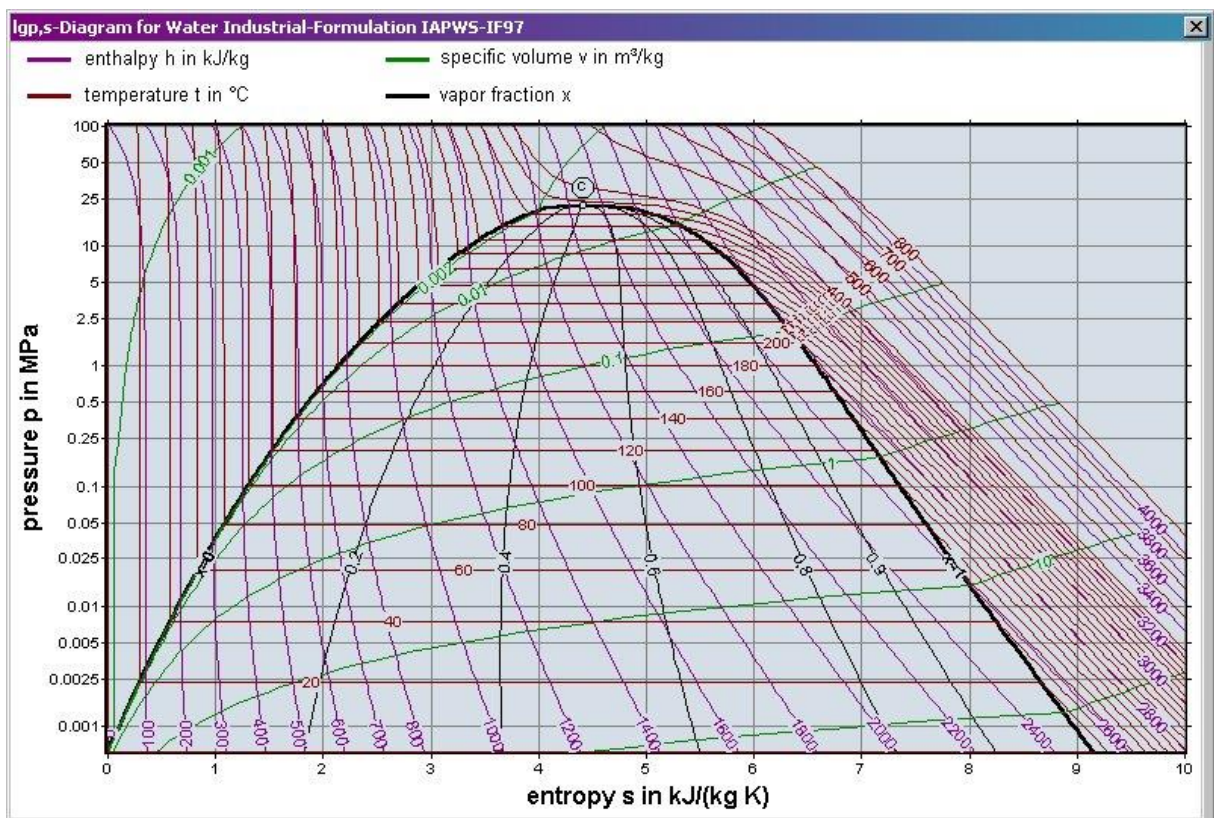
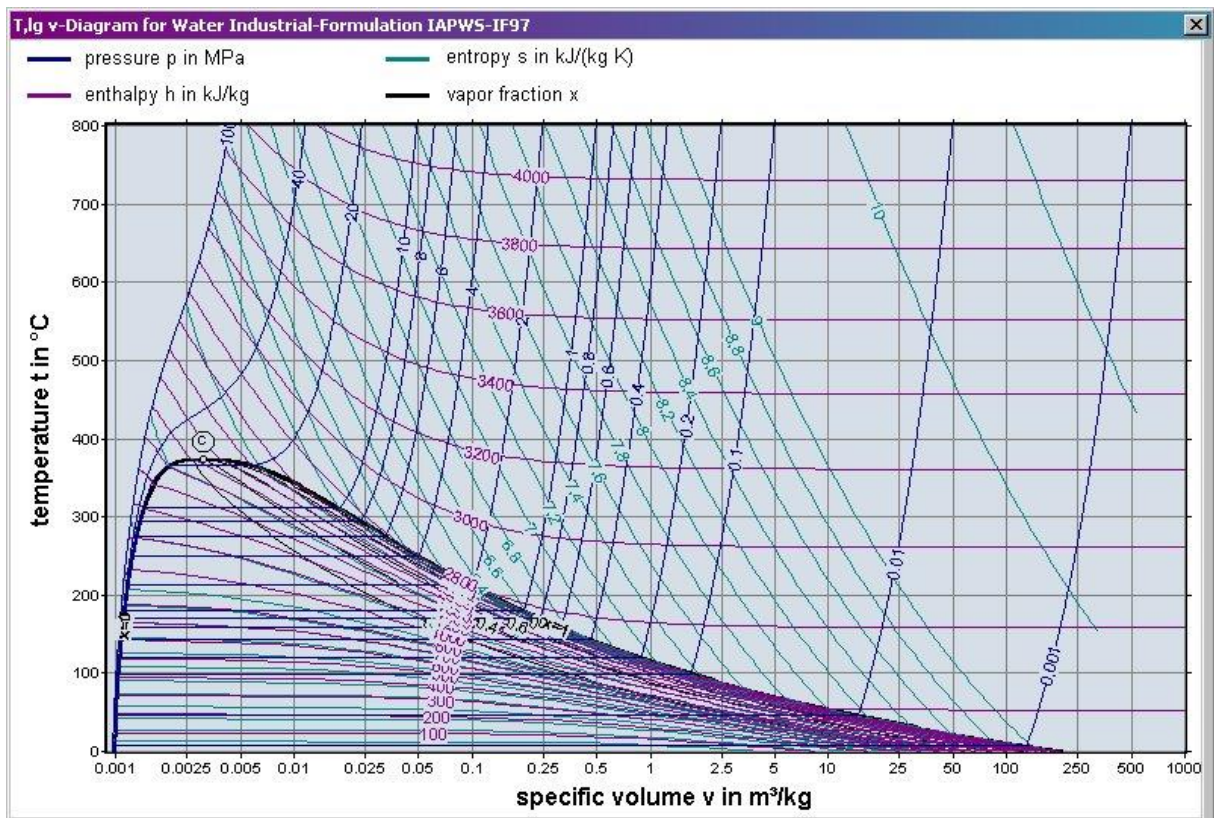


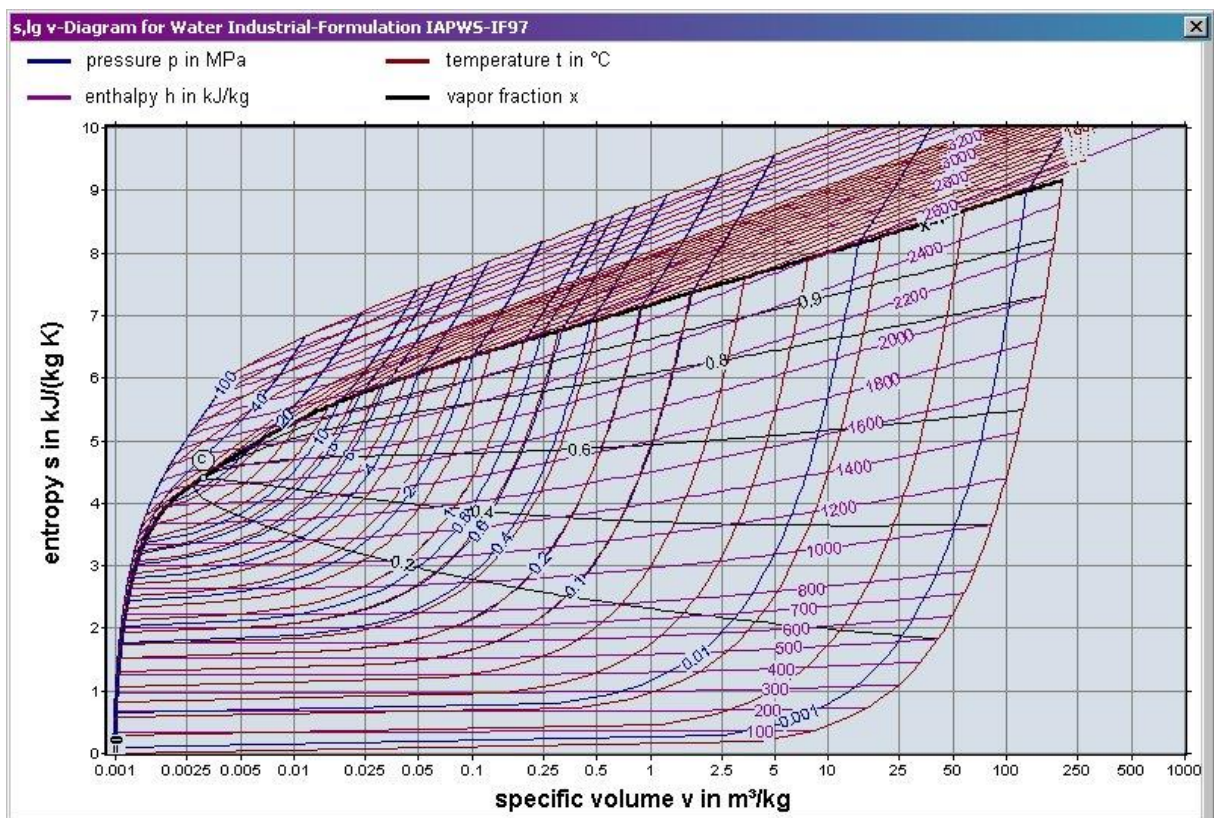
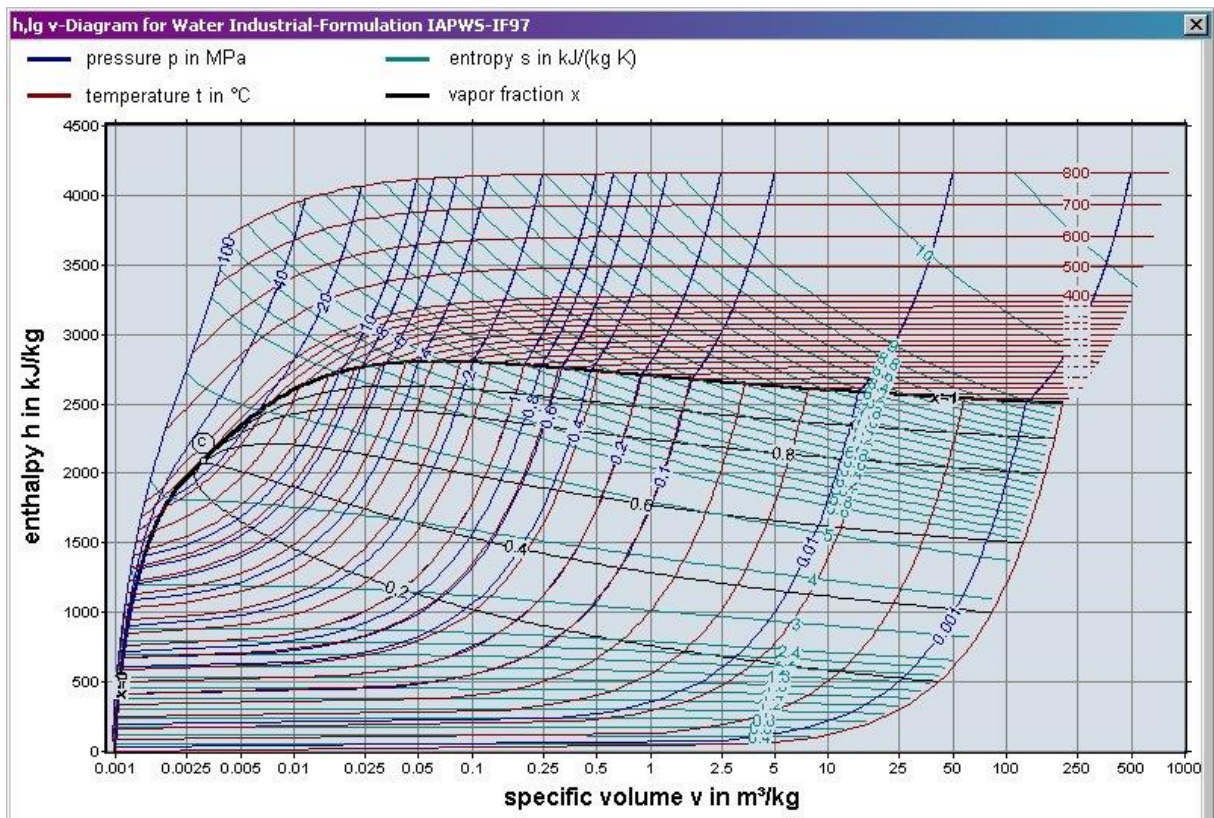












2. Application of FluidEXL *Graphics* in Excel®

The FluidEXL *Graphics* Add-In has been developed to calculate thermodynamic properties in Excel® more conveniently. Within Excel®, it enables the direct call of functions relating to Water and Steam from the LibIF97IT property program library.

2.1 Installing FluidEXL *Graphics*

Complete the following steps for initial installation of FluidEXL *Graphics*.

Before you begin, it is best to uninstall any older version of FluidEXL *Graphics*.

The installation routine for 32-bit and 64-bit versions of Excel is similar. The following instructions are valid for both versions.

After you have downloaded and extracted the zip-file:

CD_FluidEXL_Graphics_LibIF97IT_x64_Eng.zip (for 64 bit version)

or

CD_FluidEXL_Graphics_LibIF97IT_Eng.zip" (for 32 bit version).

you will see the folder

\CD_FluidEXL_Graphics_LibIF97IT_x64_Eng\ (for 64 bit version)

or

\CD_FluidEXL_Graphics_LibIF97IT_Eng\ (for 32 bit version)

in your Windows Explorer, Total Commander etc.

Now, open this folder by double-clicking on it.

Within this folder you will see the following folders and files:

\FLUFT\
 \Formulation97\
 FluidEXL_Graphics_Eng.xla
 FluidEXL_Graphics_LibIF97IT_Docu_Eng
 LC.dll
 LibIF97IT.dll
 LibIF97IT.chm
 Reg_.reg

Now, please copy the following folders and files

\FLUFT\
 \Formulation97\
 FluidEXL_Graphics_Eng.xla
 LibIF97IT.dll
 LibIF97IT.chm
 LC.dll

into the folder

C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\
 where [your name] is your name in the Windows system.

If this folder is not found, follow the next section anyway.

2.2 Registering FluidEXL *Graphics* as Add-In in Excel®

After installation in Windows®, FluidEXL *Graphics* must be registered in Excel® as an Add-In. To do this, start Excel® and carry out the following steps:

- Click the "File" button in the upper left hand corner of Excel® (see Fig. 2.1)

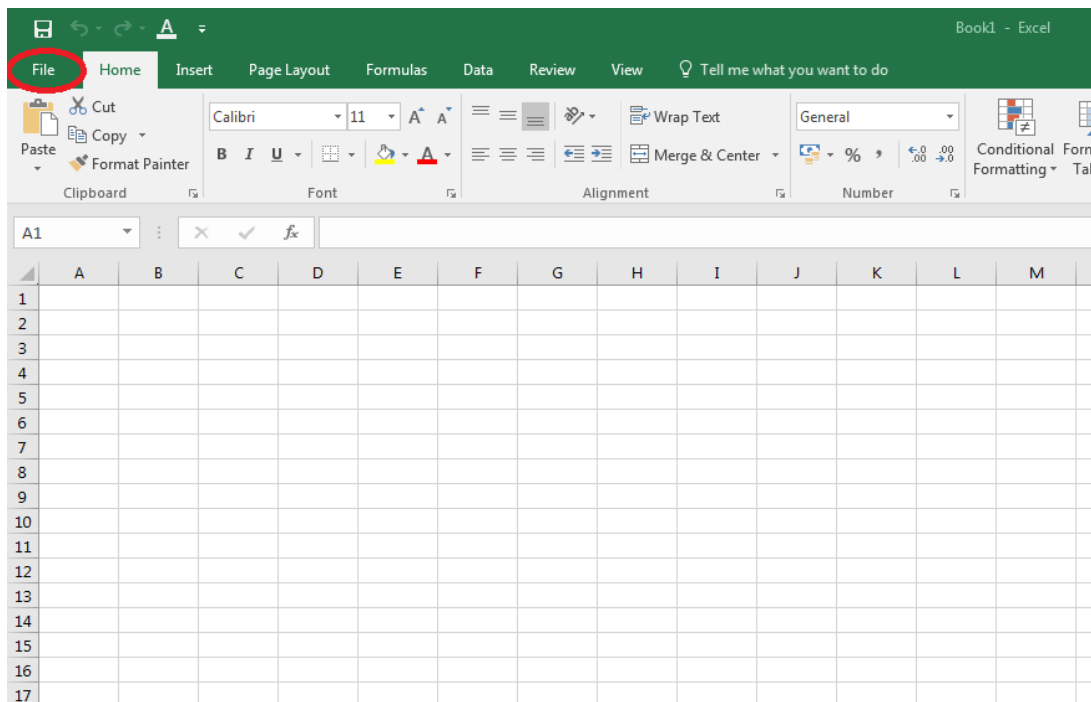


Figure 2.1: Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on the "Options" button in the menu which appears (see Fig. 2.2)

