Hochschule
Zittau/Görlitz
UNIVERSITY OF APPLIED SCIENCES

**Faculty of**
**MECHANICAL ENGINEERING**

**Department of**
**TECHNICAL THERMODYNAMICS**

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

## FluidEXL*Graphics*
## with LibIF97
## for Excel®

Prof. Hans-Joachim Kretzschmar

Dr. Ines Stoecker

Ines Jaehne

Matthias Kunick

# Software for the Industrial Formulation IAPWS-IF97 of Water and Steam Including DLL and Add-In for Excel®

## FluidEXL*Graphics*

## LibIF97

## Contents

---

© Zittau/Goerlitz University of Applied Sciences, Germany
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Phone: +49-3583-61-1846 or -1881
Fax: +49-3583-61-1846
E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de

# 0. Package Contents

## 0.1 Zip files for 32-bit Office$^{\circledR}$

The following zip files are delivered for your computer running a 32-bit Office$^{\circledR}$ version.

**English zip file "CD_FluidEXL_Graphics_LibIF97_Eng.zip" including the following files:**

| | |
|---|---|
| FluidEXL_Graphics_Eng_Setup.exe | - Self-extracting and self-installing program for FluidEXL$^{\mathit{Graphics}}$ |
| FluidEXL_Graphics_Eng.xla | - FluidEXL$^{\mathit{Graphics}}$ Add-In |
| LibIF97.hlp | - Help file for the LibIF97 property library |
| LibIF97.dll | - Dynamic link library with functions for water and steam |
| FluidEXL_Graphics_LibIF97_Docu_Eng.pdf | - User's Guide |

**German zip file "CD_FluidEXL_Graphics_LibIF97.zip" including the following files:**

| | |
|---|---|
| FluidEXL_Graphics_Setup.exe | - Self-extracting and self-installing program for FluidEXL$^{\mathit{Graphics}}$ |
| FluidEXL_Graphics.xla | - German Add-In for FluidEXL$^{\mathit{Graphics}}$ |
| LibIF97.hlp | - Help file for the LibIF97 property library |
| LibIF97.dll | - Dynamic link library with functions for water and steam |
| FluidEXL_Graphics_LibIF97_Docu_Eng.pdf | - User's Guide |

## 0.2 Zip files for 64-bit Office®

The following zip files are delivered for your computer running a 64-bit Office® version.

**English zip file "CD_FluidEXL_Graphics_LibIF97_x64_Eng.zip" including the following files and folders:**

**Files:**

| | |
|---|---|
| Setup.exe | - Self-extracting and self-installing program for FluidEXL$^{Graphics}$ |
| FluidEXL_Graphics_Eng_64_Setup.msi | - Self-extracting and self-installing program |
| FluidEXL_Graphics_Eng.xla | - FluidEXL$^{Graphics}$ Add-In |
| FluidEXL_Graphics_LibIF97_Docu_Eng.pdf | - User's Guide |
| LibIF97.dll | - Dynamic link library with functions for water and steam |
| LibIF97.hlp | - Help file for the LibIF97 property library |

**Folders:**

| | |
|---|---|
| \vcredist_x64 | - Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack" |
| \WindowsInstaller3_1 | - Folder containing the "Microsoft Windows Installer" |

**German zip file "CD_FluidEXL_Graphics_LibIF97_x64.zip" including the following files and folders:**

**Files:**

| | |
|---|---|
| Setup.exe | - Self-extracting and self-installing program for FluidEXL$^{Graphics}$ |
| FluidEXL_Graphics_64_Setup.msi | - Self-extracting and self-installing program |
| FluidEXL_Graphics.xla | - German FluidEXL$^{Graphics}$ Add-In |
| FluidEXL_Graphics_LibIF97_Docu_Eng.pdf | - User's Guide |
| LibIF97.dll | - Dynamic link library for use in Windows® programs |
| LibIF97.hlp | - Help file for the LibIF97 property library |

**Folders:**

| | |
|---|---|
| \vcredist_x64 | - Folder containing the "Microsoft Visual C++ 2010 x64 Redistributable Pack" |
| \WindowsInstaller3_1 | - Folder containing the "Microsoft Windows Installer" |