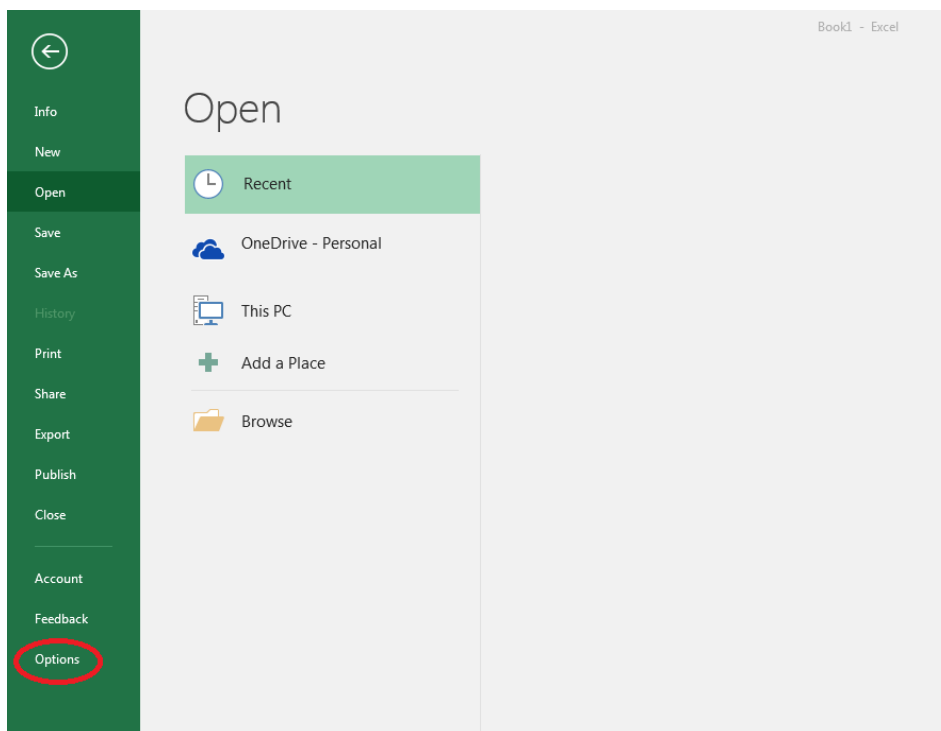


Figure 2.2: Registering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Fig. 2.3)

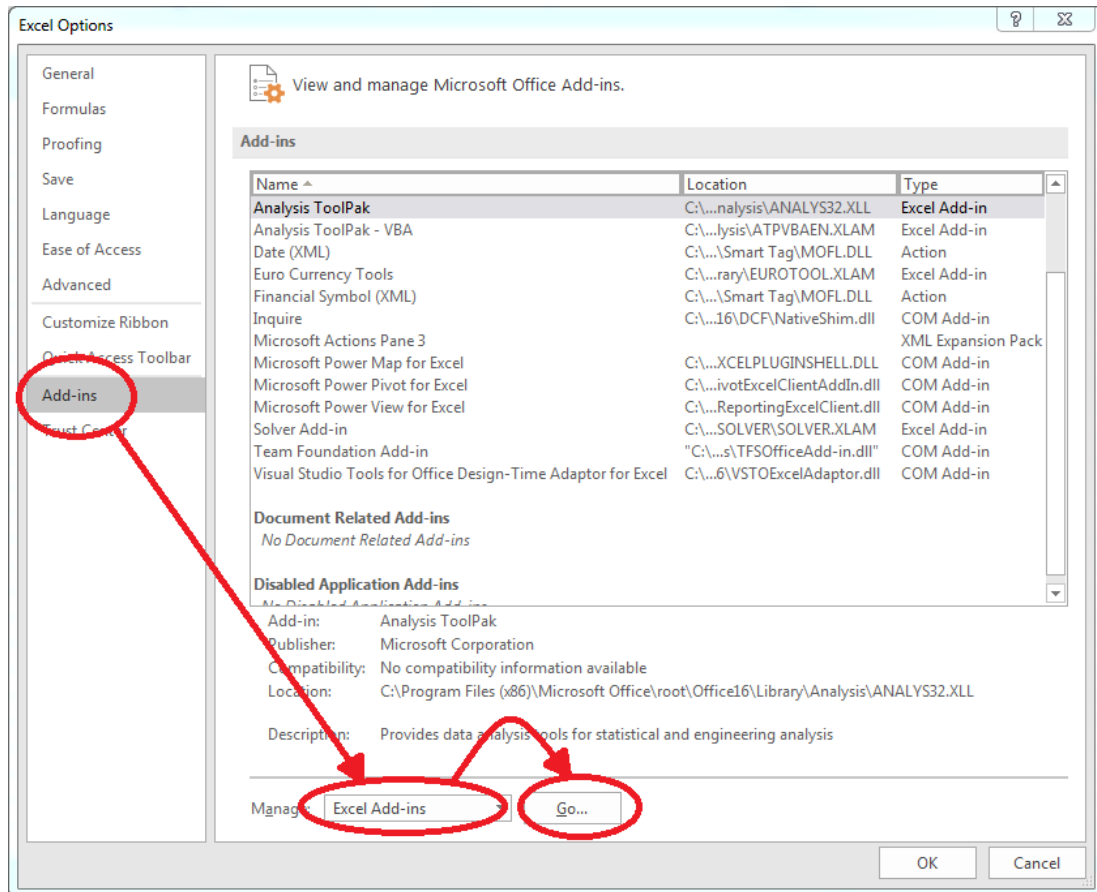


Figure 2.3: Dialog window "Excel Options"

- Select "Excel Add-ins" next to "Manage:" in the lower area of the menu
- Then click the "Go..." button
- Click "Browse" in the following window (Fig. 2.4)

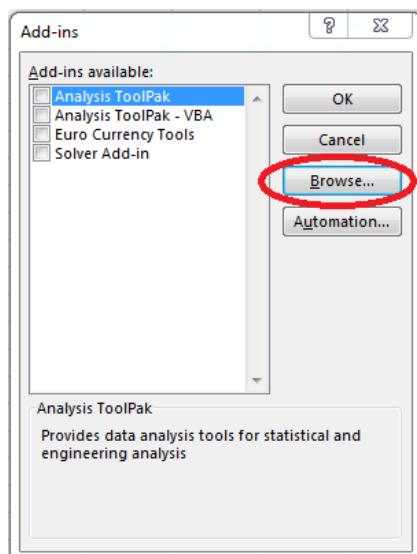


Figure 2.4: Dialog window "Add-ins"

- Excel opens the AddIns folder. This is usually
C:\Users\[your name]\AppData\Roaming\Microsoft\AddIns\.
- If the FluidEXL files have already been copied to this directory in section 2.1, please skip the following indented section. If not, follow the indented instructions to successful paste the needed files for the FluidEXL Add-In:

In the upper part of the "Browse" window the correct Add-In path is displayed (see Figure 2.5). Please note that not the entire path is displayed.

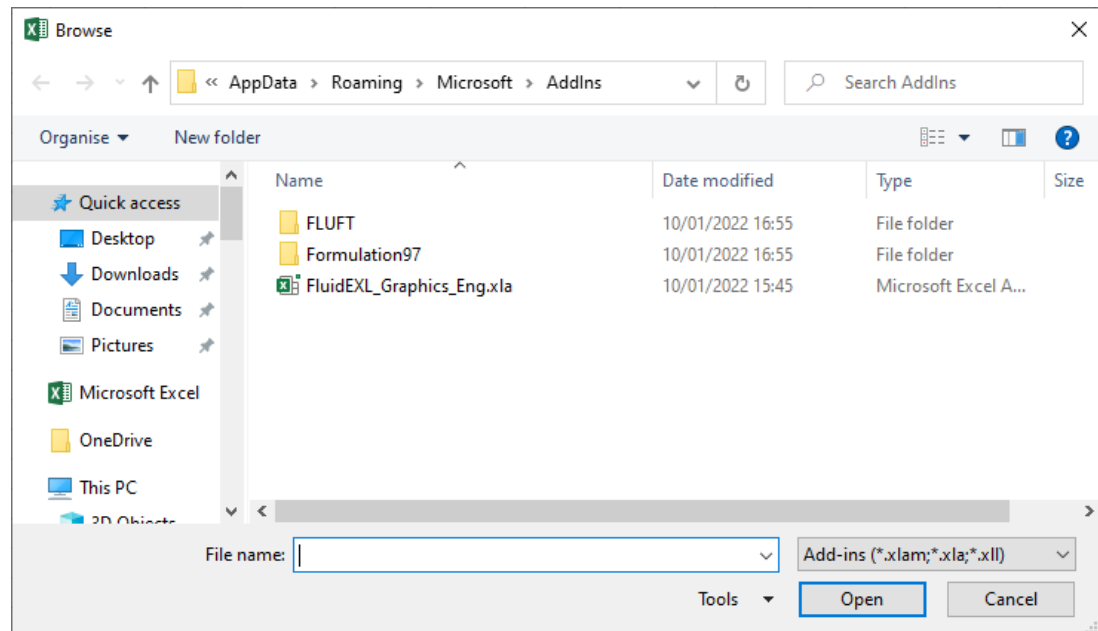


Figure 2.5: "Browse"-Window

Please copy this path and paste it into your file manager.

Now, please copy the following directories and files:

\FLUFT\
 \Formulation97\
 LC.dll
 FluidEXL_Graphics_Eng.xla
 LibIF97IT.dll
 LibIF97IT.chm

from the delivered CD-folder into this folder.

- Click "FluidEXL_Graphics_Eng.xla" in this folder (see Fig. 2.5) and click "OK."
- Now, "FluidEXL Graphics Eng" will be shown in the list of Add-ins (see Fig. 2.6).
(If a checkmark is in the box next to the name "FluidEXL Graphics Eng", this Add-In will automatically be loaded whenever Excel starts. This will continue to occur unless the checkmark is removed from the box by clicking on it.)
- In order to register the Add-In click the "OK" button in the "Add-ins" window (see Fig. 2.6).

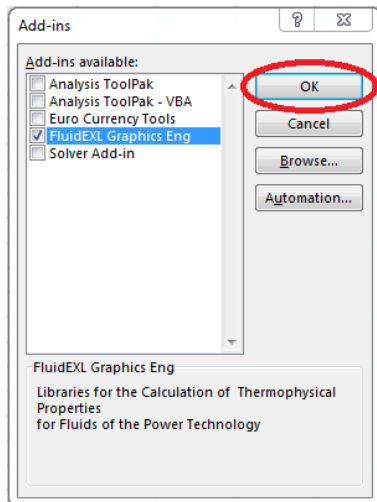


Figure 2.6: Dialog window "Add-Ins"

In order to use FluidEXL *Graphics* in the following example, click on the menu item "Add-Ins" shown in Fig. 2.7.

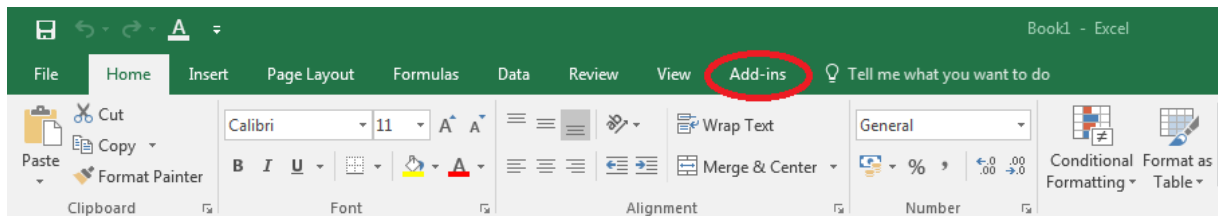


Figure 2.7: Menu item "Add-Ins"

In the upper menu region of Excel®, the FluidEXL *Graphics* menu bar will appear as marked with the red circle in Fig. 2.8.

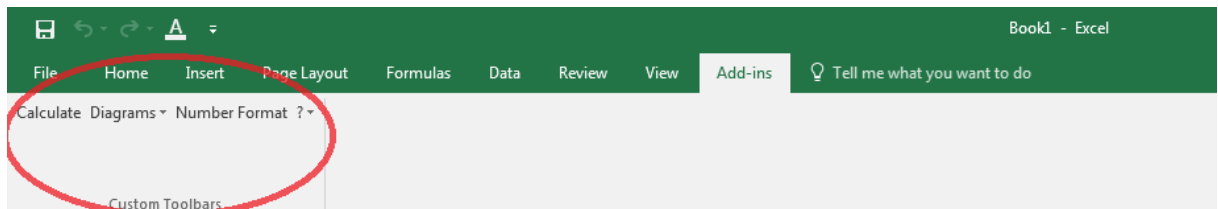


Figure 2.8: FluidEXL *Graphics* menu bar

The Installation of FluidEXL *Graphics* in Excel® is now complete.

An example calculation of "LibIF97IT" DLL library property functions can be found in chapter 2.4.

2.3 Licensing the LibIF97IT Property LibIF97ITrary

The licensing procedure has to be carried out when Excel® starts up and a FluidEXL *Graphics* prompt message appears. In this case, you will see the "License Information" window (see figure below).

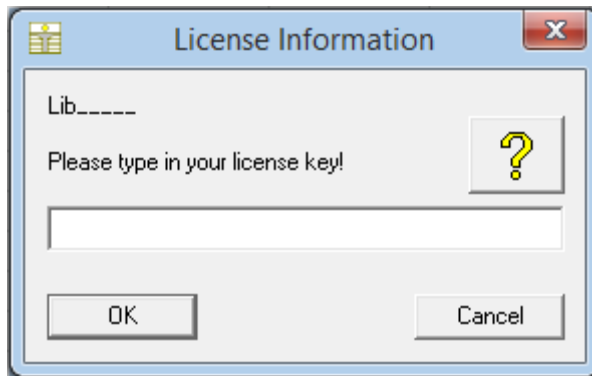


Figure 2.12: "License Information" window

Here you will have to type in the license key. You can find contact information on the "Content" page of this User's Guide or by clicking the yellow question mark in the "License Information" window. Then the following window will appear:

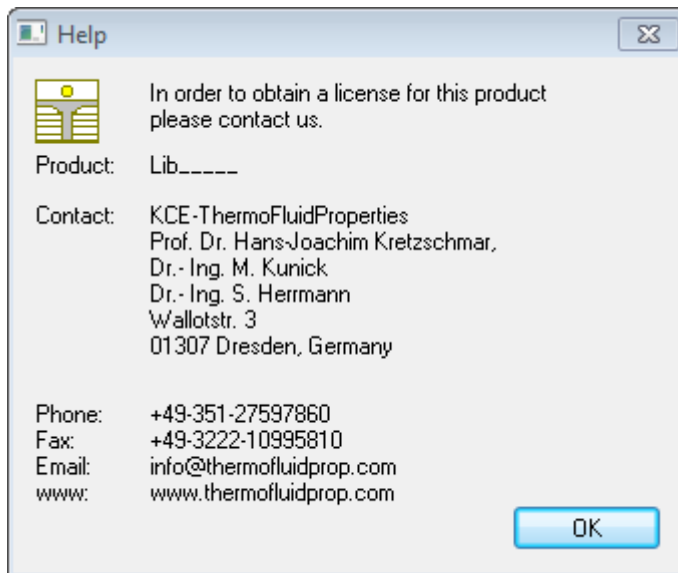


Figure 2.13: "Help" window

If you do not enter a valid license it is still possible to start Excel® by clicking "Cancel" twice. In this case, the LibIF97IT property library will display the result "-11111111" for every calculation.

The "License Information" window will appear every time you start Excel® unless you uninstall FluidEXL_{Graphics} according to the description in section 2.6 of this User's Guide.

Should you not wish to license the LibIF97IT property library, you have to delete the files
LibIF97IT.dll
LibIF97IT.chm

in the installation folder of FluidEXL_{Graphics} (the standard being)

C:\Program Files\FluidEXL_Graphics_Eng
using an appropriate program such as Explorer® or Norton Commander.

Note:

The product name "LibIF97IT____" in Figure 2.12 and 2.13 stands for the LibIF97IT_{Trary} you are installing. In this case it is the LibIF97IT library.

2.4 Example calculation

Now we will calculate, step by step, the specific enthalpy h as a function of pressure p and temperature t , using FluidEXL *Graphics*.

- Start Excel®
- Enter a value for p in bar in a cell
(Range of validity of the IF97_META: $p = 0.00611 \dots 1000$ bar
 $p = 0.00611 \dots 500$ bar for high temperature region)
- ⇒ e. g.: Enter the value 1 into cell A2
- Enter a value for t in °C in a cell
(Range of validity of the IF97: $t = t_{\min} \dots 800$ °C
high temperature region up to 2000 °C)
- ⇒ e. g.: Enter the value 80 into cell B2
- Click the cell in which the enthalpy h in kJ/kg is to be displayed.
⇒ e.g.: Click the C2 cell.
- Click "Calculate" in the menu bar of FluidEXL *Graphics*.
Now the "Insert Function" window appears (see next figure).

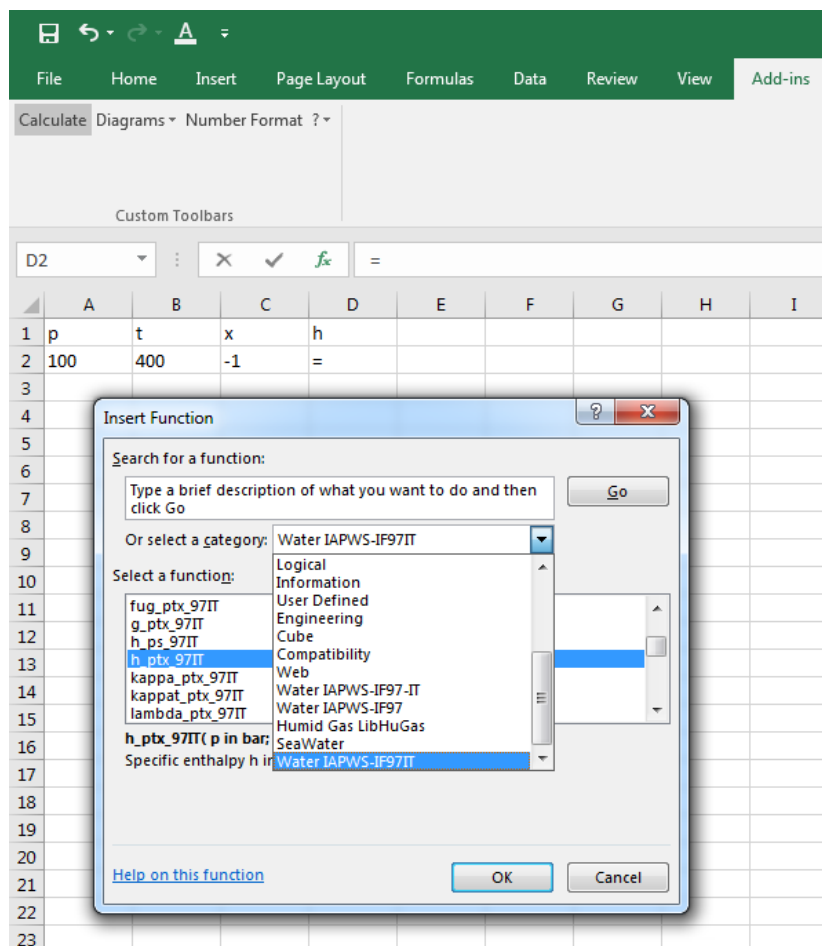


Figure 2.14: Choice of library and function name

- Search and click the "Metastable Water IAPWS-IF97" library under "Or select a category:" in the upper part of the window.
- Search and click the h_{pt_97META} function under "Select a function:" right below.