# 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.

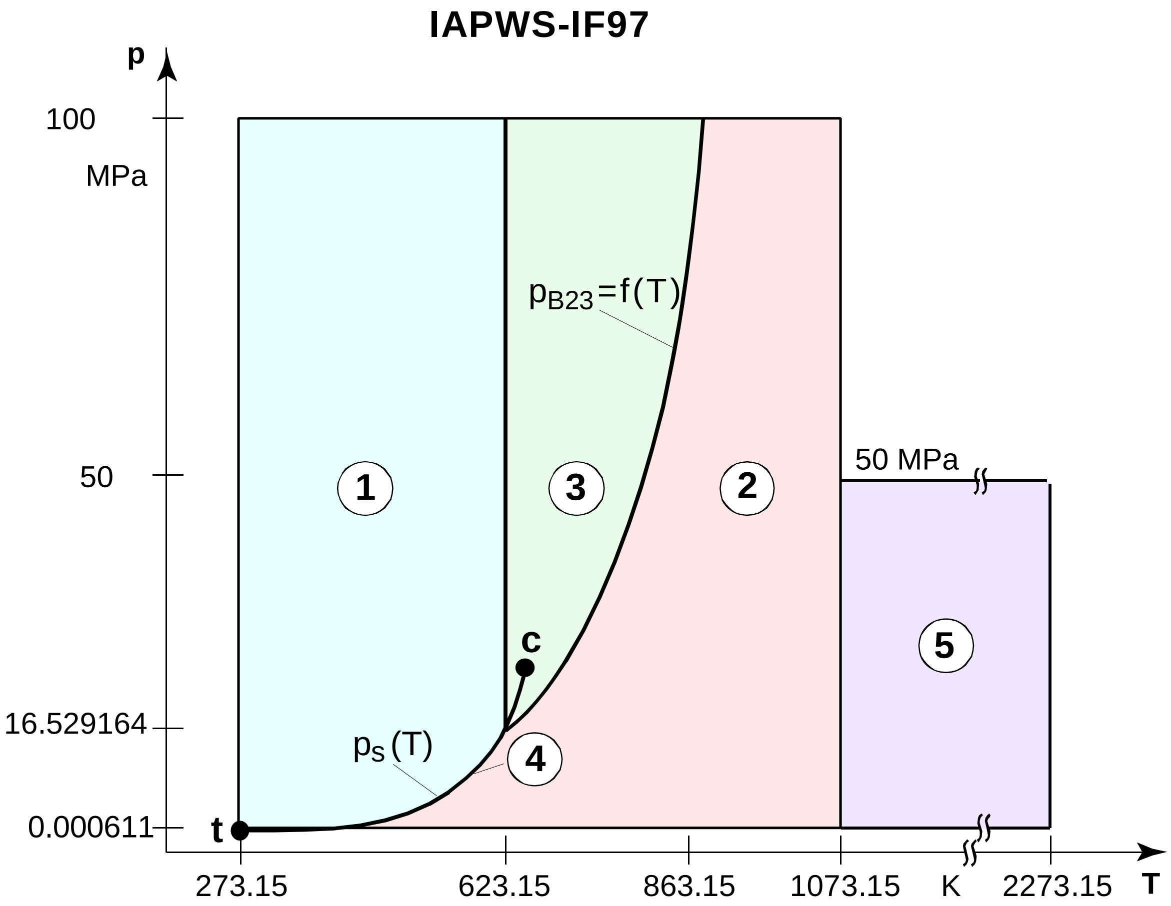


**Figure 1.1** Entire Range of Validity of the IF97

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 LibIF97 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 LibIF97 | Call from DLL LibIF97, Result as Parameter | Property or Function | Unit of the Result |
|---|---|---|---|---|---|
| $a = \mathrm{f}(p,t,x)$ | a_ptx_97 | = APTX97(P,T,X) | = C_APTX97(A,P,T,X) | Thermal diffusivity | $\mathrm{m}^2/\mathrm{s}$ |
| $\alpha_p = \mathrm{f}(p,t,x)$ | alphap_ptx_97 | = ALPHAPPTX97(P,T,X) | =C_ALPHAPPTX97 (ALPHAP,P,T,X) | Relative pressure coefficient | $\mathrm{K}^{-1}$ |
| $\alpha_v = \mathrm{f}(p,t,x)$ | alphav_ptx_97 | = ALPHAVPTX97(P,T,X) | =C_ALPHAVPTX97 (ALPHAV,P,T,X) | Isobaric cubic expansion coefficient | $\mathrm{K}^{-1}$ |
| $b = \mathrm{f}(p)$ | b_p_97 | = BP97(P) | =C_BP97 (B,P) | Laplace coefficient | m |
| $b = \mathrm{f}(t)$ | b_t_97 | = BT97(T) | =C_BT97 (B,T) | Laplace coefficient | m |
| $\beta_p = \mathrm{f}(p,t,x)$ | betap_ptx_97 | = BETAPPTX97(P,T,X) | = C_BETAPPTX97 (BETAP,P,T,X) | Isothermal stress coefficient | $\mathrm{kg/m}^3$ |
| $c_p = \mathrm{f}(p,t,x)$ | cp_ptx_97 | = CPPTX97(P,T,X) | = C_CPPTX97(CP,P,T,X) | Specific isobaric heat capacity | kJ/(kg · K) |
| $c_v = \mathrm{f}(p,t,x)$ | cv_ptx_97 | = CVPTX97(P,T,X) | = C_CVPTX97(CV,P,T,X) | Specific isochoric heat capacity | kJ/(kg · K) |
| $\delta_T = \mathrm{f}(p,t,x)$ | deltat_ptx_97 | = DELTATPTX97 (P,T,X) | = C_DELTATPTX97 (DELTAT,P,T,X) | Isothermal throttling coefficient | $\mathrm{kJ/(kg \cdot kPa^{-1})}$ |
| $\left(\frac{\partial v}{\partial p}\right)_T = \mathrm{f}(p,t,x)$ | dv_dp_T_ptx_97 | = DVDPT97(P,T,X) | = C_DVDPT97(DVP,P,T,X) | Differential quotient $\left(\frac{\partial v}{\partial p}\right)_\mathrm{T}(p,t,x)$ | $\mathrm{m}^3/(\mathrm{kg \cdot kPa})$ |
| $\left(\frac{\partial v}{\partial T}\right)_p = \mathrm{f}(p,t,x)$ | dv_dT_p_ptx_97 | = DVDTP97(P,T,X) | = C_DVDTP97(DVT,P,T,X) | Differential quotient $\left(\frac{\partial v}{\partial T}\right)_\mathrm{p}(p,t,x)$ | $\mathrm{m}^3/(\mathrm{kg \cdot K})$ |
| $e = \mathrm{f}(p,t,x,t_\mathrm{U})$ | e_ptx_tu_97 | = EPTXTU97(P,T,X,TU) | = C_EPTXTU97(E;P,T,X,TU) | Specific exergy | kJ/kg |
| $\varepsilon = \mathrm{f}(p,t,x)$ | epsilon_ptx_97 | = EPSPTX97 (P,T,X) | = C_EPSPTX97(EPS,P,T,X) | Dielectric constant | - |
| $\eta = \mathrm{f}(p,t,x)$ | eta_ptx_97 | = ETAPTX97(P,T,X) | = C_ETAPTX97(ETA,P,T,X) | Dynamic viscosity | Pa · s = kg/(m · s) |
| $f = \mathrm{f}(p,t,x)$ | f_ptx_97 | = FPTX97 (P,T,X) | = C_FPTX97(F,P,T,X) | Specific Helmholtz energy | kJ/kg |
| $f^* = \mathrm{f}(p,t,x)$ | fug_ptx_97 | = FUGPTX97 (P,T,X) | = C_FUGPTX97(FUG,P,T,X) | Fugacity | bar |
| $g = \mathrm{f}(p,t,x)$ | g_ptx_97 | = GPTX97 (P,T,X) | = C_GPTX97(G,P,T,X) | Specific Gibbs energy | kJ/kg |
| $h = \mathrm{f}(p,s)$ | h_ps_97 | = HPS97(P,S) | = C_HPS97(HPS,P,S) | Backward function: Specific enthalpy from pressure and entropy | kJ/kg |
| $h = \mathrm{f}(p,t,x)$ | h_ptx_97 | = HPTX97(P,T,X) | = C_HPTX97(H,P,T,X) | Specific enthalpy | kJ/kg |