Here it is possible to get more information on the range of validity, measuring units, error responses, etc. by clicking the "Help on this function" button.

- Click "OK".

The window shown in the next figure will now appear.

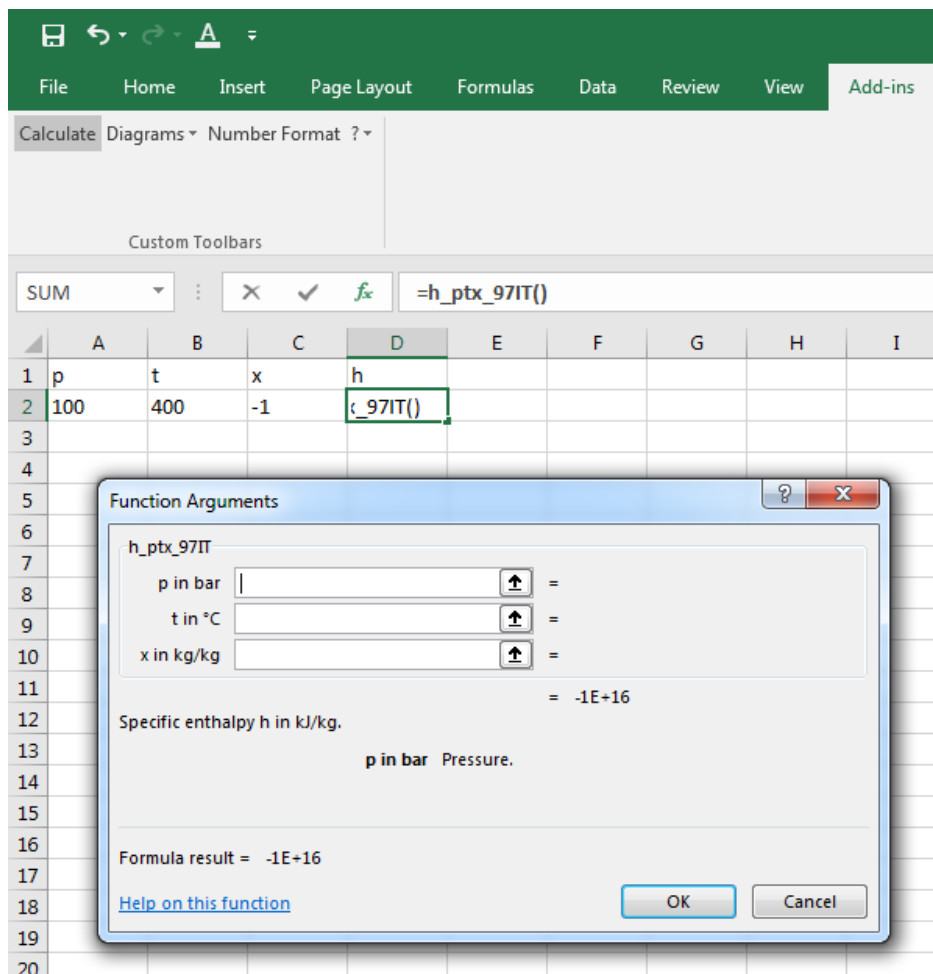


Figure 2.15: Input menu for the function

- The Cursor is now situated on the line next to "p in bar". You can now enter the value for p either by clicking the cell with the value for p , by entering the name of the cell with the value for p , or by entering the value for p directly.

⇒ e. g.: Click on the cell A2

- Situate the cursor next to "t in °C" and enter the value for t by clicking the cell with the value for t , by entering the name of the cell with the value for t , or by entering the value for t directly.

⇒ e. g.: Type B2 into the window next to "t in °C"

The window should now look like the following figure:

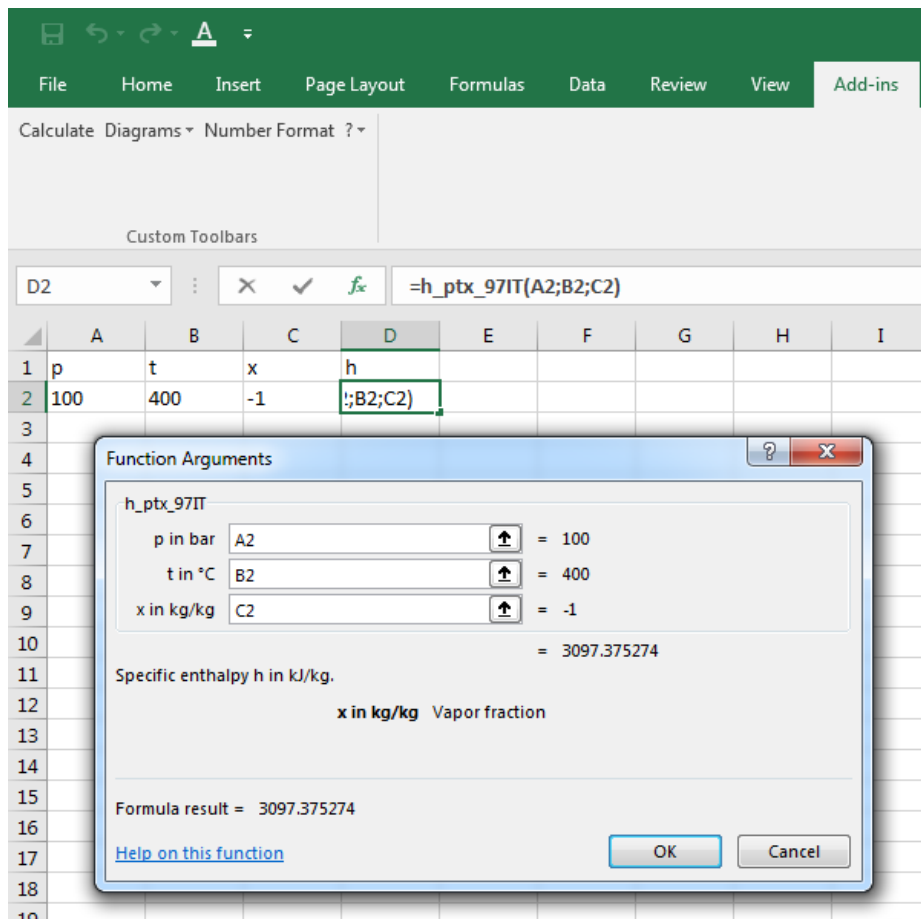


Figure 2.16: Input menu showing the result

- Click the "OK" button.

The result for h in kJ/kg appears in the cell selected above.

⇒ The result in our sample calculation here is: $h = 2632.878321$ in kJ/kg.

The calculation of $h = f(p, t)$ has thus been completed. You can now arbitrarily change the values for p or T in the appropriate cells. The specific enthalpy is recalculated and updated every time you change the data. This shows that the Excel® data flow and the DLL calculations are working together successfully.

Note:

If the calculation results in -1 , this indicates that the values entered are located outside the range of validity of LibIF97ITIT_META. More detailed information on each function and its range of validity is available in Chapter 3.

For further property functions calculable in FluidEXL *Graphics*, see the function table in Chapter 1.

Number Formats

When using FluidEXL *Graphics* you have the option of choosing special number formats in advance.

Changes can be made as follows:

- Click the cell or select and click on the cells you wish to format.
(In empty cells the new format will be applied once a value has been entered.)
- Click "Number Format" in the FluidEXL *Graphics* menu bar.
- Select the desired number format in the dialog box which appears:
 - "STD – Standard": Insignificant zeros behind the decimal point are not shown.
 - "FIX – Fixed Number of Digits": All set decimal places are shown, including insignificant zeros.
 - "SCI – Scientific Format": Numbers are always shown in the exponential form with the set number of decimal places.
- Set the "Number of decimal places" by entering the number into the appropriate window.
- Confirm this by clicking the "OK" button.

As an example, the table below shows the three formats for the number 1.230 adjusted for three decimal places:

STD	1.23
FIX	1.230
SCI	1.230E+00

This formatting can also be applied to cells which have already been calculated.

2.5 Representation of Calculated Properties in Thermodynamic Diagrams

In the following section, the calculated state point is to be represented in thermodynamic diagrams with the help of FluidEXL *Graphics*. Calculations can be represented in the following diagrams:

T - s Diagram
h - s Diagram
$lg\ p$ - h Diagram
$lg\ p$ - $lg\ v$ Diagram
$lg\ p$ - T Diagram
p - T Diagram
T - h Diagram
T - $lg\ v$ Diagram
$lg\ p$ - s Diagram
h - $lg\ v$ Diagram
s - $lg\ v$ Diagram

In order to represent the calculated values in a T - s diagram, for example, the temperature and specific entropy values for the point to be represented must be marked.

- Click on the cell with the value for t (as t is the ordinate in the diagram).
⇒ [Click cell B2 in our example.](#)

Hold down the "Ctrl" key and simultaneously click the cell with the value for s (as s is the abscissa in the diagram). Release the "Ctrl" key.

Note:

The value pairs to be depicted (Y,X), here (t,s), must always be located in the same row or column.

⇒ [For this example, hold down the "Ctrl" key and click the cell E2.](#)

- As displayed in the next figure, click "Diagrams" in the FluidEXL *Graphics* menu bar and choose "T,s-Diagram" in the drop-down menu.

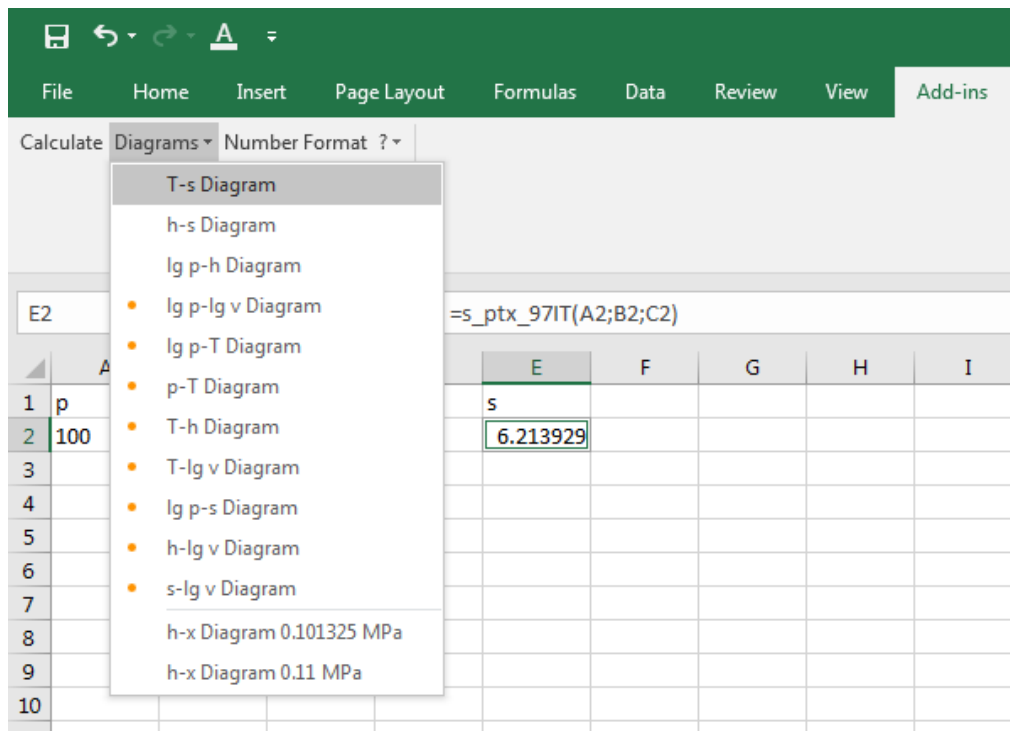


Figure 2.18: Marking the values and choice of the diagram

The T - s diagram shown in the figure below will appear. The calculated state point is marked as a red point.

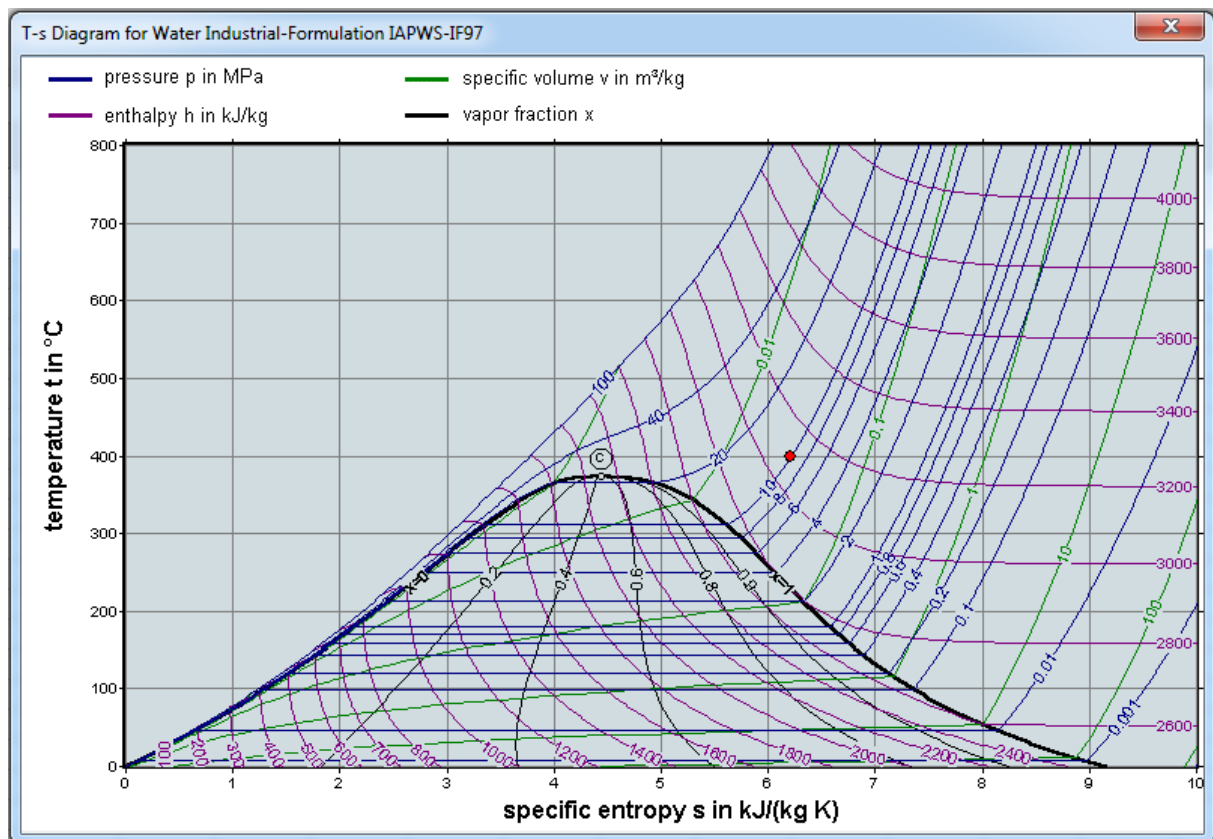


Figure 2.19: T - s Diagram including the state point

Proceed in the same way if you wish to represent values in the h - s diagram:

- Click the cell with the value for h .
⇒ Click the cell D2 for the example.
- Hold down the "Ctrl" key and simultaneously click on the cell with the value for s . Release the "Ctrl" key.
⇒ For this example, click the E2 cell while holding down the "Ctrl" key.
- Click "Diagrams" in the menu bar of FluidEXL *Graphics*, and click " h - s diagram" in the menu which appears.
In the h - s diagram then displayed, the state point is marked in red.

If the calculated state point should be represented in the $lg\ p$ - h diagram, mark the value of p first and then mark the value of h . Then proceed as above.

Note – Diagrams with various state points:

If you calculate various state points, they can be represented in one selected diagram. To do this, first mark with the cursor those values which are to represent the values of y in the diagram. Afterwards, hold down the "Ctrl" key and mark the corresponding values which are to represent the values of x in the diagram. Note once more that all value pairs which should be represented (Y,X) must be located in one row in Excel®. Proceed as described above.

Note – Diagrams without any state points:

If you wish to have a look at a diagram without performing a calculation, mark two empty cells located in one row, and select a diagram.

Printing Diagrams

The state diagrams can be printed with the help of Word® which also belongs to the Office suite®.

- When the selected diagram is on the screen, hold down the "Alt" key and press the "Print" key briefly.
(This keyboard shortcut copies the current window, e.g., the diagram, into the Windows clipboard where it is ready to be pasted into other Windows® application programs.)
- Start Word by clicking "Start" in the Windows task bar, then "Programs", and then "Microsoft Word".
- As the diagram is to be printed in landscape format, change the (now loaded) Word application window into the landscape format.
In order to do so, click "File" in the upper menu bar of Word, and then "Page Setup". Click "Margins" in the window which now appears, then "Landscape". Confirm this change by clicking "OK".
- In order to paste the diagram out of the Windows clipboard, click "Edit" in the upper menu bar of Word, and then "Paste".
The diagram out of FluidEXL *Graphics* appears in the Word application window and is ready to save and/or print.
- Start the printing process by clicking "File" in the upper menu bar of Word, and then "Print". Proceed as usual in the "Print" window which appears.