| **Functional Dependence** | **Function Name** | **Call as Function from DLL LibIF97** | **Call from DLL LibIF97, Result as Parameter** | **Property or Function** | **Unit of the Result** |
|---|---|---|---|---|---|
| $\kappa = f(p,t,x)$ | kappa_ptx_97 | = KAPPTX97(P,T,X) | = C_KAPPTX97(KAP,P,T,X) | Isentropic exponent | - |
| $\kappa_T = f(p,t,x)$ | kappat_ptx_97 | = KAPPATPTX97(P,T,X) | = C_KAPPATPTX97 (KAPPAT,P,T,X) | Isothermal compressibility | $kPa^{-1}$ |
| $\lambda = f(p,t,x)$ | lambda_ptx_97 | = LAMPTX97(P,T,X) | = C_LAMPTX97(LAM,P,T,X) | Heat conductivity | $W/(m \cdot K)$ |
| $\mu = f(p,t,x)$ | my_ptx_97 | = MYPTX97(P,T,X) | = C_ MYPTX97(MY,P,T,X) | Joule-Thomson coefficient | $K\ kPa^{-1}$ |
| $n = f(p,t,x,wl)$ | n_ptxwl_97 | = NPTXWL97(P,T,X,WL) | = C_NPTXWL97(N,P,T,X,WL) | Refractive index | - |
| $\nu = f(p,t,x)$ | ny_ptx_97 | = NYPTX97(P,T,X) | = C_NYPTX97(NUE,P,T,X) | Kinematic viscosity | $m^2/s$ |
| $p = f(h,s)$ | p_hs_97 | = PHS97(H,S) | = C_PHS97(PHS,H,S) | Backward function: Pressure from enthalpy and entropy | bar |
| $p = f(v,h)$ | p_vh_97 | = PVH97(H,S) | = C_PVH97(PHS,H,S) | Backward function: Pressure from volume and enthalpy | bar |
| $p = f(v,u)$ | p_vu_97 | = PVU97(H,S) | = C_PVU97(PHS,H,S) | Backward function: Pressure from volume and internal energy | bar |
| $Pr = f(p,t,x)$ | Pr_ptx_97 | = PRPTX97(P,T,X) | = C_PRPTX97(PR,P,T,X) | *Prandtl*-number | - |
| $p_s = f(t)$ | ps_t_97 | = PST97(T) | = C_PST97(PS,T) | Vapor pressure | bar |
| $\rho = f(p,t,x)$ | rho_ptx_97 | = RHOPTX97(P,T,X) | = C_RHOPTX97(RHO,P,T,X) | Density | $kg/m^3$ |
| $s = f(p,h)$ | s_ph_97 | = SPH97(P,H) | = C_SPH97(SPH,P,H) | Backward function: Specific entropy from pressure and enthalpy | $kJ/(kg \cdot K)$ |
| $s = f(p,t,x)$ | s_ptx_97 | = SPTX97(P,T,X) | = C_SPTX97(S,P,T,X) | Specific entropy | $kJ/(kg \cdot K)$ |
| $\sigma = f(p)$ | sigma_p_97 | = SIGMAP97(P) | = C_SIGMAP97(SIG,P) | Surface tension from pressure | $mN/m = mPa \cdot m$ |
| $\sigma = f(t)$ | sigma_t_97 | = SIGMAT97(T) | = C_SIGMAT97(SIG,T) | Surface tension from temperature | $mN/m = mPa \cdot m$ |
| $t = f(h,s)$ | t_hs_97 | = THS97(H,S) | = C_THS97(THS,H,S) | Backward function: Temperature from enthalpy and entropy | °C |
| $t = f(p,h)$ | t_ph_97 | = TPH97(P,H) | = C_TPH97(TPH,P,H) | Backward function: Temperature from pressure and enthalpy | °C |
| $t = f(p,s)$ | t_ps_97 | = TPS97(P,S) | = C_TPS97(TPS,P,S) | Backward function: Temperature from pressure and entropy | °C |

| **Functional Dependence** | **Function Name** | **Call as Function from DLL LibIF97** | **Call from DLL LibIF97, Result as Parameter** | **Property or Function** | **Unit of the Result** |
|---|---|---|---|---|---|
| $t = \mathrm{f}(v,h)$ | t_vh_97 | = TVH97(P,H) | = C_TVH97(TPH,P,H) | Backward function: Temperature from volume and enthalpy | °C |
| $t = \mathrm{f}(v,u)$ | t_vu_97 | = TVU97(P,H) | = C_TVU97(TPH,P,H) | Backward function: Temperature from volume and internal energy | °C |
| $t_s = \mathrm{f}(p)$ | ts_p_97 | = TSP97(P) | = C_TSP97(TS,P) | Saturation temperature | °C |
| $u = \mathrm{f}(p,t,x)$ | u_ptx_97 | = UPTX97(P,T,X) | = C_UPTX97(U,P,T,X) | Specific internal energy | kJ/kg |
| $v = \mathrm{f}(p,h)$ | v_ph_97 | = VPH97(P,S) | = C_VPH97(VPS,P,S) | Backward function: Specific volume from pressure and enthalpy | m$^3$/kg |
| $v = \mathrm{f}(p,s)$ | v_ps_97 | = VPS97(P,S) | = C_VPS97(VPS,P,S) | Backward function: Specific volume from pressure and entropy | m$^3$/kg |
| $v = \mathrm{f}(p,t,x)$ | v_ptx_97 | = VPTX97(P,T,X) | = C_VPTX97(V,P,T,X) | Specific volume | m$^3$/kg |
| $w = \mathrm{f}(p,t,x)$ | w_ptx_97 | = WPTX97(P,T,X) | = C_WPTX97(W,P,T,X) | Isentropic speed of sound | m/s |
| $x = \mathrm{f}(h,s)$ | x_hs_97 | = XHS97(H,S) | = C_XHS97(XHS,H,S) | Backward function: Vapor fraction from enthalpy and entropy | kg/kg |
| $x = \mathrm{f}(p,h)$ | x_ph_97 | = XPH97(P,H) | = C_XPH97(XPH,P,H) | Backward function: Vapor fraction from pressure and enthalpy | kg/kg |
| $x = \mathrm{f}(p,s)$ | x_ps_97 | = XPS97(P,S) | = C_XPS97(XPS,P,S) | Backward function: Vapor fraction from pressure and entropy | kg/kg |
| $x = \mathrm{f}(v,h)$ | x_vh_97 | = XVH97(P,H) | = C_XVH97(XPH,P,H) | Backward function: Vapor fraction from volume and enthalpy | kg/kg |
| $x = \mathrm{f}(v,u)$ | x_vu_97 | = XVU97(P,H) | = C_XVU97(XPH,P,H) | Backward function: Vapor fraction from volume and internal energy | kg/kg |
| $z = \mathrm{f}(p,t,x)$ | z_ptx_97 | = ZPTX97(P,T,X) | = C_ZPTX97(Z,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<br>Exception to 900°C for the functions for $a$, $\eta$, $\lambda$, $v$, 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: $t_t = 0$ °C ... $t_c = 373.946$ °C
$p_t = 0.00611$ bar ... $p_c = 220.64$ bar (c – critical point) )

**Note.**

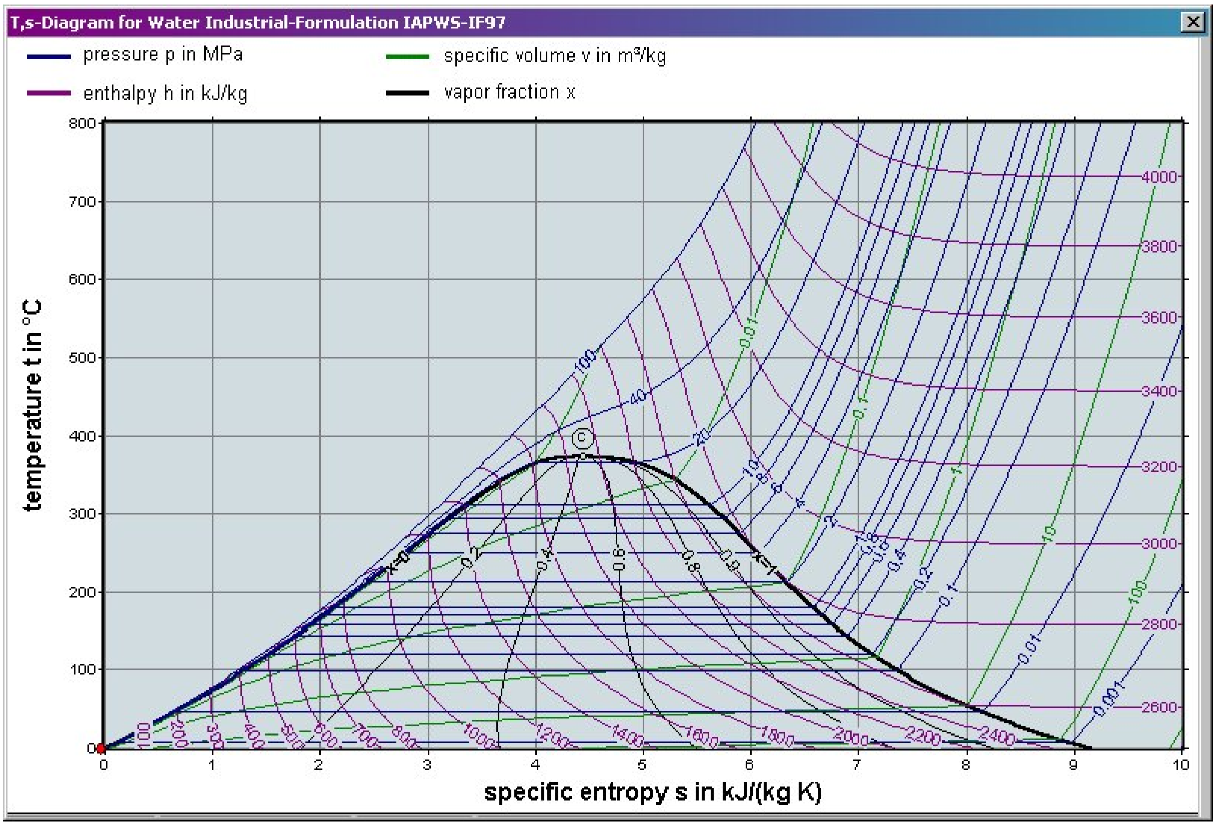
*If the calculation results in –1, the values entered represent a state point beyond the range of validity of IAPWS-IF97. For further information on each function and its range of validity see Chapter 4. The same information may also be accessed via the online help pages.*

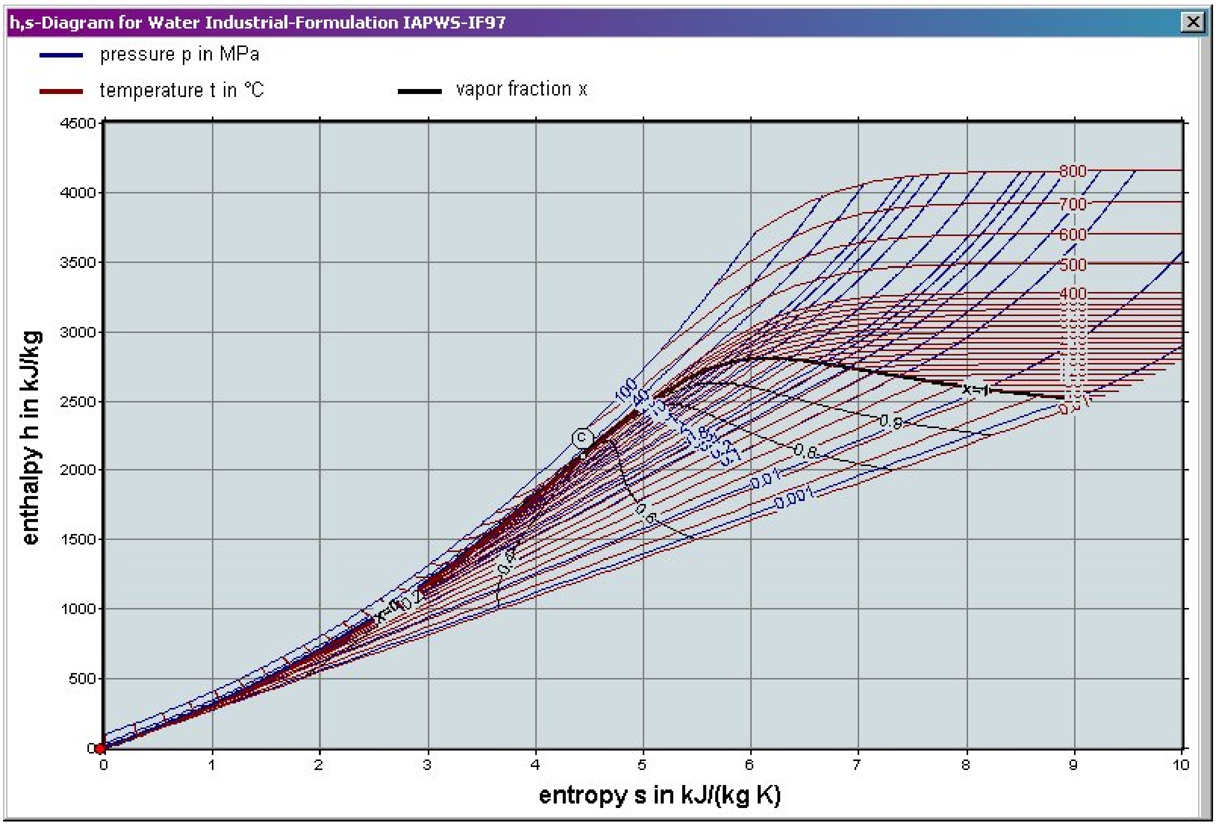
# 1.3 Thermodynamic Diagrams

FluidEXL$^{Graphics}$ enables the user to represent the calculated properties in the following thermodynamic diagrams:

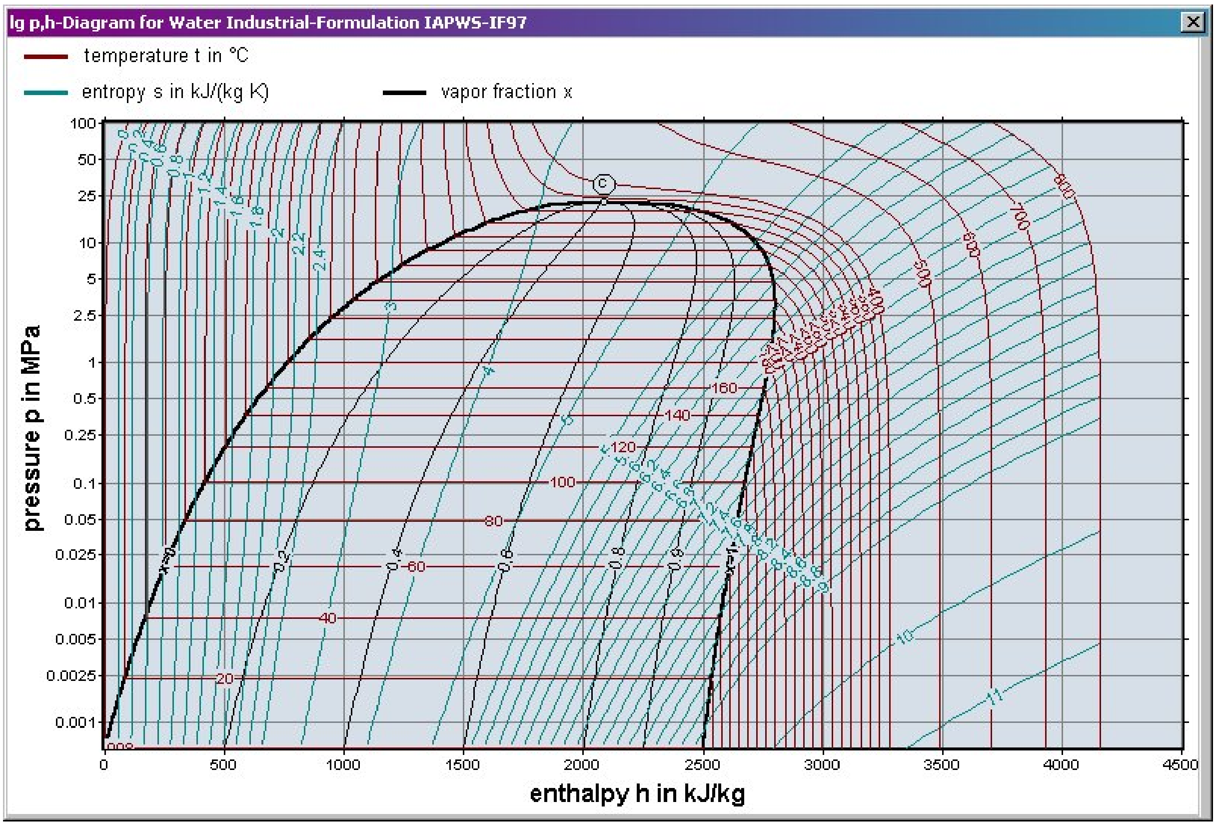
- *T-s* diagram
- *T-h* diagram
- *h-s* diagram
- *T-lg v* diagram
- *lg p-h* diagram
- *lg p-s* diagram
- *lg p-lg v* diagram
- *h-lg v* diagram
- *lg p-T* diagram
- *s-lg v*-diagram
- *p-T* diagram