The diagram will be printed in the A4 landscape format, if you do not change the preferences.

In order to continue working in Excel, click "Microsoft Excel - ..." in the Windows task bar.

Proceed in the same way to print further diagrams.

2.6 The FluidEXL *Graphics* Help System

As mentioned earlier, FluidEXL *Graphics* also provides detailed help functions.

Information on individual property functions may be accessed via the following steps:

- Click "Calculate" in the FluidEXL *Graphics* menu bar.
- Click on the "LibIF97IT" library under "Or select a category:" in the "Insert Function" window which will appear.
- Click the "Help on this function" button in the lower left-hand edge of the "Insert Function" window.

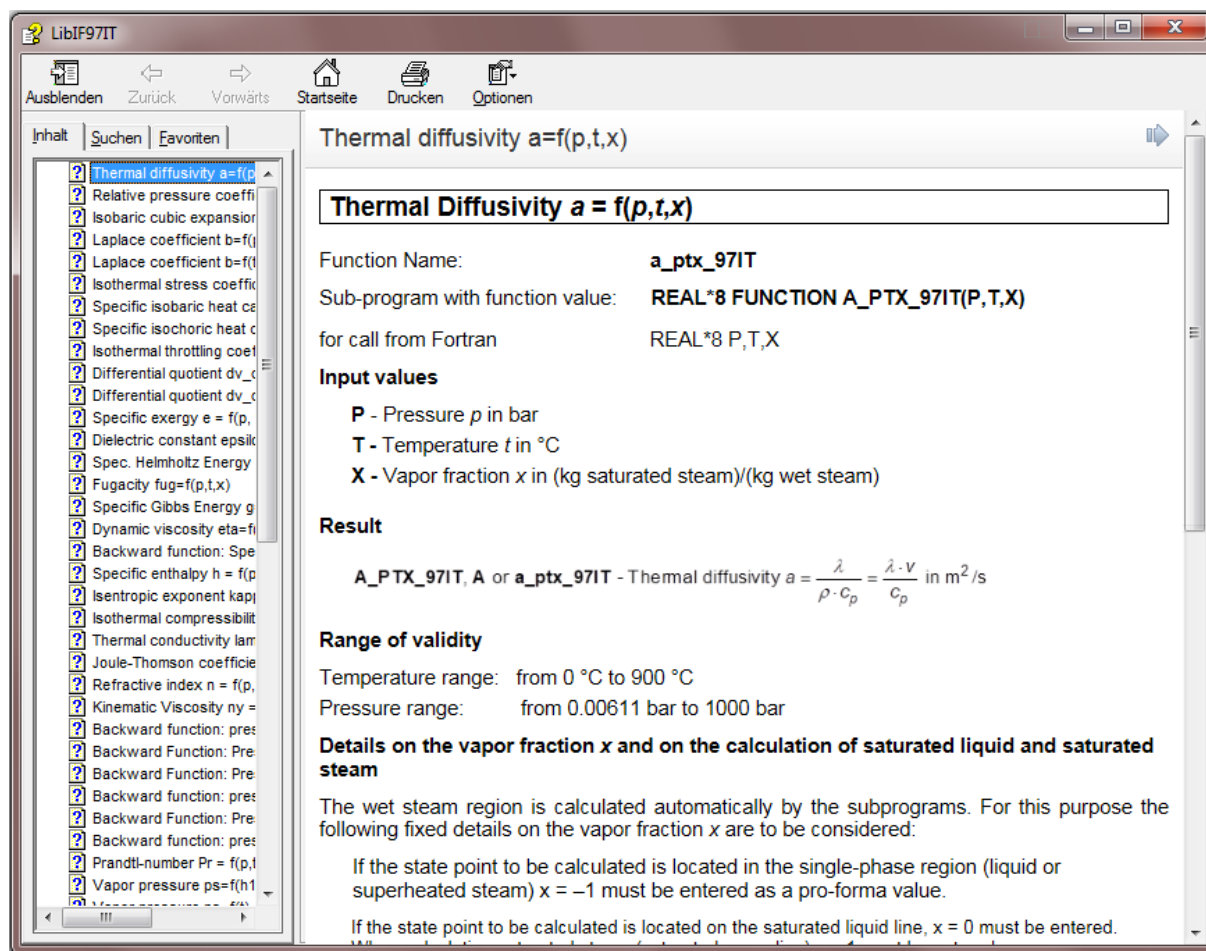


Figure 2.17: Help Window

If the LibIF97IT.chm function help cannot be found, you will be redirected to a Microsoft® help website by your standard browser. In this case, the LibIF97IT.chm file has to be copied into the folder of FluidEXL *Graphics*, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng

to use the help system.

2.7 Removing FluidEXLGraphics

2.7.1 Removing LibIF97ITIT Library

Should you wish to remove only the LibIF97ITIT library, delete the files

LibIF97ITIT.dll

LibIF97ITIT.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

C:\Program Files\FluidEXL_Graphics_Eng

by using an appropriate program such as Explorer® or Norton Commander.

2.7.2 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in versions of Excel® from 2007 onwards (for earlier versions see 2.6.3)

In order to unregister the FluidEXL *Graphics* Add-In in versions of Excel® from 2007 onwards start Excel® and carry out the following commands:

- Click the "File" button in the upper left corner of Excel®
- Click on the "Options" button in the menu which appears

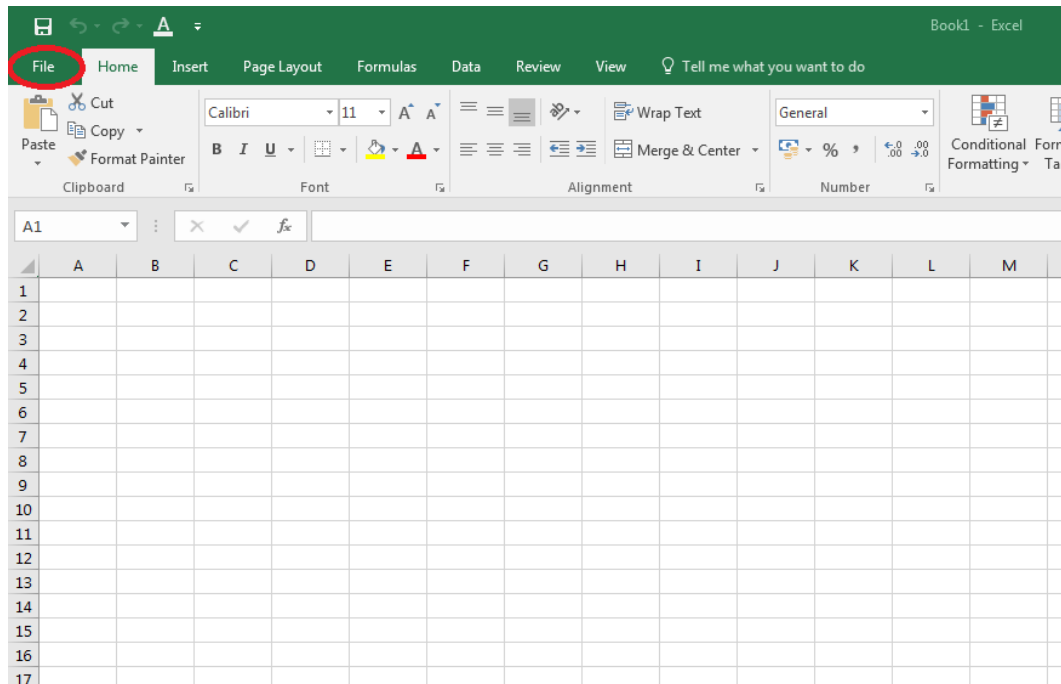


Figure 2.18: Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016

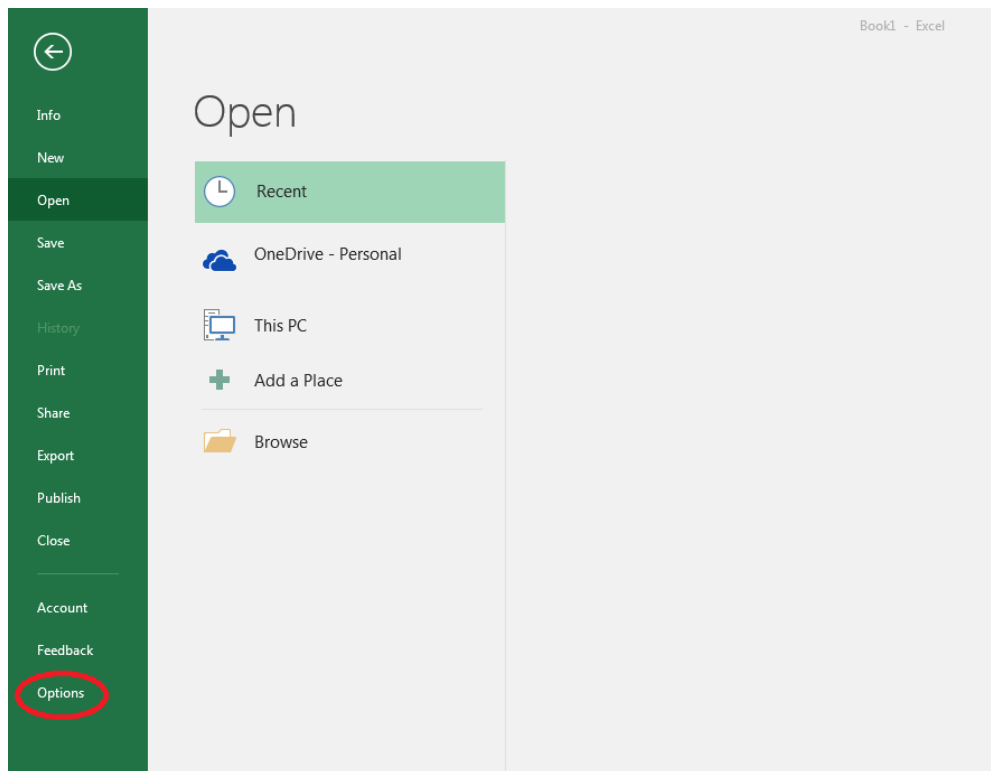


Figure 2.19 Unregistering FluidEXL *Graphics* as Add-In in Excel® 2016

- Click on "Add-Ins" in the next menu (Figure 2.20)

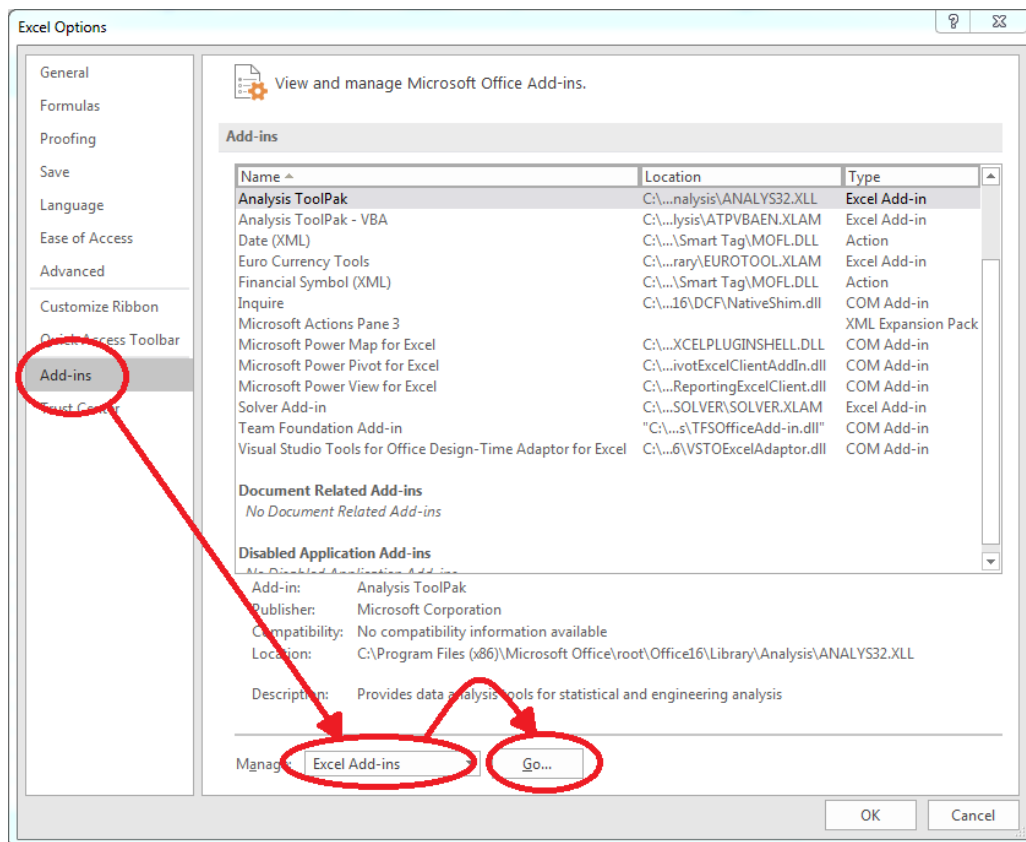


Figure 2.20: Dialog window "Add-Ins"

- If it is not shown in the list automatically, chose and click "Excel Add-ins" next to "Manage:" in the lower area of the menu

- Afterwards click the "Go..." button
- Remove the checkmark in front of "FluidEXL Graphics Eng" in the window which now appears. Click the "OK" button to confirm your entry.

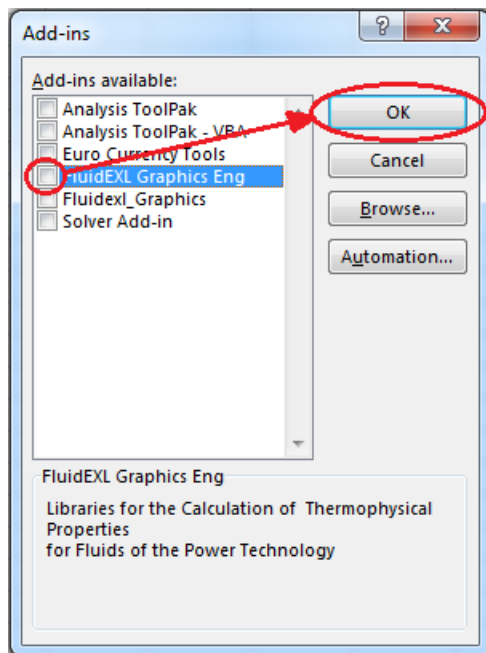


Figure 2.21: Dialog window "Add-Ins"

In order to remove FluidEXL *Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel."

Now, double click on "Add or Remove Programs."

In the list box of the "Add or Remove Programs" window that appears, select "FluidEXL Graphics Eng"

by clicking on it and then clicking the "Add/Remove..." button.

Click "Automatic" in the following dialog box and then the "Next >" button.

Click "Finish" in the "Perform Uninstall" window.

Answer the question of whether all shared components should be removed with "Yes to All." Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* has been completely removed from your computer.

2.7.3 Unregistering and uninstalling FluidEXL *Graphics* as Add-In in Excel®, versions 2003 or earlier

To remove FluidEXL *Graphics* completely, proceed as follows: First the registration of FluidEXL_Graphics_Eng.xla has to be cancelled in Excel®.

In order to do this, click "Tools" in the upper menu bar of Excel® and here "Add-Ins...". Untick the box on the left-hand side of

"FluidEXL Graphics Eng"

in the window that appears and click the "OK" button. The additional menu bar of FluidEXL *Graphics* disappears from the upper part of the Excel® window. Afterwards, we

recommend closing Excel®.

If the FluidEXL *Graphics* menu bar does not disappear, take the following steps:

Click "View" in the upper menu bar of Excel®, then "Toolbars" and then "Customize..." in the list box which appears.

"FluidEXL Graphics Eng"

is situated at the bottom of the "Toolbars" entries, which must be selected by clicking on it. Delete the entry by clicking "Delete". You will be asked whether you really want to delete the toolbar – click "OK".

Within the next step delete the files

LibIF97ITIT.dll

LibIF97ITIT.chm

in the directory selected for the installation of FluidEXL *Graphics*, in the standard case,

C:\Program Files\FuildEXL_Graphics_Eng

using an appropriate program such as Explorer® or Norton Commander.

In order to remove FluidEXL *Graphics* from Windows and the hard drive, click "Start" in the Windows task bar, select "Settings" and click "Control Panel". Now double-click on "Add or Remove Programs". In the list box of the "Add/Remove Programs" window that appears select

"FluidEXL Graphics Eng"

by clicking on it and click the "Add/Remove..." button. In the following dialog box, click "Automatic" and then "Next >". Click "Finish" in the "Perform Uninstall" window. Answer the question whether all shared components shall be removed with "Yes to All". Finally, close the "Add/Remove Programs" and "Control Panel" windows.

Now FluidEXL *Graphics* has been removed.