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

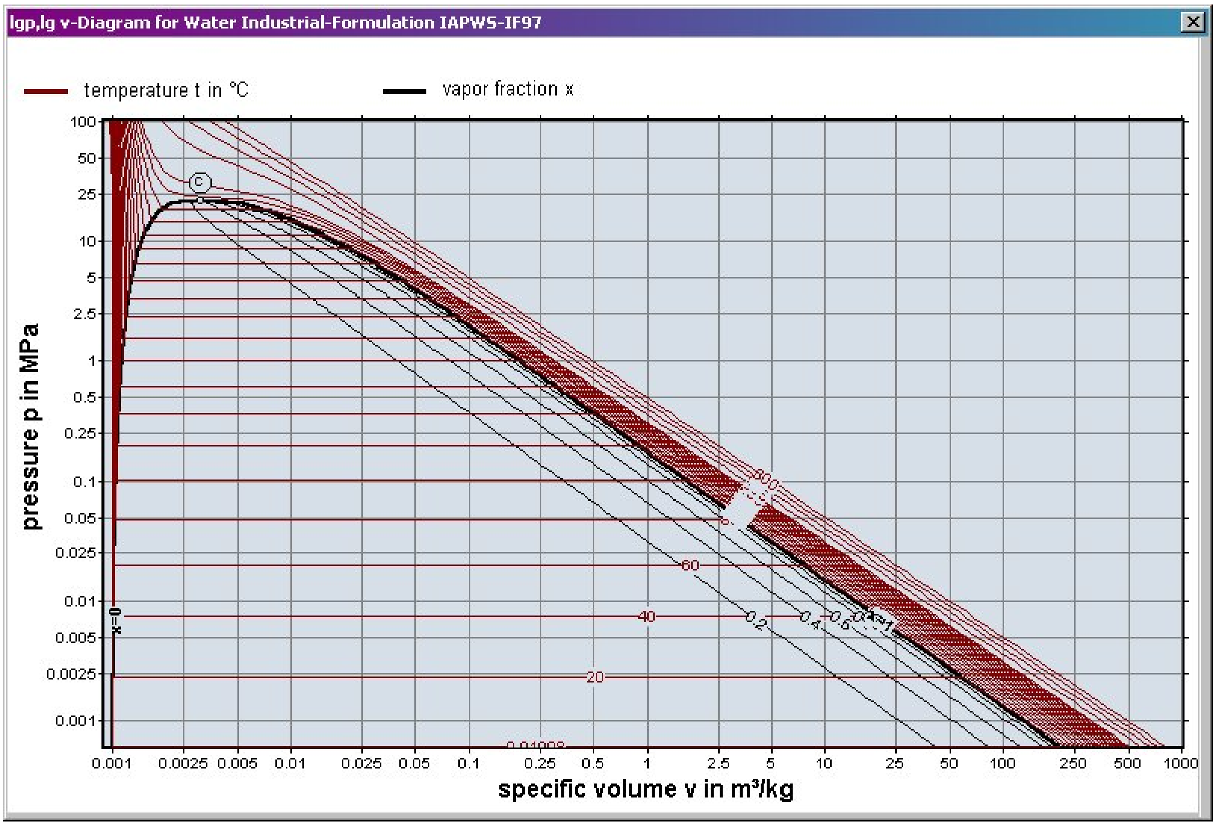




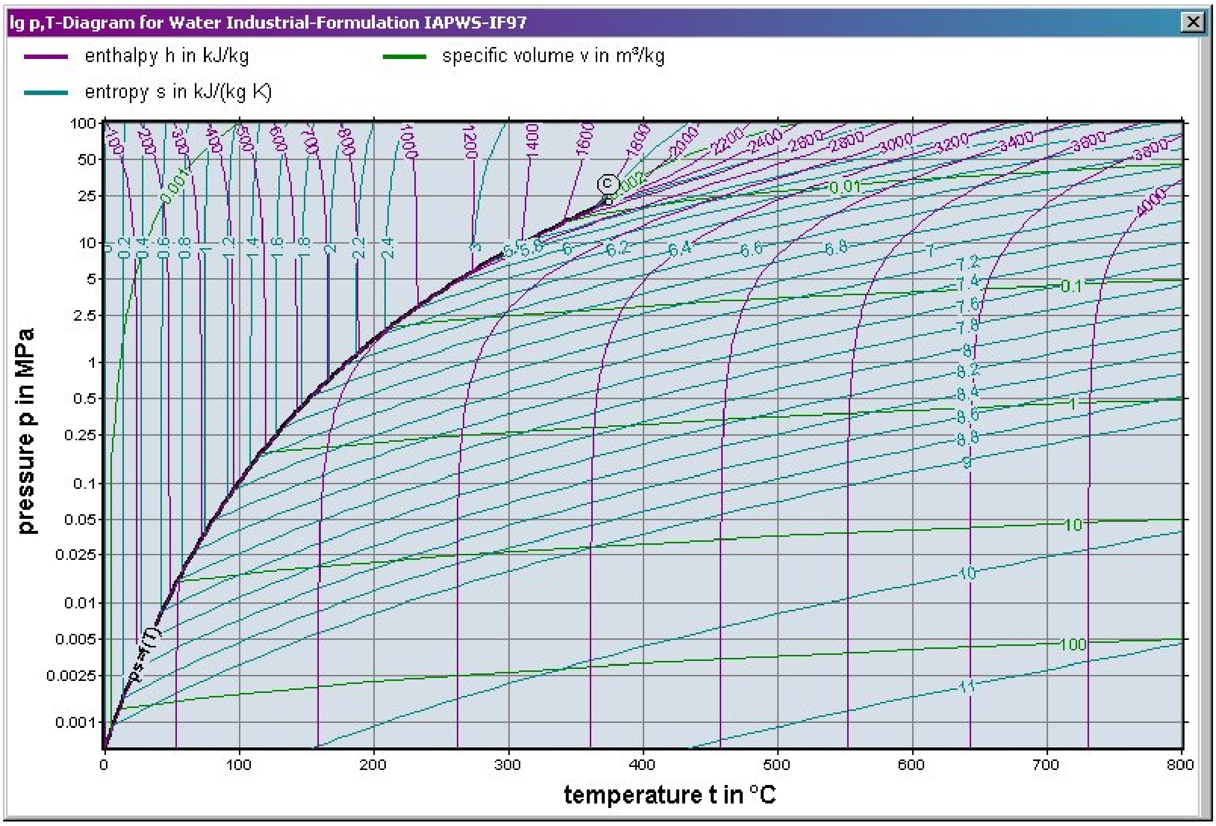
h,s-Diagram for Water Industrial-Formulation IAPWS-IF97



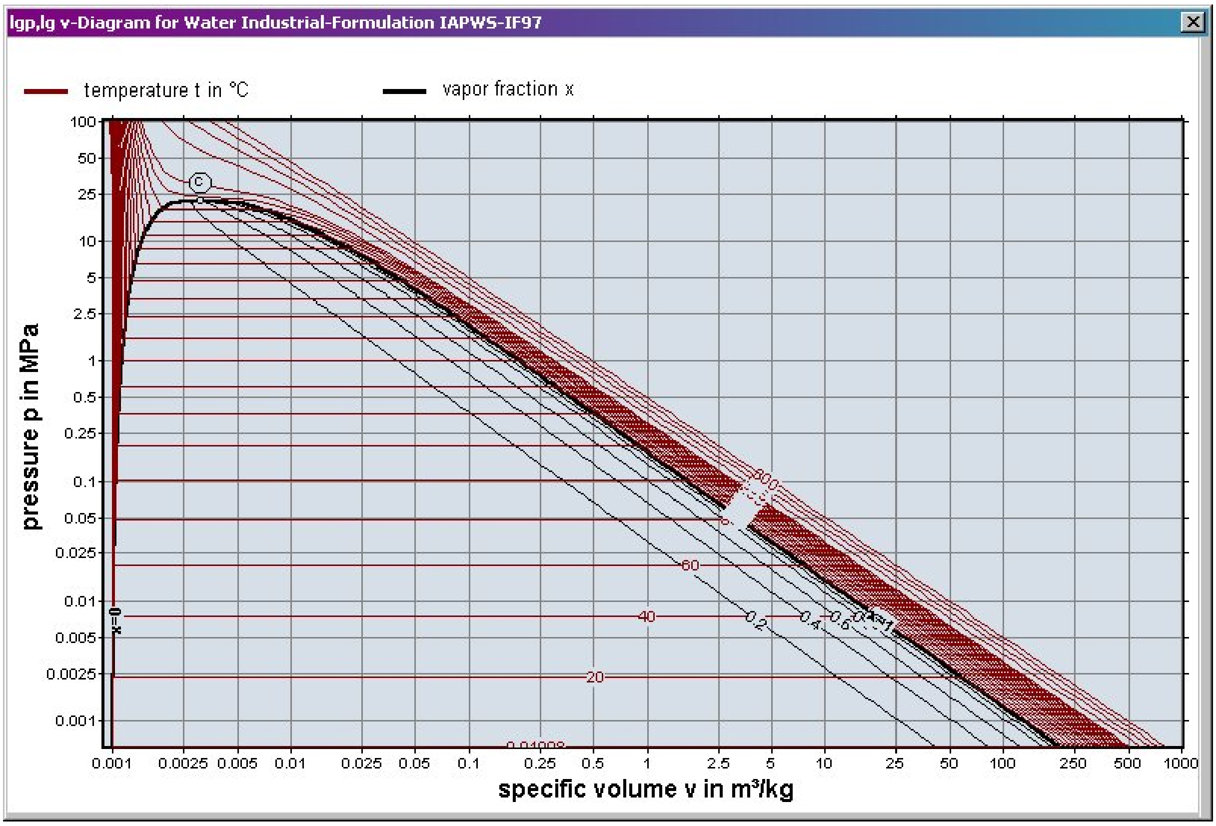
lg p,h-Diagram for Water Industrial-Formulation IAPWS-IF97