3. Program Documentation

Thermal Diffusivity $a = f(p, t, x)$

Function Name: **a_ptx_97IT**

Sub-program with function value: **REAL*8 FUNCTION A_PTX_97IT(P,T,X)**
for call from Fortran **REAL*8 P,T,X**

Input values

- P** - Pressure p in bar
- T** - Temperature t in °C
- X** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

A_PTX_97IT, A or a_ptx_97IT - Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p} = \frac{\lambda \cdot v}{c_p}$ in m²/s

Range of validity

- Temperature range: from 0 °C to 900 °C
- Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.
The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

- Temperature ranges from $t_l = 0$ °C to $t_c = 373.946$ °C
- Pressure ranges from $p_l = 0.00611$ bar to $p_c = 220.64$ bar)

Results for wrong input values

Result **A_PTX_97IT, A = -1E16** or **a_ptx_97IT = -1E16** for input values:

- Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or $t > 900$ °C or $t < 0$ °C
($x = -1$)
- Saturation lines: at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or
($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64$ bar
or $p < 0.00611$ bar or at $p > 220.64$ bar or $p < 0.00611$ bar
and $t > 373.946$ °C or $t < 0$ °C
or $|t - t_s(p)| > 0.1$ K

References:

Internal calculation from ρ or v and c_p [1], [2], [3] and λ [6]

Relative Pressure Coefficient $\alpha_p = f(p, t, x)$

Function Name: **alphap_ptx_97IT**

Sub-program with function value: **REAL*8 FUNCTION ALPHAP_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

- P** - Pressure p in bar
- T** - Temperature t in °C
- X** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ALPHAP_PTX_97IT, **ALPHAP** or **alphap_ptx_97IT** - Relative pressure coefficient α_p in K^{-1}

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **ALPHAP_PTX_97IT**, **ALPHAP** = **-1E16** or **alphap_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 800\text{ °C}$ or $t < 0\text{ °C}$
 Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$
 or $p < 0.00611\text{ bar}$ or at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 or $|t - t_s(p)| > 0.1\text{ K}$

References:

Internal calculation from ρ or v and c_p [1], [2], [3] and λ [6]

Isobaric Cubic Expansion Coefficient $\alpha_v = f(p, t, x)$

Function Name: **alphav_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION ALPHAV_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ALPHAV_PTX_97IT, ALPHAV or alphav_ptx_97IT - Isobaric cubic expansion coefficient α_v in K^{-1}

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **ALPHAV_PTX_97IT, ALPHAV = -1E16 or alphav_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Laplace Coefficient $b = f(p)$

Function Name: **b_p_97IT**
 Sub-program with function value: **REAL*8 FUNCTION B_P_97IT(P)**
 for call from Fortran **REAL*8 P**

Input values

P - Pressure p in bar

Result

B_PTX_97IT, **B** or **b_pt_97IT** - Laplace coefficient b in m

Range of validity

Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **B_P_97IT**, **B** = **-1E16** or **b_p_97IT** = **-1E16** for input values:

Saturation lines: at $p > 220.64$ bar or $p < 0.00611$ bar

References: [1], [2], [3]

Laplace Coefficient $b = f(t)$

Function Name: **b_t_97IT**
 Sub-program with function value: **REAL*8 FUNCTION B_T_97IT(T)**
 for call from Fortran **REAL*8 T**

Input values

T - Temperature t in °C

Result

B_T_97IT, **B** or **b_t_97IT** - Laplace coefficient b in m

Range of validity

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Results for wrong input values

Result **B_T_97IT**, **B** = **-1E16** or **b_t_97IT** = **-1E16** for input values:

Saturation lines: $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$

References: [1], [2], [3]

Isothermal Stress Coefficient $\beta_p = f(p, t, x)$

Function Name: **betap_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION BETAP_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

BETAP_PTX_97IT, **BETAP** or **betap_ptx_97IT** - Isothermal stress coefficient β_p in kg/m³

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **BETAP_PTX_97IT**, **BETAP** = **-1E16** or **betap_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Specific Isobaric Heat Capacity $c_p = f(p, t, x)$

Function Name: **cp_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION CP_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CP_PTX_97IT, **CP** or **cp_ptx_97IT** - Specific isobaric heat capacity c_p in kJ/kg K

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **CP_PTX_97IT**, **CP** = **-1E16** or **cp_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Specific Isochoric Heat Capacity $c_v = f(p, t, x)$

Function Name: **cv_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION CV_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

CV_PTX_97IT, **CV** or **cv_ptx_97IT** - Specific isochoric heat capacity c_v in kJ/kg K

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **CV_PTX_97IT**, **CV** = **-1E16** or **cv_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Isothermal Throttling Coefficient $\delta_T = f(p, t, x)$

Function Name: **deltat_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION DELTAT_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

DELTAT_PTX_97IT, DELTAT or **deltat_ptx_97IT** - Isothermal throttling coefficient δ_T in $\text{kJ kg}^{-1} \text{kPa}^{-1}$

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **DELTAT_PTX_97IT, DELTAT = -1E16** or **deltat_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Differential Quotient $\left(\frac{\partial v}{\partial p}\right)_T = f(p, t, x)$

Function Name: **dv_dp_T_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION DVDP_T_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

DVDP_T_PTX_97IT - Differential quotient $\left(\frac{\partial v}{\partial p}\right)_T$ in $\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{kPa}^{-1}$

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **dv_dp_T_ptx_97IT** or **DVDP_T_PTX_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Differential Quotient $\left(\frac{\partial v}{\partial T}\right)_p = f(p, t, x)$

Function Name: **dv_dT_p_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION DVDT_P_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

DVDT_P_PTX_97IT - Differential quotient $\left(\frac{\partial v}{\partial T}\right)_p$ in $\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **dv_dT_p_ptx_97IT** or **DVDT_P_PTX_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Specific Exergy $e = f(p, t, x, t_u)$

Function Name: **e_ptxtu_97IT**
 Sub-program with function value: **REAL*8 FUNCTION E_PTXTU_97IT(P,T,X,TU)**
 for call from Fortran **REAL*8 P,T,X,TU**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)
TU - Environment temperature t_u in °C

Result

E_PTXTU_97IT, **E** or **e_ptx_tu_97IT** - Specific exergy (of the enthalpy) e in kJ/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_t = 0$ °C ... $t_c = 373.946$ °C
 $p_t = 0.00611$ bar ... $p_c = 220.64$ bar)

Results for wrong input values

Result **E_PTXTU_97IT**, **E** = **-1E16** or **e_ptxtu_97IT** = **-1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 ($x = -1$) $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64$ bar or $p < 0.00611$ bar or
 at $p > 220.64$ bar or $p < 0.00611$ bar
 and $t > 373.946$ °C or $t < 0$ °C
 at $|t - t_s(p)| > 0.1$ K

References: [1], [2], [3]

Dielectric Constant $\varepsilon = f(p, t, x)$

Function Name: **epsilon_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION EPS_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

EPS_PTX_97IT, **EPS** or **epsilon_ptx_97IT** - Dielectric constant ε

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **EPS_PTX_97IT**, **EPS** = **-1E16** or **epsilon_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Specific Helmholtz Energy $f = f(p, t, x)$

Function Name: **f_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION F_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

F_PTX_97IT, **F** or **f_ptx_97IT** - Specific Helmholtz energy f in kJ/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **F_PTX_97IT**, **F** = **-1E16** or **f_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Fugacity $f^* = f(p, t, x)$

Function Name: **fug_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION FUG_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

FUG_PTX_97IT, FUG or fug_ptx_97IT - Fugacity f^* in bar

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **FUG_PTX_97IT, FUG = -1E16 or fug_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Specific Gibbs Energy $g = f(p, t, x)$

Function Name: **g_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION G_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

G_PTX_97IT, G or **g_ptx_97IT** - Specific Gibbs energy g in kJ/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **G_PTX_97IT, G = -1E16** or **g_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Dynamic Viscosity $\eta = f(p, t, x)$

Function Name: **eta_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION ETA_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

ETA_PTX_97IT, **ETA** or **eta_ptx_97IT** - Dynamic viscosity η in Pa s

Range of validity

Temperature range: from 0 °C to 900 °C
 Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **ETA_PTX_97IT**, **ETA** = **-1E16** or **eta_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 900\text{ °C}$ or $t < 0\text{ °C}$
 Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References:

[7], internal calculation from ρ or v [1], [2], [3]

Backward Function: Specific Enthalpy $h = f(p,s)$

Function Name: **h_ps_97IT**
 Sub-program with function value: **REAL*8 FUNCTION H_PS_97IT(P,S)**
 for call from Fortran **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/kg K

Result

H_PS_97IT, H or **h_ps_97IT** - Specific enthalpy h in kJ/kg

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Entropy range: according to temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to entropy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of h in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **H_PS_97IT, H = -1E16** or **h_ps_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Specific Enthalpy $h = f(p, t, x)$

Function Name: **h_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION H_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

H_PTX_97IT, **H** or **h_ptx_97IT** - Specific enthalpy h in kJ/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **H_PTX_97IT**, **H** = **-1E16** or **h_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$
 Wet steam region: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Isentropic Exponent $\kappa = f(p, t, x)$

Function Name: **kappa_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION KAPPA_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

KAPPA_PTX_97IT, **KAPPA** or **kappa_ptx_97IT** - Isentropic exponent $\kappa = -\frac{v}{p} \left(\frac{\partial p}{\partial v} \right)_s = \frac{w^2}{p \cdot v}$

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0$ °C to $t_c = 373.946$ °C

Pressure ranges from $p_l = 0.00611$ bar to $p_c = 220.64$ bar)

Results for wrong input values

Result **KAPPA_PTX_97IT**, **KAPPA** = **-1E16** or **kappa_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 ($x = -1$) $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Saturation lines: at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64$ bar or $p < 0.00611$ bar or
 at $p > 220.64$ bar or $p < 0.00611$ bar
 and $t > 373.946$ °C or $t < 0$ °C
 at $|t - t_s(p)| > 0.1$ K

References: [1], [2], [3]

Isothermal Compressibility $\kappa_T = f(p, t, x)$

Function Name: **kappat_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION KAPPAT_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

KAPPAT_PTX_97IT, KAPPAT or kappat_ptx_97IT - Isothermal compressibility κ_T in kPa^{-1}

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **KAPPAT_PTX_97IT, KAPPAT = -1E16 or kappat_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Thermal Conductivity $\lambda = f(p, t, x)$

Function Name: **lambda_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION LAMBDA_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

LAMBDA_PTX_97IT, **LAM** or **lambda_ptx_97IT** - Thermal conductivity λ in W/m·K

Range of validity

Temperature range: from 0 °C to 900 °C
 Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **LAMBDA_PTX_97IT**, **LAMBDA = -1E16** or **lambda_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 900\text{ °C}$ or $t < 0\text{ °C}$
 Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References:

[6], Internal calculation from ρ or v [1], [2], [3]

Joule-Thomson Coefficient $\mu = f(p, t, x)$

Function Name: **my_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION MY_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

MY_PTX_97IT, MY or my_ptx_97IT - Joule-Thomson coefficient μ in K kPa⁻¹

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **MY_PTX_97IT, MY = -1E16** or **my_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Refractive Index $n = f(p, t, x, w)$

Function Name: **n_ptxwl_97IT**
 Sub-program with function value: **REAL*8 FUNCTION N_PTXWL_97IT(P,T,X,WL)**
 for call from Fortran **REAL*8 P,T,X,WL**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)
WL - Wavelength w in μm

Result

N_PTXWL_97IT, N or **n_ptxwl_97** - Refractive index n

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar
 Wavelength region: from 0.2 μm to 1.1 μm

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **N_PTXWL_97IT, N = -1E16** or **n_ptxwl_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Kinematic Viscosity $\nu = f(p, t, x)$

Function Name: **ny_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION NY_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

NY_PTX_97IT, **NY** or **ny_ptx_97IT** - Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot \nu$ in m^2 / s

Range of validity

Temperature range: from 0 °C to 900 °C
 Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0 \text{ °C}$ to $t_c = 373.946 \text{ °C}$
 Pressure ranges from $p_l = 0.00611 \text{ bar}$ to $p_c = 220.64 \text{ bar}$)

Results for wrong input values

Result **NY_PTX_97IT**, **NY** = **-1E16** or **ny_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000 \text{ bar}$ or $p < 0.00611 \text{ bar}$ or
 ($x = -1$) $t > 900 \text{ °C}$ or $t < 0 \text{ °C}$

Saturation lines: at $p = -1$ and $t > 373.946 \text{ °C}$ or $t < 0 \text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64 \text{ bar}$ or $p < 0.00611 \text{ bar}$ or
 at $p > 220.64 \text{ bar}$ or $p < 0.00611 \text{ bar}$
 and $t > 373.946 \text{ °C}$ or $t < 0 \text{ °C}$
 at $|t - t_s(p)| > 0.1 \text{ K}$

References:

Internal calculation from η [7] and ρ or ν [1], [2], [3]

Backward Function: Pressure $p = f(h,s)$

Function Name: **p_hs_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_HS_97IT(H,S)**
 for call from Fortran **REAL*8 H,S**

Input values

H - Specific enthalpy h in kJ/kg
S - Specific entropy s in kJ/kg K

Result

P_HS_97IT, p or **p_hs_97IT** - Pressure p in bar

Range of validity

Enthalpy range and entropy range according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of h and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_HS_97IT, P = -1E16** or **p_hs_97IT = -1E16** for input values:

$s < -0.009$ kJ/kg K

$h < h'(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Pressure $p = f(t, h)$

Function Name: **p_th_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_TH_97IT(T,H,ISOL)**
 for call from Fortran **REAL*8 T,H**
INTEGER*4 ISOL

Input values

T – Temperature in °C
H - Specific enthalpy h in kJ/kg
ISOL - Solution

Result

P_TH_97IT, p or **p_th_97IT** - Pressure p in bar

Range of validity

Temperature range: from 0 °C to 800 °C
 Enthalpy range and entropy range: according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C
 High temperature region: to 2000 °C at pressures to 500 bar
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C
 Solution: For this backward equation 1 or 2 has to be entered, because there
 are two solutions possible.

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_TH_97IT, P = -1E16** or **p_hs_97IT = -1E16** for input values:

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$
 $t > 2000 \text{ °C}$ or $t < 0 \text{ °C}$ or
 $t > 800 \text{ °C}$ at $p > 500 \text{ bar}$
 $ISOL$ is not 1 or 2

References: [1], [2], [3]

Backward Function: Pressure $p = f(t, v)$

Function Name: **p_tv_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_TV_97IT(T,V)**
 for call from Fortran **REAL*8 T,V**

Input values

T – Temperature in °C
V - Specific volume v in m³/kg

Result

P_TV_97IT, p or **p_tv_97IT** - Pressure p in bar

Range of validity

Temperature range: from 0 °C to 800 °C
 Specific volume range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and v the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_TV_97IT, P = -1E16** or **p_tv_97IT = -1E16** for input values:

$t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar
 $v < 0.0009$ m³/kg

References: [1], [2], [3]

Backward Function: Pressure $p = f(v, h)$

Function Name: **p_vh_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_VH_97IT(V,H)**
 for call from Fortran **REAL*8 V,H**

Input values

V - Specific volume v in m^3/kg

H - Specific enthalpy h in kJ/kg

Result

P_VH_97IT, p or **p_vh_97IT** - Pressure p in bar

Range of validity

Enthalpy range and entropy range: according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_VH_97IT, P = -1E16** or **p_vh_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Pressure $p = f(v,s)$

Function Name: **p_vs_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_VS_97IT(V,S)**
 for call from Fortran **REAL*8 V,S**

Input values

V - Specific volume v in m^3/kg
S - Specific entropy s in kJ/kg K

Result

P_VS_97IT, p or **p_vs_97IT** - Pressure p in bar

Range of validity

Specific volume range and entropy range according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_VS_97IT, P = -1E16** or **p_vs_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$
 $s < s(0.00611 \text{ bar}, x)$ at $s'(0.00611 \text{ bar}) < h < s''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Pressure $p = f(v, u)$

Function Name: **p_vu_97IT**
 Sub-program with function value: **REAL*8 FUNCTION P_VU_97IT(V,U)**
 for call from Fortran **REAL*8 V,U**

Input values

V - Specific volume h in kJ/kg
U - Specific internal energy u in kJ/kg

Result

P_VU_97IT, p or **p_vu_97IT** - Pressure p in bar

Range of validity

Specific volume and internal energy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and u the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **P_VU_97IT, P = -1E16** or **p_vu_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$
 $u < u(0.00611 \text{ bar}, x)$ at $u'(0.00611 \text{ bar}) < u < u''(0.00611 \text{ bar})$

References: [1], [2], [3]

Prandtl-Number $Pr = f(p, t, x)$

Function Name: **Pr_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION PR_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

PR_PTX_97IT, Pr or Pr_ptx_97IT - Prandtl-number $Pr = \frac{\nu}{a} = \frac{\eta \cdot c_p}{\lambda}$

Range of validity

Temperature range: from 0 °C to 900 °C
 Pressure range: from 0.00611 bar to 1000 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$
 Pressure ranges from $p_t = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **PR_PTX_97IT, Pr = -1E16 or Pr_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 900\text{ °C}$ or $t < 0\text{ °C}$
 Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References:

Internal calculation of η [7], [6], and ρ or ν and c_p [1], [2], [3]

Vapor Pressure $p_s = f(h_1)$

Function Name: **ps_h1_97IT**
 Sub-program with function value: **REAL*8 FUNCTION PS_H1_97IT(T)**
 for call from Fortran **REAL*8 T**

Input values

H1 - Temperature t in °C

Result

PS_H1_97IT, **PS** or **ps_h1_97IT** - Vapor pressure p_s in bar

Range of validity

Enthalpy range according temperatures from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Results for wrong input values

Result **PS_H1_97IT**, **PS** = **-1E16** or **ps_h1_97IT** = **-1E16** for input values:
 $t < 0\text{ °C}$ or $t > 373.946\text{ °C}$

References: [1], [2], [3]

Vapor Pressure $p_s = f(t)$

Function Name: **ps_t_97IT**
 Sub-program with function value: **REAL*8 FUNCTION PS_T_97IT(T)**
 for call from Fortran **REAL*8 T**

Input values

T - Temperature t in °C

Result

PS_T_97IT, PS or **ps_t_97IT** - Vapor pressure p_s in bar

Range of validity

from $t_t = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Results for wrong input values

Result **PS_T_97IT, PS = -1E16** or **ps_t_97IT = -1E16** for input values:
 $t < 0\text{ °C}$ or $t > 373.946\text{ °C}$

References: [1], [2], [3]

Density $\rho = f(p, t, x)$

Function Name: **rho_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION RHO_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

RHO_PTX_97IT, RHO or **rho_ptx_97IT** - Density $\rho = \frac{1}{v}$ in kg/m³

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **RHO_PTX_97IT, RHO = -1E16** or **rho_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Wet steam region: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Backward Function: Specific Entropy $s = f(p, h)$

Function Name: **s_ph_97IT**
 Sub-program with function value: **REAL*8 FUNCTION S_PH_97IT(P,H)**
 for call from Fortran **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