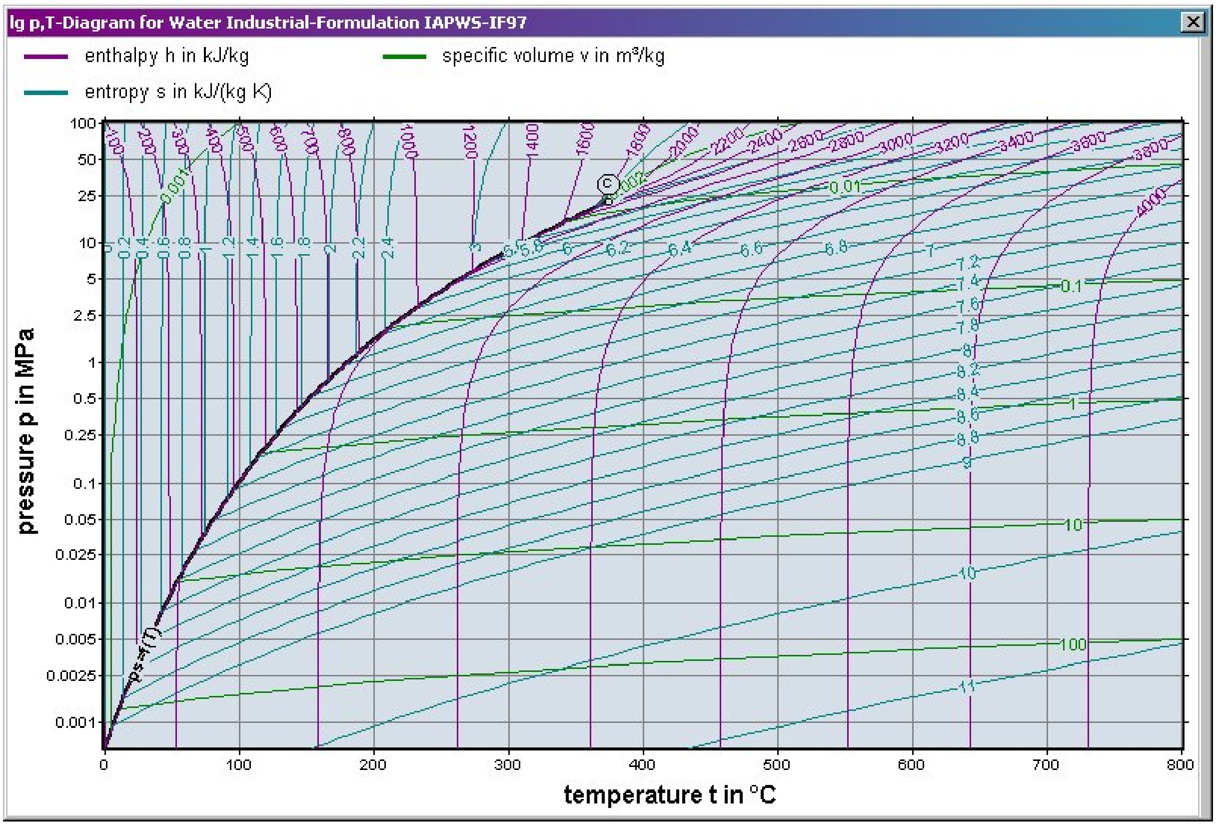


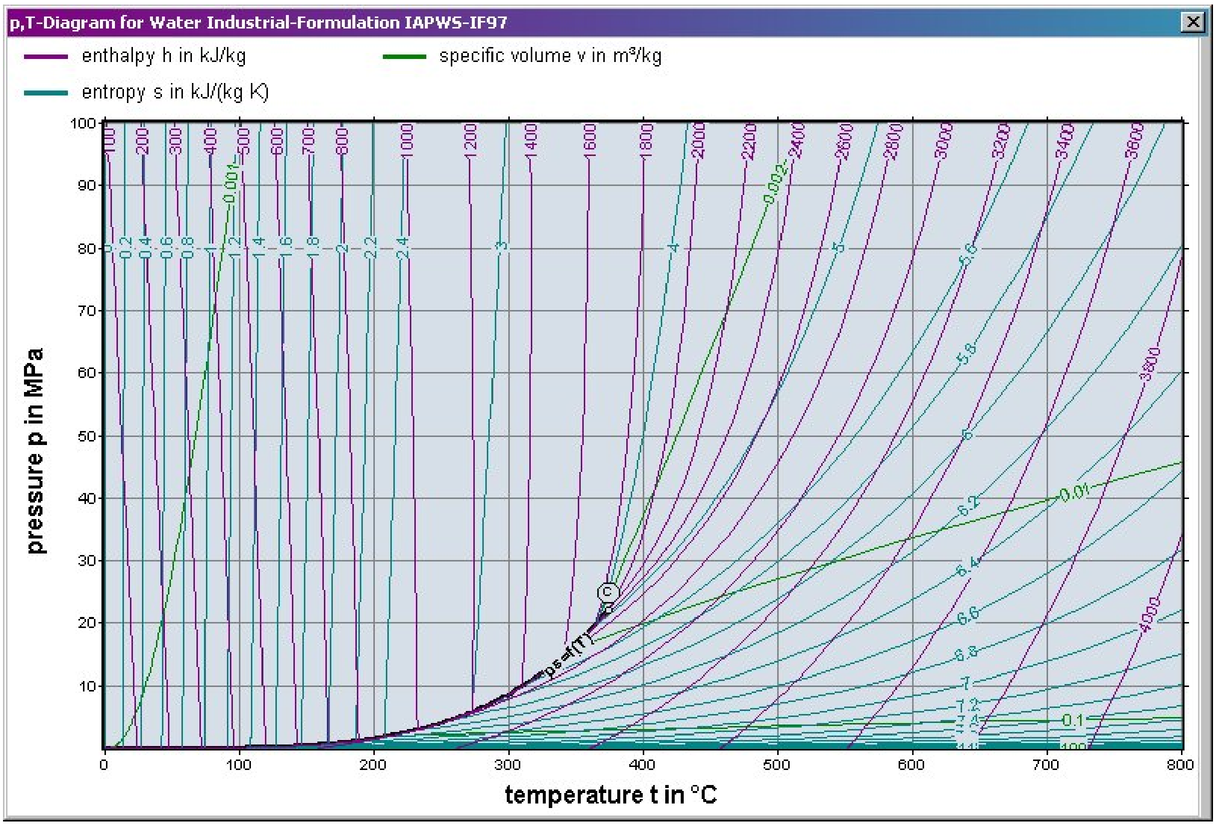
lgp,lg v-Diagram for Water Industrial-Formulation IAPWS-IF97