S_PH_97IT, S or **s_ph_97IT** - Specific entropy s in kJ/kg K

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Enthalpy range: according temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to enthalpy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of s in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **S_PH_97IT, S = -1E16** or **s_ph_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Specific Entropy $s = f(p, t, x)$

Function Name: **s_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION S_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

S_PTX_97IT, **S** or **s_ptx_97IT** - Specific entropy s in kJ/kg K

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **S_PTX_97IT**, **S** = **-1E16** or **s_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$
 Wet steam region: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Surface Tension $\sigma = f(p)$

Function Name: **sigma_p_97IT**
 Sub-program with function value: **REAL*8 FUNCTION SIGMA_P_97IT(P)**
 for call from Fortran **REAL*8 P**

Input values

P - Pressure p in bar

Result

SIGMA_P_97IT, SIGMA or **sigma_p_97IT** - Surface tension σ in mN/m = mPa · m

Range of validity

from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **SIGMA_P_97IT, SIGMA = -1E16** or **sigma_p_97IT = -1E16** for input values:
 $p < 0.00611$ bar or $p > 220.64$ bar

References:

[8], internal calculation with $t_s = f(p)$ [1], [2], [3]

Surface Tension $\sigma = f(t)$

Function Name: **sigma_t_97IT**
 Sub-program with function value: **REAL*8 FUNCTION SIGMA_T_97IT(T)**
 for call from Fortran **REAL*8 T**

Input values

T - Temperature t in °C

Result

SIGMA_T_97IT, **SIGMA** or **sigma_t_97** - Surface tension σ in mN/m = mPa · m

Range of validity

from $t_l = 0$ °C to $t_c = 373.946$ °C

Results for wrong input values

Result **SIGMA_T_97IT**, **SIGMA** = **-1E16** or **sigma_t_97IT** = **-1E16** for input values:
 $t < 0$ °C or $t > 373.946$ °C

References: [8]

Backward Function: Temperature $t = f(h,s)$

Function Name: **t_hs_97IT**

Sub-program with function value: **REAL*8 FUNCTION T_HS_97IT(H,S)**
 for call from Fortran **REAL*8 H,S**

Input values

H - Specific enthalpy h in kJ/kg

S - Specific entropy s in kJ/kg K

Result

T_HS_97IT, T or **t_hs_97IT** - Temperature t in °C

Range of validity

Enthalpy range and entropy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of h and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Results for wrong input values

Result **T_HS_97IT, T = -1E16** or **t_hs_97IT = -1E16** for input values:

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

$s < -0.009 \text{ kJ/kg K}$

References: [1], [2], [3]

Backward Function: Temperature $t = f(p, h)$

Function Name: **t_ph_97IT**
 Sub-program with function value: **REAL*8 FUNCTION T_PH_97IT(P,H)**
 for call from Fortran **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

T_PH_97IT, T or **t_ph_97IT** - Temperature t in °C

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Enthalpy range: according temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to enthalpy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **T_PH_97IT, T = -1E16** or **t_ph_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Backward Function: Temperature $t = f(p,s)$

Function Name: **t_ps_97IT**
 Sub-program with function value: **REAL*8 FUNCTION T_PS_97IT(P,S)**
 for call from Fortran **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/kg K

Result

T_PS_97IT, T or **t_ps_97IT** - Temperature t in °C

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Entropy range: according temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to entropy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **T_PS_97IT, T = -1E16** or **t_ps_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Backward Function: Temperature $t = f(p, v)$

Function Name: **t_pv_97IT**
 Sub-program with function value: **REAL*8 FUNCTION T_PV_97IT(P,V,ISOL)**
 for call from Fortran **REAL*8 P,V**
INTEGER*4 ISOL

Input values

P – Pressure in bar
V - Specific volume v in m^3/kg
ISOL - Solution

Result

T_PV_97IT, **t** or **t_pv_97IT** - Pressure p in bar

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Specific volume rang: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C
 Solution: For this backward equation 1 or 2 has to be entered, because there are two solutions possible.

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and v the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **T_PV_97IT**, **T = -1E16** or **t_pv_97IT = -1E16** for input values:

$p > 1000$ bar or $p < 0.00611$ bar or
 $p > 500$ bar at $t > 800$ °C
 $v < 0.0009$ m^3/kg
 $ISOL$ is not 1 or 2

References: [1], [2], [3]

Backward Function: Temperature $t = f(v, h)$

Function Name: **t_vh_97IT**

Sub-program with function value: **REAL*8 FUNCTION T_VH_97IT(V,H)**
 for call from Fortran **REAL*8 V,H**

Input values

V - Specific volume v in m^3/kg

H - Specific enthalpy h in kJ/kg

Result

T_VH_97IT, T or **t_vh_97IT** - Temperature t in $^{\circ}\text{C}$

Range of validity

Pressure range: from 0.00611 bar to 1000 bar

Enthalpy range: according temperatures from 0°C to 800°C

High temperature region: to 500 bar and to enthalpy regarding 2000°C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **T_VH_97IT, T = -1E16** or **t_vh_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$

$h < h'(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Temperature $t = f(v,s)$

Function Name: **t_vs_97IT**

Sub-program with function value: **REAL*8 FUNCTION T_VS_97IT(V,S)**
 for call from Fortran **REAL*8 V,S**

Input values

V - Specific volume v in m^3/kg

S - Specific entropie s in $\text{kJ}/(\text{kg K})$

Result

T_VS_97IT, T or **t_vs_97IT** - Temperature t in $^{\circ}\text{C}$

Range of validity

Pressure range: from 0.00611 bar to 1000 bar

Entropy range: according temperatures from 0°C to 800°C

High temperature region: to 500 bar and to enthalpy regarding 2000°C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611 \text{ bar}$ to $p_c = 220.64 \text{ bar}$

Results for wrong input values

Result **T_VS_97IT, T = -1E16** or **t_vs_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$

$s < s(0.00611 \text{ bar}, x)$ at $s'(0.00611 \text{ bar}) < s < s''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Temperature $t = f(v, u)$

Function Name: **t_vu_97IT**
 Sub-program with function value: **REAL*8 FUNCTION T_VU_97IT(V,U)**
 for call from Fortran **REAL*8 V,U**

Input values

V - Specific volume v in m^3/kg
U - Specific internal energy u in kJ/kg

Result

T_VU_97IT, T or **t_vu_97IT** - Temperature t in $^{\circ}\text{C}$

Range of validity

Specific volume and internal energy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0°C to 800°C
 High temperature region: according to pressures to 500 bar and temperatures to 2000°C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and u the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of t in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **T_VU_97IT, T = -1E16** or **t_vu_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$
 $u < u'(0.00611 \text{ bar}, x)$ at $u'(0.00611 \text{ bar}) < u < u''(0.00611 \text{ bar})$

References: [1], [2], [3]

Saturation Temperature $t_s = f(p)$

Function Name: **ts_p_97IT**
 Sub-program with function value: **REAL*8 FUNCTION TS_P_97IT(P)**
 for call from Fortran **REAL*8 P**

Input values

P - Pressure p in bar

Result

TS_P_97IT, T or **ts_p_97IT** - Saturation temperature t_s in °C

Range of validity

from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **TS_P_97IT, T = -1E16** or **ts_p_97IT = -1E16** for input values:
 $p < 0.00611$ bar or $p > 220.64$ bar

References: [1], [2], [3]

Specific Internal Energy $u = f(p, t, x)$

Function Name: **u_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION U_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

U_PTX_97IT, U or **u_ptx_97IT** - Specific internal energy u in kJ/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **U_PTX_97IT, U = -1E16** or **u_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Wet steam region: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Backward Function: Specific Volume $v = f(h,s)$

Function Name: **v_hs_97IT**
 Sub-program with function value: **REAL*8 FUNCTION V_HS_97IT(H,S)**
 for call from Fortran **REAL*8 H,S**

Input values

H - Specific enthalpy h in kJ/kg
S - Specific entropie s in kJ/(kg K)

Result

V_HS_97IT, V or **v_hs_97IT** - Specific volume v in m³/kg

Range of validity

Enthalpy range: according to temperatures from 0 °C to 800 °C
 Entropie range: according to temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to enthalpy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of h and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of v in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **V_HS_97IT, V = -1E16** or **v_hs_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Backward Function: Specific Volume $v = f(p, h)$

Function Name: **v_ph_97IT**
 Sub-program with function value: **REAL*8 FUNCTION V_PH_97IT(P,H)**
 for call from Fortran **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

V_PH_97IT, V or **v_ph_97IT** - Specific volume v in m³/kg

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Enthalpy range: according to temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to enthalpy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of v in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **V_PH_97IT, V = -1E16** or **v_ph_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Backward Function: Specific Volume $v = f(p,s)$

Function Name: **v_ps_97IT**
 Sub-program with function value: **REAL*8 FUNCTION V_PS_97IT(P,S)**
 for call from Fortran **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/kg K

Result

V_PS_97IT, V or **v_ps_97IT** - Specific volume v in m³/kg

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Entropy range: according to temperatures from 0 °C to 800 °C
 High temperature region: to 500 bar and to entropy regarding 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of v in the appropriate region will be carried out.

Wet steam region: Pressure ranges from $p_t = 0.00611$ bar to $p_c = 220.64$ bar

Results for wrong input values

Result **V_PS_97IT, V = -1E16** or **v_ps_97IT = -1E16** for input values:

Single phase region: $p > 1000$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 2000$ °C or $t < 0$ °C or
 $t > 800$ °C at $p > 500$ bar

Wet steam region: $p > 220.64$ bar or $p < 0.00611$ bar or
 at internal calculation result $t > 373.946$ °C or $t < 0$ °C

References: [1], [2], [3]

Specific Volume $v = f(p, t, x)$

Function Name: **v_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION V_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

V_PTX_97IT, V or **v_ptx_97IT** - Specific volume v in m³/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 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:

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.

If the state point to be calculated is located in the wet steam region, a value for x between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) must be entered.

When calculating wet steam either the given value for t and $p = -1$ or the given value for p and $t = -1$ and in both cases the value for x between 0 and 1 must be entered.

If p and t and x are entered as given values, the program considers p and t to be appropriate to represent the vapor pressure curve.

(Wet steam region of the IAPWS-IF97: $t_l = 0\text{ °C} \dots t_c = 373.946\text{ °C}$
 $p_l = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **V_PTX_97IT, V = -1E16** or **v_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Wet steam region: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($0 \leq x \leq 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Backward Function: Specific volume $v = f(t, h)$

Function Name: **v_th_97IT**
 Sub-program with function value: **REAL*8 FUNCTION V_TH_97IT(T,H,ISOL)**
 for call from Fortran **REAL*8 T,H**
INTEGER*4 ISOL

Input values

T – Temperature in °C
H - Specific enthalpy h in kJ/kg
ISOL - Solution

Result

V_TH_97IT, **v** or **v_th_97IT** – Specific volume in m³/kg

Range of validity

Temperature range: from 0 °C to 800 °C
 Enthalpy range and entropy range: according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C
 High temperature region: to 2000 °C at pressures to 500 bar
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C
 Solution: For this backward equation 1 or 2 has to be entered, because there
 are two solutions possible.

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **V_TH_97IT**, **V** = **-1E16** or **v_hs_97IT** = **-1E16** for input values:

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$
 $t > 2000 \text{ °C}$ or $t < 0 \text{ °C}$ or
 $t > 800 \text{ °C}$ at $p > 500 \text{ bar}$
 $ISOL$ is not 1 or 2

References: [1], [2], [3]

Isentropic Speed of Sound $w = f(p, t, x)$

Function Name: **w_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION W_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

W_PTX_97IT, W or w_ptx_97IT - Isentropic speed of sound w in m/s

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **W_PTX_97IT, W = -1E16** or **w_ptx_97IT = -1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(h,s)$

Function Name: **x_hs_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_HS_97IT(H,S)**
 for call from Fortran **REAL*8 H,S**

Input values

H - Specific enthalpy h in kJ/kg
S - Specific entropy s in kJ/kg K

Result

X_HS_97IT, X or **x_hs_97IT** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Enthalpy range and entropy range according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C

High temperature region: according pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of h and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Results for wrong input values

Result **X_HS_97IT, X = -1E16** or **x_hs_97IT = -1E16** for input values:

$s < -0.009$ kJ/kg K

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

if the state point is located in the single phase region

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(p, h)$

Function Name: **x_ph_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_PH_97IT(P,H)**
 for call from Fortran **REAL*8 P,H**

Input values

P - Pressure p in bar
H - Specific enthalpy h in kJ/kg

Result

X_PH_97IT, X or **x_ph_97IT** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Pressure range: from 0.00611 bar to 1000 bar

Enthalpy range: according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C

High temperature region: according pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Results for wrong input values

Result **X_PH_97IT, X = -1E16** or **x_ph_97IT = -1E16** for input values:
 if the state point is located in the single phase region
 $p > 220.64$ bar or $p < 0.00611$ bar

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(p, v)$

Function Name: **x_pv_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_PV_97IT(P,V,ISOL)**
 for call from Fortran **REAL*8 T,H**
INTEGER*4 ISOL

Input values

P – Pressure in bar
V - Specific volume v in m^3/kg
ISOL - Solution

Result

X_PV_97IT, **x** or **x_pv_97IT** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Pressure range: from 0.00611 bar to 1000 bar
 Specific volume rang: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C
 Solution: For this backward equation 1 or 2 has to be entered, because there are two solutions possible.

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and v the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **X_PV_97IT**, **X** = **-1E16** or **x_pv_97IT** = **-1E16** for input values:

$p > 1000 \text{ bar}$ or $p < 0.00611 \text{ bar}$ or
 $p > 500 \text{ bar}$ at $t > 800 \text{ °C}$
 $v < 0.0009 \text{ m}^3/\text{kg}$
 $ISOL$ is not 1 or 2

References: [1], [2], [3]

Backward Function: Vapor fraction $x = f(t, h)$

Function Name: **x_th_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_TH_97IT(T,H)**
 for call from Fortran **REAL*8 T,H**
INTEGER*4 ISOL

Input values

T – Temperature in °C
H - Specific enthalpy h in kJ/kg
ISOL - Solution

Result

X_TH_97IT, **x** or **x_th_97IT** – Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature range: from 0 °C to 800 °C
 Enthalpy range and entropy range: according to pressures from 0.00611 bar to 1000 bar and
 Temperatures from 0 °C to 800 °C
 High temperature region: to 2000 °C at pressures to 500 bar
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C
 Solution: For this backward equation 1 or 2 has to be entered, because there
 are two solutions possible.

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **X_TH_97IT**, **X** = **-1E16** or **x_hs_97IT** = **-1E16** for input values:

$h < h(0.00611 \text{ bar}, x)$ at $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$
 $t > 2000 \text{ °C}$ or $t < 0 \text{ °C}$ or
 $t > 800 \text{ °C}$ at $p > 500 \text{ bar}$
 $ISOL$ is not 1 or 2

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(t, v)$

Function Name: **x_tv_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_TV_97IT(T,V)**
 for call from Fortran **REAL*8 T,V**

Input values

T – Temperature in °C
V - Specific volume v in m^3/kg

Result

X_TV_97IT, x or x_tv_97IT - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Temperature range: from 0 °C to 800 °C
 Specific volume rang: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C
 High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of t and v the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **X_TV_97IT, X = -1E16** or **x_tv_97IT = -1E16** for input values:

$t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$
 $v < 0.0009\text{ m}^3/\text{kg}$

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(v, h)$

Function Name: **x_vh_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_VH_97IT(V,H)**
 for call from Fortran **REAL*8 V,H**

Input values

V - Specific volume v in m^3/kg

H - Specific enthalpy h in kJ/kg

Result

X_VH_97IT, X or **x_vh_97IT** - Vapor fraction x in $(\text{kg saturated steam})/(\text{kg wet steam})$

Range of validity

Enthalpy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and h the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Results for wrong input values

Result **X_VH_97IT, X = -1E16** or **x_vh_97IT = -1E16** for input values:

if the state point is located in the single phase region

$p > 220.64 \text{ bar}$ or $p < 0.00611 \text{ bar}$

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(v, s)$

Function Name: **x_vs_97IT**

Sub-program with function value: **REAL*8 FUNCTION X_VS_97IT(V,S)**
 for call from Fortran **REAL*8 V,S**

Input values

V - Specific volume v in m^3/kg

S - Specific entropy s in kJ/kg K

Result

X_VS_97IT, **x** or **x_vs_97IT** - Vapor fraction x in $(\text{kg saturated steam})/(\text{kg wet steam})$

Range of validity

Specific volume range and entropy range according to pressures from 0.00611 bar to 1000 bar and Temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. Afterwards the calculation of p in the appropriate region will be carried out.

Results for wrong input values

Result **X_VS_97IT**, **X = -1E16** or **x_vs_97IT = -1E16** for input values:

$v < 0.0009 \text{ m}^3/\text{kg}$

$s < s(0.00611 \text{ bar}, x)$ at $s'(0.00611 \text{ bar}) < s < s''(0.00611 \text{ bar})$

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(v, u)$

Function Name: **x_vu_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_VU_97IT(V,U)**
 for call from Fortran **REAL*8 V,U**

Input values

V - Specific volume v in m^3/kg
U - Specific internal energy u in kJ/kg

Result

X_VU_97IT, X or **x_vu_97IT** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Enthalpy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C

High temperature region: according to pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of v and u the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Results for wrong input values

Result **X_VU_97IT, X = -1E16** or **x_vu_97IT = -1E16** for input values:
 if the state point is located in the single phase region
 $p > 220.64 \text{ bar}$ or $p < 0.00611 \text{ bar}$

References: [1], [2], [3]

Backward Function: Vapor Fraction $x = f(p,s)$

Function Name: **x_ps_97IT**
 Sub-program with function value: **REAL*8 FUNCTION X_PS_97IT(P,S)**
 for call from Fortran **REAL*8 P,S**

Input values

P - Pressure p in bar
S - Specific entropy s in kJ/kg K

Result

X_PS_97IT, X or **x_ps_97IT** - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Range of validity

Pressure range: from 0.00611 bar to 1000 bar

Entropy range: according to pressures from 0.00611 bar to 1000 bar and temperatures from 0 °C to 800 °C

High temperature region: according pressures to 500 bar and temperatures to 2000 °C

Details on the calculation of wet steam

The wet steam region is calculated automatically. This means that from the given values of p and s the function will determine whether the state point to be calculated is located within the single-phase region (liquid or steam) or the wet steam region. When calculating wet steam the value for x between 0 and 1 is calculated (0 for saturated liquid, 1 for saturated steam). If the state point to be calculated is located in the single-phase region the result $x = -1$ will be returned.

Results for wrong input values

Result **X_PS_97IT, X = -1E16** or **x_ps_97IT = -1E16** for input values:

if the state point is located in the single phase region

$p > 220.64$ bar or $p < 0.00611$ bar

References: [1], [2], [3]

Compression Factor $z = f(p, t, x)$

Function Name: **z_ptx_97IT**
 Sub-program with function value: **REAL*8 FUNCTION Z_PTX_97IT(P,T,X)**
 for call from Fortran **REAL*8 P,T,X**

Input values

P - Pressure p in bar
T - Temperature t in °C
X - Vapor fraction x in (kg saturated steam)/(kg wet steam)

Result

Z_PTX_97IT, **Z** or **z_ptx_97IT** - Compression factor z

Range of validity

Temperature range: from 0 °C to 800 °C
 Pressure range: from 0.00611 bar to 1000 bar
 High temperature region: to 2000 °C at pressures to 500 bar

Details on the vapor fraction x and on the calculation of saturated liquid and saturated 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:

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.

If the state point to be calculated is located on the saturated liquid line, $x = 0$ must be entered. When calculating saturated steam (saturated vapor line) $x = 1$ must be entered.

The calculation for x -values between 0 and 1 is not possible.

When calculating saturated liquid or saturated steam, it is adequate to enter either the given value for t and $p = -1$, or the given value for p and $t = -1$, plus the value for x ($x = 0$ or $x = 1$). If p and t and x are entered as given values, the program will consider p and t to be appropriate to represent the vapor pressure curve.

(Saturated liquid and saturated vapor line:

Temperature ranges from $t_l = 0\text{ °C}$ to $t_c = 373.946\text{ °C}$

Pressure ranges from $p_l = 0.00611\text{ bar}$ to $p_c = 220.64\text{ bar}$)

Results for wrong input values

Result **Z_PTX_97IT**, **Z** = **-1E16** or **z_ptx_97IT** = **-1E16** for input values:

Single phase region: $p > 1000\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 ($x = -1$) $t > 2000\text{ °C}$ or $t < 0\text{ °C}$ or
 $t > 800\text{ °C}$ at $p > 500\text{ bar}$

Saturation lines: at $p = -1$ and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$ or
 ($x = 0$ or $x = 1$) at $t = -1$ and $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$ or
 at $p > 220.64\text{ bar}$ or $p < 0.00611\text{ bar}$
 and $t > 373.946\text{ °C}$ or $t < 0\text{ °C}$
 at $|t - t_s(p)| > 0.1\text{ K}$

References: [1], [2], [3]

Property Libraries for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

Water and Steam

Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards IAPWS-IF97-S01, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

Library LibIF97_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

Humid Combustion Gas Mixtures

Library LibHuGas

- Model: Ideal mixture of the real fluids:
 CO_2 - Span, Wagner H_2O - IAPWS-95
 O_2 - Schmidt, Wagner N_2 - Span et al.
 Ar - Tegeler et al.
 and of the ideal gases:
 SO_2 , CO , Ne
 (Scientific Formulation of Bücker et al.)
 Consideration of:
 • Dissociation from VDI 4670
 • Poynting effect

Humid Air

Library LibHuAir

- Model: Ideal mixture of the real fluids:
 • Dry air from Lemmon et al.
 • Steam, water and ice from IAPWS-IF97 and IAPWS-06
 Consideration of:
 • Condensation and freezing of steam
 • Dissociation from VDI 4670
 • Poynting effect from ASHRAE RP-1485

Extremely Fast Property Calculations

- Spline-Based Table
 Look-up Method (SBTL)

Library LibSBTL_IF97 Library LibSBTL_95 Library LibSBTL_HuAir

- For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

Carbon Dioxide Including Dry Ice

Library LibCO2

- Formulation of Span and Wagner (1996)

Seawater

Library LibSeaWa

- IAPWS Industrial Formulation 2013

Ice

Library LibICE

- Ice from IAPWS-06, Melting and sublimation pressures from IAPWS-08, Water from IAPWS-IF97, Steam from IAPWS-95 and -IF97

Ideal Gas Mixtures

Library LibIdGasMix

- Model: Ideal mixture of the ideal gases:
- | | | | |
|---------------|----------------------|---------------|------------|
| Ar | NO | He | Propylene |
| Ne | H_2O | F_2 | Propane |
| N_2 | SO_2 | NH_3 | Iso-Butane |
| O_2 | H_2 | Methane | n-Butane |
| CO | H_2S | Ethane | Benzene |
| CO_2 | OH | Ethylene | Methanol |
| Air | | | |

Consideration of:

- Dissociation from the VDI Guideline 4670

Library LibIDGAS

- Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

Humid Air

Library ASHRAE LibHuAirProp

- Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:
 - Dry air
 - Steam

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

www.ashrae.org/bookstore

Dry Air Including Liquid Air

Library LibRealAir

- Formulation of Lemmon et al. (2000)

Refrigerants

Ammonia

Library LibNH3

- Formulation of Tillner-Roth et al. (1993)

R134a

Library LibR134a

- Formulation of Tillner-Roth and Baehr (1994)

Iso-Butane

Library LibButane_Iso

- Formulation of Bücker and Wagner (2006)

n-Butane

Library LibButane_n

- Formulation of Bücker and Wagner (2006)

Mixtures for Absorption Processes

Ammonia/Water Mixtures

Library LibAmWa

- IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)
 Helmholtz energy equation for the mixing term (also useable for calculating the Kalina Cycle)

Water/Lithium Bromide Mixtures

Library LibWaLi

- Formulation of Kim and Infante Ferreira (2004)
 Gibbs energy equation for the mixing term

Liquid Coolants

Liquid Secondary Refrigerants

Library LibSecRef

- Liquid solutions of water with
- | | |
|-----------------------------------|---------------------|
| $\text{C}_2\text{H}_6\text{O}_2$ | Ethylene glycol |
| $\text{C}_3\text{H}_8\text{O}_2$ | Propylene glycol |
| $\text{C}_2\text{H}_5\text{OH}$ | Ethanol |
| CH_3OH | Methanol |
| $\text{C}_3\text{H}_8\text{O}_3$ | Glycerol |
| K_2CO_3 | Potassium carbonate |
| CaCl_2 | Calcium chloride |
| MgCl_2 | Magnesium chloride |
| NaCl | Sodium chloride |
| $\text{C}_2\text{H}_3\text{KO}_2$ | Potassium acetate |
| CHKO_2 | Potassium formate |
| LiCl | Lithium chloride |
| NH_3 | Ammonia |
- Formulation of the International Institute of Refrigeration (IIR 2010)

Ethanol

Library LibC2H5OH

Formulation of
Schroeder et al. (2014)

Methanol

Library LibCH3OH

Formulation of
de Reuck and Craven (1993)

Propane

Library LibPropane

Formulation of
Lemmon et al. (2009)

Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane $C_8H_{24}O_4Si_4$ **Library LibD4**

Decamethylcyclopentasiloxane $C_{10}H_{30}O_5Si_5$ **Library LibD5**

Tetradecamethylhexasiloxane $C_{14}H_{42}O_6Si_6$ **Library LibMD4M**

Hexamethyldisiloxane $C_6H_{18}OSi_2$ **Library LibMM**

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane $C_{12}H_{36}O_6Si_6$ **Library LibD6**

Decamethyltetrasiloxane $C_{10}H_{30}O_3Si_4$ **Library LibMD2M**

Dodecamethylpentasiloxane $C_{12}H_{36}O_4Si_5$ **Library LibMD3M**

Octamethyltrisiloxane $C_8H_{24}O_2Si_3$ **Library LibMDM**

Formulation of Colonna et al. (2008)

Nitrogen and Oxygen

Libraries LibN2 and LibO2

Formulations of Span et al. (2000)
and Schmidt and Wagner (1985)

Hydrogen

Library LibH2

Formulation of
Leachman et al. (2009)

Helium

Library LibHe

Formulation of
Arp et al. (1998)

Hydrocarbons

Decane $C_{10}H_{22}$ **Library LibC10H22**

Isopentane C_5H_{12} **Library LibC5H12_Iso**

Neopentane C_5H_{12} **Library LibC5H12_Neo**

Isohexane C_6H_{14} **Library LibC6H14**

Toluene C_7H_8 **Library LibC7H8**

Formulation of Lemmon and Span (2006)

Further Fluids

Carbon monoxide **CO** **Library LibCO**

Carbonyl sulfide **COS** **Library LibCOS**

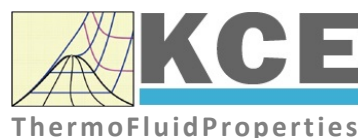
Hydrogen sulfide **H₂S** **Library LibH2S**

Nitrous oxide **N₂O** **Library LibN2O**

Sulfur dioxide **SO₂** **Library LibSO2**

Acetone C_3H_6O **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

The following thermodynamic and transport properties can be calculated^a:

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity a

Backward Functions

- $T, v, s(p, h)$
- $T, v, h(p, s)$
- $p, T, v(h, s)$
- $p, T(v, h)$
- $p, T(v, u)$

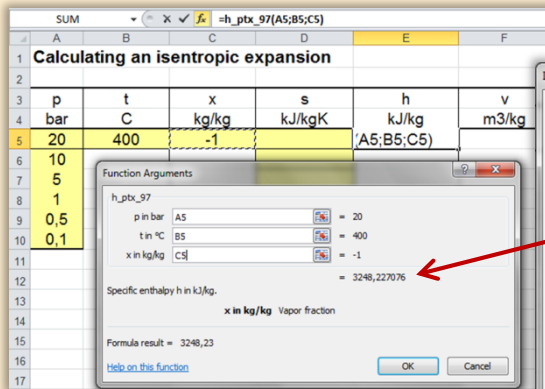
Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

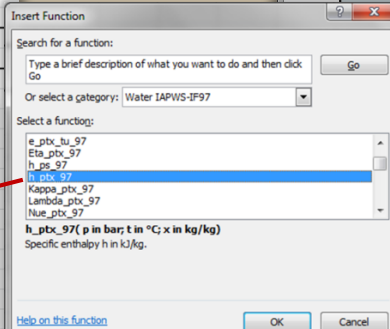
^a Not all of these property functions are available in all property libraries.

Property Software for Calculating Heat Cycles, Boilers, Turbines and Refrigerators

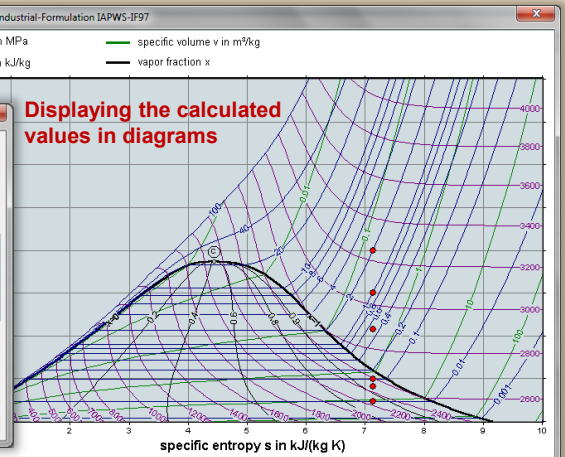
Add-In **FluidEXL** Graphics for Excel®



Choosing a property library and a function



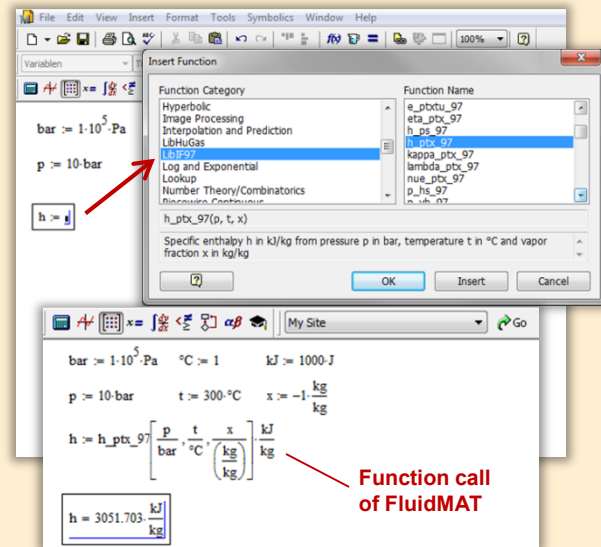
Displaying the calculated values in diagrams



Menu for the input of given property values

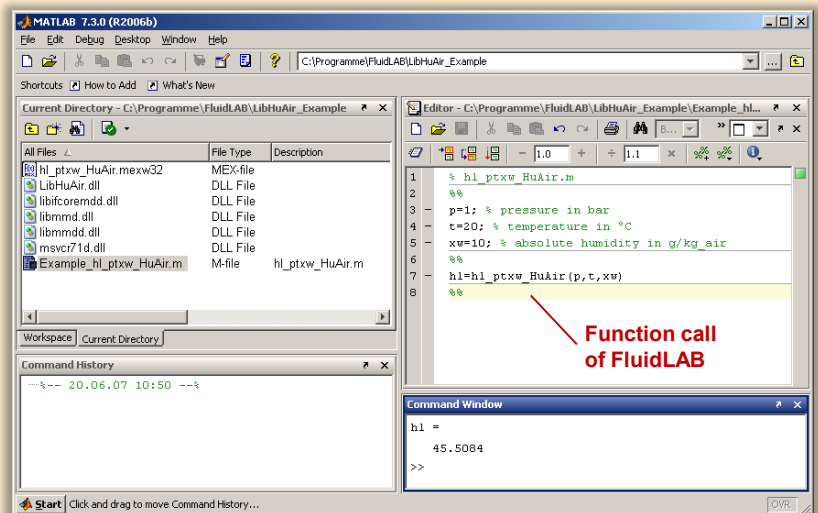
Add-On **FluidMAT** for Mathcad®
Add-On **FluidPRIME** for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.



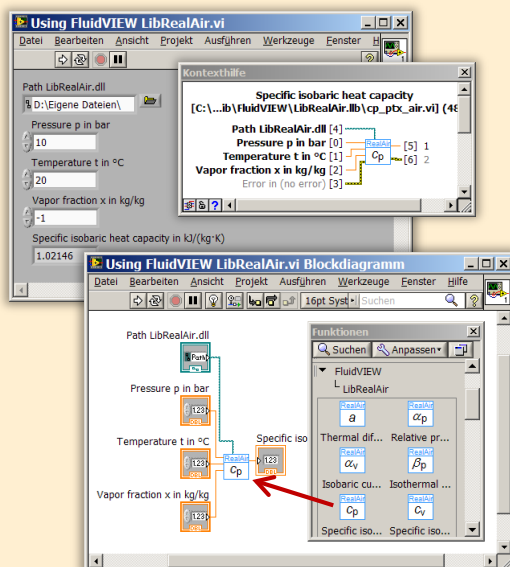
Add-On **FluidLAB** for MATLAB® and SIMULINK®

Using the Add-In FluidLAB the property functions can be called in MATLAB® and SIMULINK®.



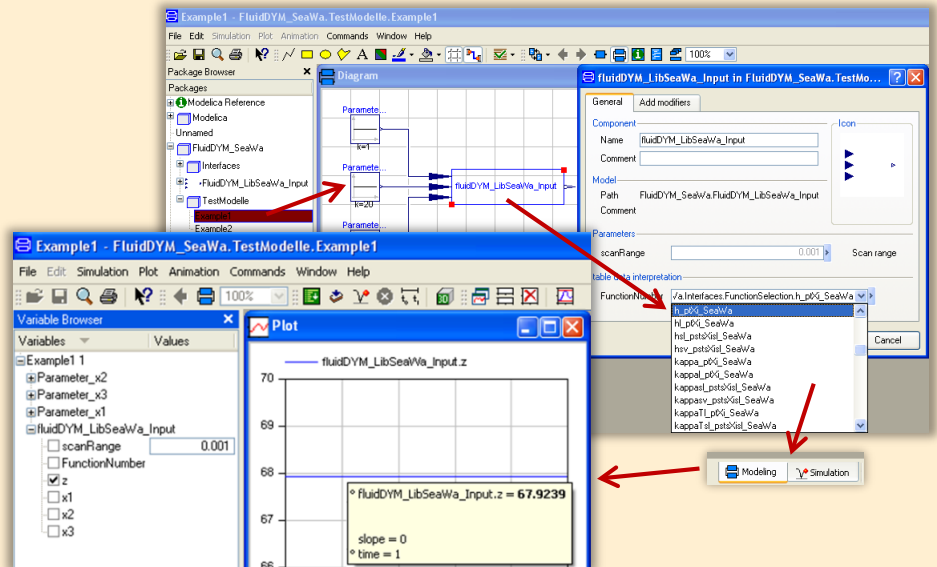
Add-On **FluidVIEW** for LabVIEW™

The property functions can be calculated in LabVIEW™.

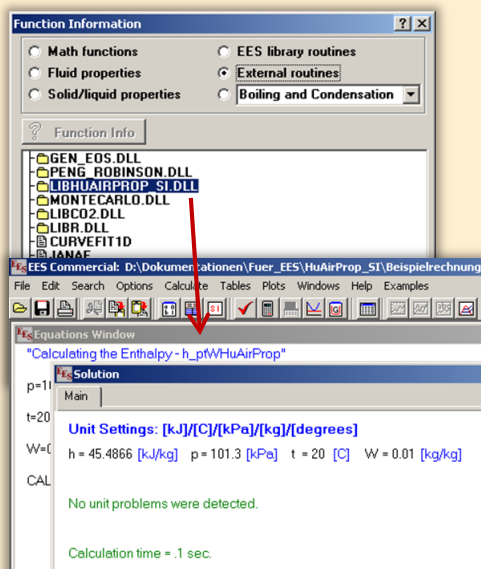


Add-On **FluidDYM** for DYMOLA® (Modelica) and SimulationX®

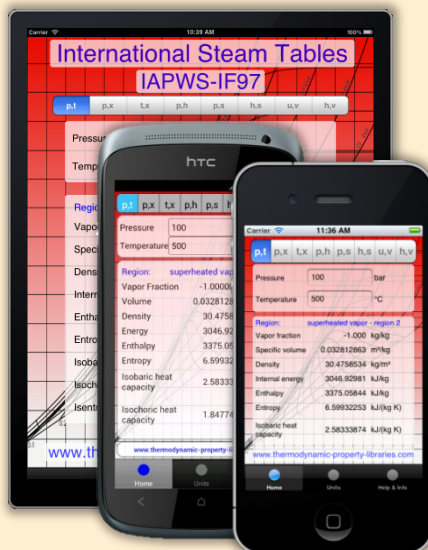
The property functions can be called in DYMOLA® and SimulationX®.



Add-On FluidEES for Engineering Equation Solver®



App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets



Online Property Calculator at www.thermofluidprop.com

Zittau's Fluid Property Calculator

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p: bar

Temperature t: °C

Vapor fraction x: kg/kg

Calculate / Recalculate

Result:

Specific enthalpy h = 3097.38 kJ/kg

For further information on property libraries available for EXCEL®, MATLAB®, Mathcad®, Engineering Equation Solver®, DYMOLA® (Modelica), SimulationX®, and LabView® click [here](#)

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found [here](#)

PDF with the description

© Zittau/Görlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stöcker
Programmer: Joachim Posselt

Tel.: +49-3583-61-1946 or -1981
Fax: +49-3583-61-1946
E-mail: info@thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com
www.thermofluidprop.com

Property Software for Pocket Calculators

FluidCasio



fx 9750 G II CFX 9850 fx-GG20 CFX 9860 G Graph 85 ALGEBRA FX 2.0

FluidHP



HP 48 HP 49

FluidTI



TI Nspire CX CAS TI 83 TI 84 TI 89

TI Voyage 200

TI 92

For more information please contact:



KCE-ThermoFluidProperties UG & Co. KG
Prof. Dr. Hans-Joachim Kretzschmar
Wallotstr. 3
01307 Dresden, Germany

Internet: www.thermofluidprop.com
Email: info@thermofluidprop.com
Phone: +49-351-27597860
Mobile: +49-172-7914607
Fax: +49-3222-1095810

The following thermodynamic and transport properties^a can be calculated in Excel®, MATLAB®, Mathcad®, Engineering Equation Solver® (EES), DYMOLA® (Modelica), SimulationX® and LabVIEW™:

Thermodynamic Properties

- Vapor pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- Prandtl number Pr
- Thermal diffusivity α

Backward Functions

- $T, v, s(p, h)$
- $T, v, h(p, s)$
- $p, T, v(h, s)$
- $p, T(v, h)$
- $p, T(v, u)$

Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

^a Not all of these property functions are available in all property libraries.

5. References

- [1] Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam IAPWS-IF97.
Available at the IAPWS website <http://www.iapws.org>
- [2] Kretzschmar, H.-J., Wagner, W.:
International Steam Tables.
Springer-Verlag, Berlin (2018)
- [3] Wagner, W.; Cooper, J.R.; Dittmann, A.; Kijima, J.; Kretzschmar, H.-J.; Kruse, A.; Mares, R.; Oguchi, K.; Sato, H.; Stöcker, I.; Sifner, O.; Takaishi, Y.; Tanishita, I.; Trübenbach, J.; Willkommen, Th.:
The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.
J. Eng. Gas Turbines Power 122 (2000) No 1, pp. 150-182
- [4] Advisory Note No. 3, Calculation of Thermodynamic Derivatives for Water and Steam from the IAPWS Formulations 2007. Available at the IAPWS website
<http://www.iapws.org>
- [5] R15-11: Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance (September 2011)
- [6] Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance. Available at the IAPWS website <http://www.iapws.org>
- [7] Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance. Available at the IAPWS website <http://www.iapws.org>
- [8] Release on Surface Tension of Ordinary Water Substance 1994.
Available at the IAPWS website <http://www.iapws.org>
- [9] Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. Available at the IAPWS website <http://www.iapws.org>
- [10] Revised Supplementary Release on Saturation Properties of Ordinary Water Substance 1992. Available at the IAPWS website <http://www.iapws.org>
- [11] R14-08(2011): Revised Release on the Pressure along the Melting and Sublimation Curves of Ordinary Water Substance (September 2011)
- [12] R12-08: Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance (September 2008)
- [13] R9-97: Release on the Refractive Index of Ordinary Water Substance as a Function of Wavelength, Temperature and Pressure (September 1997)
- [14] R8-97: Release on the Static Dielectric Constant of Ordinary Water Substance for Temperatures from 238 K to 873 K and Pressures up to 1000 MPa (September 1997)

- [15] R7-97(2012): Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam

- [16] R6-95(2016): Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use

- [17] R1-76(2014): Revised Release on the Surface Tension of Ordinary Water Substance

- [18] G13-15: Guideline on the Fast Calculation of Steam and Water Properties with the Spline-Based Table Look-Up Method (SBTL) (July 2015)

- [19] G9-12: Guideline on a Low-Temperature Extension of the IAPWS-95 Formulation for Water Vapor (October 2012)

- [20] G9-12: Guideline on a Low-Temperature Extension of the IAPWS-95 Formulation for Water Vapor (October 2012)

- [21] G1-90: Electrolytic Conductivity (Specific Conductance) of Liquid and Dense Supercritical Water from 0°C to 800°C and Pressures up to 1000 MPa (May 1990)

6. Satisfied Customers

Period from 2018 to 2022

The following companies and institutions use the property libraries:

- FluidEXL *Graphics* for Excel® incl. VBA
- FluidLAB for MATLAB® and Simulink
- FluidMAT for Mathcad®
- FluidPRIME for Mathcad Prime®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™
- FluidPYT for Python
- FluidJAVA for Java
- DLLs for Windows Applications
- Shared Objects for Linux
- Shared Objects for macOS.

2022

ASTG, Graz, Austria	12/2022
Wandschneider + Gutjahr, Hamburg	
RWE Supply & Trading, Essen	11/2022
Stadtwerke Rosenheim	
CEA, Saclay, France	10/2022
RWE Supply & Trading, Essen	
SEEC Saudi Energy Efficiency Center, Riyadh, Saudi Arabia	
MAN, Copenhagen, Denmark	
Hermeler & Partner Consulting Engineers, Sassenberg	09/2022
Envi Con, Nürnberg	
Drill Cool Systems, Bakersfield CA, USA	
RWE Supply & Trading, Essen	
Maerz Ofenbau, Zürich, Switzerland	
Saale Energie, Schkopau	
ERGO, Dresden	
Mainova, Frankfurt/Main	
Bundeswehr, Koblenz	08/2022
RWE Supply & Trading, Essen	
Grenzebach Corporation, Newnan GE, USA	
AGRANA, Gmuend, Austria	07/2022
MIBRAG, Zeitz	
Hochschule Niederrhein, Krefeld	
ULT, Löbau	06/2022
LEAG, Cottbus	
VPC Group, Vetschau	

Wärme, Hamburg	
ILK, Dresden	
Stricker IB, Küssnacht a. Rigi, Switzerland	
LEAG, Cottbus	05/2022
RWE Supply & Trading, Essen	
IGT Tomalla, Kreuztal	
B+T Engineering, Dübendorf, Switzerland	
Stricker IB, Küssnacht a. Rigi, Switzerland	
Vogelsang & Benning, Bochum	04/2022
Frischli, Rehburg-Loccum	
BPS Consulting, Sprengel	03/2022
HS Hannover, Maschinenbau & BioVT	
M+M Turbinentechnik, Bad Salzungen	
Uni. Strathclyde, Glasgow, UK	02/2022
Delta Energy Group, Jiaozhou City, Qingdao, China	
Wetzel IB, Guben	
Wijbenga, PC Geldermalsen, The Netherlands	
Voith Paper, Heidenheim	
HS Zittau/Görlitz, Maschinenwesen	01/2022
Thermische Abfallbehandlung, Lauterbach	
Webb Institute, Glen Cove NY, USA	
TU Berlin, Umweltverfahrenstechnik	
SachsenEnergie, Dresden	
Doosan, Chang-won-si, Gyeongsangnam-do, South Korea	
KW3, LH Veenendaal, The Netherlands	
Université du Luxembourg, Esch-sur-Alzette	
Enseleit IB, Mansfeld	
Caliqua/Equans, Zürich, Switzerland	
Rudnick & Enners, Alpenrod	

2021

Wenisch IB, Vetschau	12/2021
PPCHEM, Hinwil, Switzerland	
KW3, The Netherlands	
BASF Ludwigshafen	
Air-Consult, Jena	
Sjerp & Jongeneel, RB Zoetermeer, The Netherlands	11/2021
Maerz Ofenbau, Zürich, Switzerland	
RWE Supply & Trading, Essen	
Hahn IB, Dresden	10/2021
Therm, South Africa	
RWE Supply & Trading, Essen	
TH Nürnberg, Verfahrenstechnik	09/2021
RWE Supply & Trading, Essen	
Enseleit IB, Mansfeld	
SachsenEnergie, Dresden	
BSH Hausgeräte, Berlin	

Norsk Energi, Oslo, Norway	08/2021
AKM Industrieanlagen, Haltern	
Drill Cool Systems, Bakersfield CA, USA	
Siemens Energy Global, Erlangen	07/2021
Wulff & Umag, Husum	
Planungsbüro Waidhas, Chemnitz	
Burkhardt Energie Technik, Mühlhausen	
Lücke IB, Paderborn	06/2021
TU Dresden, Energieverfahrenstechnik	
Wärme, Hamburg	
AL-KO Therm, Kötz	
PCK Raffinerie, Schwedt	
Vogelsang & Benning, Bochum	05/2021
MTU, München	
VPC Group, Vetschau	
AVG, Köln	04/2021
TH Ulm, Institut für Fahrzeugtechnik	
Marty IB, Oberwil, Switzerland	
HypTec, Lebring, Austria	
Lopez IB, Getxo, Bizkaia, Spain	03/2021
GM Remediation Systems, Leoben, Austria	
Jager Kältetechnik, Osnabrück	
T&M Automation, GR Leidschendam, The Netherlands	
RWE Supply & Trading, Essen	
Stadtwerke Leipzig	
Beuth Hochschule für Technik, Berlin	
Beleth IB, Woeth	02/2021
ZTL, Thal, Austria	
ETABO Bochum	
RWE Supply & Trading, Essen	
Onyx Germany, Berlin	
TU Dresden, Kältetechnik	
GOHL-KTK, Durmersheim	
Therm Development, South Africa	
thermofin, Heinsdorfergrund	
RWE Supply & Trading, Essen	01/2021
STEAG, Essen	
ETA Energieberatung, Pfaffenhofen	
Enex Power, Kirchseeon	

2020

Drill Cool, Bakersfield CA, USA	12/2020
Manders, The Netherlands	
RWE Supply & Trading, Essen	
NEOWAT Lodz, Poland	
University of Duisburg-Essen, Duisburg	11/2020
Stellenbosch University, South Africa	

University De France-COMTe, France	
RWE, Essen	
STEAG, Herne	
Isenmann Ingenieurbüro	
University of Stuttgart, ITLR, Stuttgart	
Norsk Energi, Oslo, Norway	
TGM Kanis, Nürnberg	
Stadtwerke Neuburg	10/2020
Smurfit Kappa, Roermond, The Netherlands	
RWE, Essen	
Hochschule Zittau/Görlitz, Wirtschaftsingenieurwesen	
Stadtwerke, Neuburg	
ILK, Dresden	
ATESTEO, Alsdorf	
Hochschule Zittau/Görlitz, Maschinenwesen	
TH Nürnberg, Verfahrenstechnik	
Drill Cool, Bakersfield CA, USA	09/2020
RWE, Essen	
2Meyers Ingenieurbüro, Nürnberg	
FELUWA, Mürlenbach	
Stadtwerke Neuburg	
Caverion, Wien, Austria	
GMVA Niederrhein, Oberhausen	
INWAT Lodz, Poland	
Troche Ingenieurbüro, Hayingen	08/2020
CEA Saclay, France	
VPC, Vetschau	07/2020
FSK System-Kälte-Klima, Dortmund	
Exergie Etudes, Sarl, Switzerland	
AWG Wuppertal	
STEAG Energy Services, Zwingenberg	
Hochschule Braunschweig	06/2020
DBI, Leipzig	
GOHL-KTK, Dumersheim	
TU Dresden, Energieverfahrenstechnik	
BASF SE, ESI/EE, Ludwigshafen	
Wärme Hamburg	
Ruchti Ingenieurbüro, Uster, Switzerland	
IWB, Basel, Switzerland	
Midiplan, Bietingen-Bissingen	05/2020
Knieschke, Ingenieurbüro	
RWE, Essen	
Leser, Hamburg	
AGRANA, Gmünd, Austria	
EWT Wassertechnik, Celle	
Hochschule Darmstadt	04/2020
MTU München CCP	
HAW Hamburg	03/2020

Hanon, Novi Jicin, Czech Republic	
TU Dresden, Kältetechnik	
MAN, Copenhagen, Denmark	
EnerTech, Radebeul	02/2020
LEAG, Cottbus	
B+B Engineering Magdeburg	
Hochschule Offenburg	
WIB, Dennheritz	01/2020
Universität Duisburg-Essen, Strömungsmaschinen	
Kältetechnik Dresden-Bremen	
TH Ingolstadt	
Vattenfall AB, Jokkmokk, Sweden	
Fraunhofer UMSICHT	

2019

PEU Leipzig, Rötha	12/2019
MB-Holding, Vestenbergsgreuth	
RWE, Essen	
Georg-Büchner-Hochschule, Darmstadt	11/2019
EEB ENERKO, Aldenhoven	
Robert Benoufa Energietechnik, Wiesloch	
Kehrein & Kubanek Klimatechnik, Moers	10/2019
Hanon Systems Autopal Services, Hluk, Czech Republic	
CEA Saclay, Gif Sur Yvette cedex, France	
Saudi Energy Efficiency Center SEEC, Riyadh, Saudi Arabia	
VPC, Vetschau	09/2019
jGanser PM + Engineering, Forchheim	
Endress+Hauser Flowtec AG, Reinach, Switzerland	
Ruchti IB, Uster, Switzerland	
ZWILAG Zwischenlager Würenlingen, Switzerland	08/2019
Hochschule Zittau/Görlitz, Faculty Maschinenwesen	
Stadtwerke Neubrandenburg	
Physikalisch Technische Bundesanstalt PTB, Braunschweig	
GMVA Oberhausen	07/2019
Endress+Hauser Flowtec AG, Reinach, Switzerland	
WARNICA, Waterloo, Canada	
MIBRAG, Zeitz	06/2019
Pöyry, Zürich, Switzerland	
RWTH Aachen, Institut für Strahlantriebe und Turbomaschinen	
Midiplan, Bietigheim-Bissingen	
GKS Schweinfurt	
HS Zittau/Görlitz, Wirtschaftswissenschaften und Wirtschaftsingenieurwesen	
ILK Dresden	
HZDR Helmholtz Zentrum Dresden-Rossendorf	
TH Köln, Technische Gebäudeausrüstung	05/2019
IB Knittel, Braunschweig	
Norsk Energi, Oslo, Norway	

STEAG, Essen	
Stora Enso, Eilenburg	
IB Lücke, Paderborn	
Haarslev, Sonderso, Denmark	
MAN Augsburg	
Wieland Werke, Ulm	04/2019
Fels-Werke, Elbingerode	
Univ. Luxembourg, Luxembourg	
BTU Cottbus, Power Engineering	03/2009
Eins-Energie Sachsen, Schwarzenberg	
TU Dresden, Kälte- und Kryotechnik	
ITER, St. Paul Lez Durance Cedex, France	
Fraunhofer UMSICHT, Oberhausen	
Comparex Leipzig for Spedition Thiele HEMMERSBACH	
Rückert NaturGas, Lauf/Pegnitz	
BASF, Basel, Switzerland	02/2019
Stadtwerke Leipzig	
Maerz Ofenbau Zürich, Switzerland	
Hanon Systems Germany, Kerpen	
Thermofin, Heinsdorfergrund	01/2019
BSH Berlin	

2018

Jaguar Energy, Guatemala	12/2018
WEBASTO, Gilching	
Smurfit Kappa, Oosterhout, Netherlands	
Univ. BW München	
RAIV, Liberec for VALEO, Prague, Czech Republic	11/2018
VPC Group Vetschau	
SEITZ, Wetzikon, Switzerland	
MVV, Mannheim	10/2018
IB Troche	
KANIS Turbinen, Nürnberg	
TH Ingolstadt, Institut für neue Energiesysteme	
IB Kristl & Seibt, Graz, Austria	09/2018
INEOS, Köln	
IB Lücke, Paderborn	
Südzucker, Ochsenfurt	08/2018
K&K Turbinenservice, Bielefeld	07/2018
OTH Regensburg, Elektrotechnik	
Comparex Leipzig for LEAG, Berlin	06/2018
Münstermann, Telgte	05/2018
TH Nürnberg, Verfahrenstechnik	
Universität Madrid, Madrid, Spanien	
HS Zittau/Görlitz, Wirtschaftsingenieurwesen	
HS Niederrhein, Krefeld	
Wilhelm-Büchner HS, Pfungstadt	03/2018

GRS, Köln	
WIB, Dennheritz	
RONAL AG, Härklingen, Schweiz	02/2018
Ingenieurbüro Leipert, Riegelsberg	
AIXPROCESS, Aachen	
KRONES, Neutraubling	
Doosan Lentjes, Ratingen	01/2018