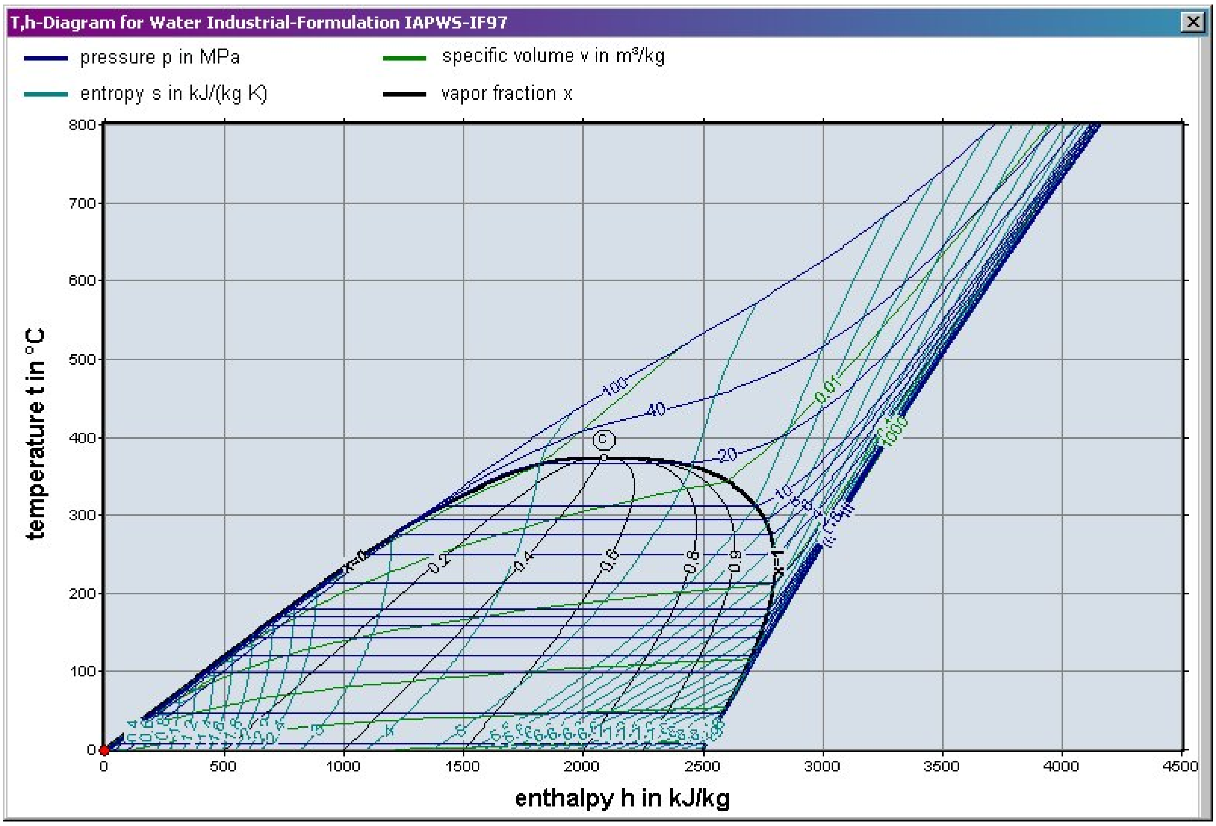


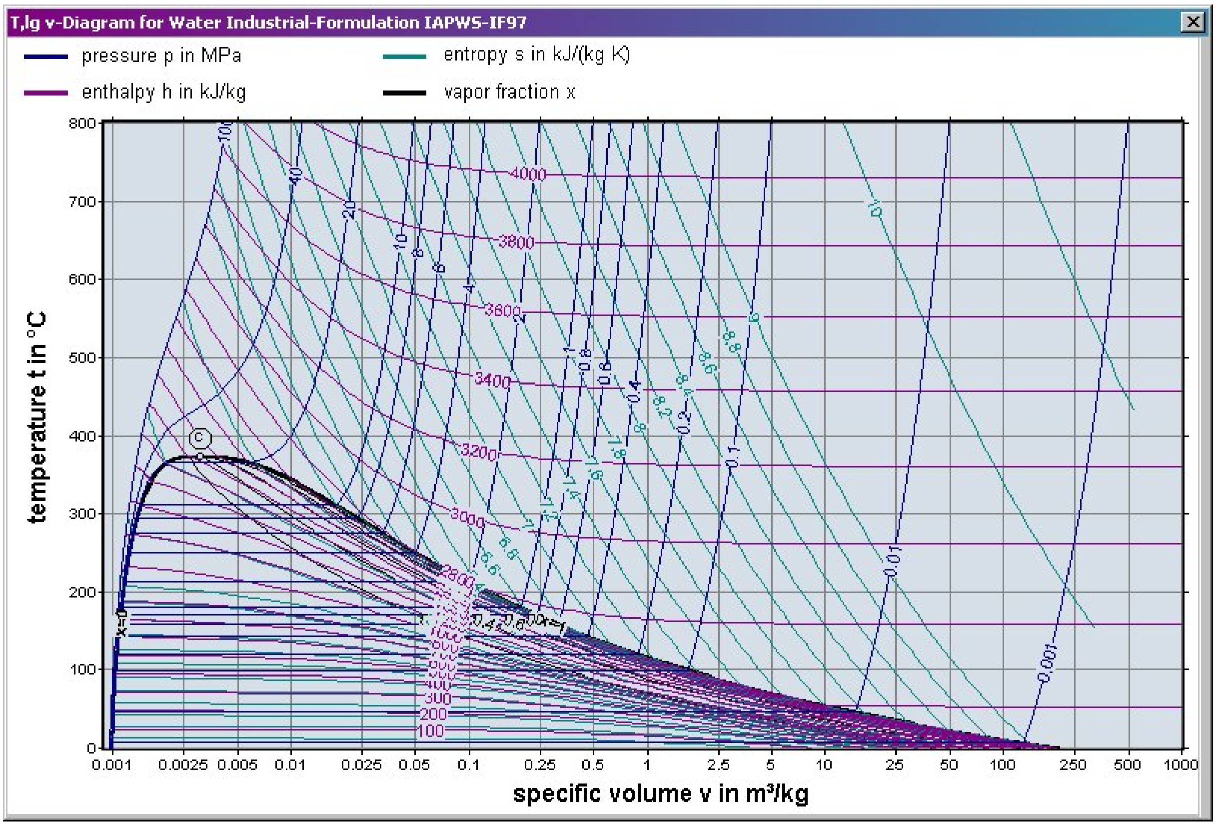
lg p,T-Diagram for Water Industrial-Formulation IAPWS-IF97

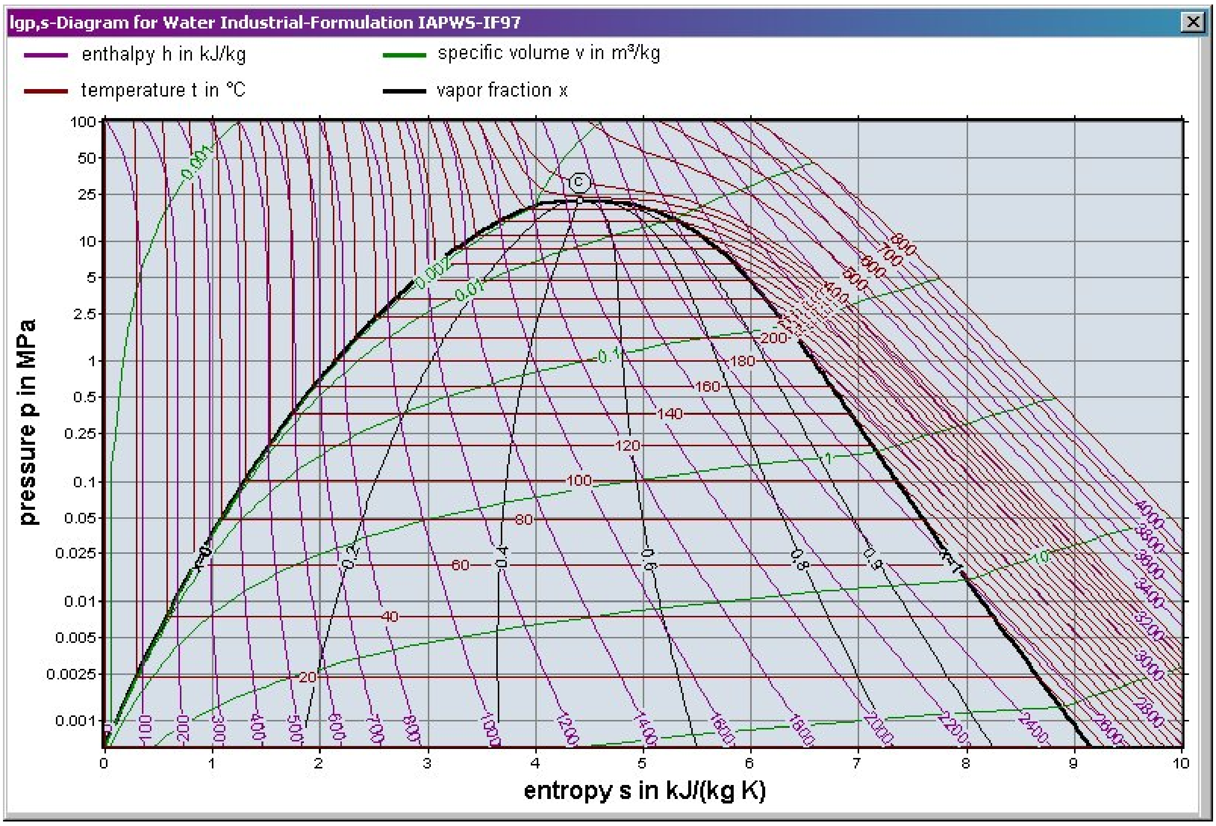

lgp,lg v-Diagram for Water Industrial-Formulation IAPWS-IF97
temperature t in °C
vapor fraction x
pressure p in MPa
100
50
25
10
5
2.5
1
0.5
0.25
0.1
0.05
0.025
0.01
0.005
0.0025
0.001
specific volume v in m³/kg
0.001
0.0025
0.005
0.01
0.025
0.05
0.1
0.25
0.5
1
2.5
5
10
25
50
100
250
500
1000
C
x=0
x=1
0.2
0.4
0.6
0.8
20
40
60
800
0.01002

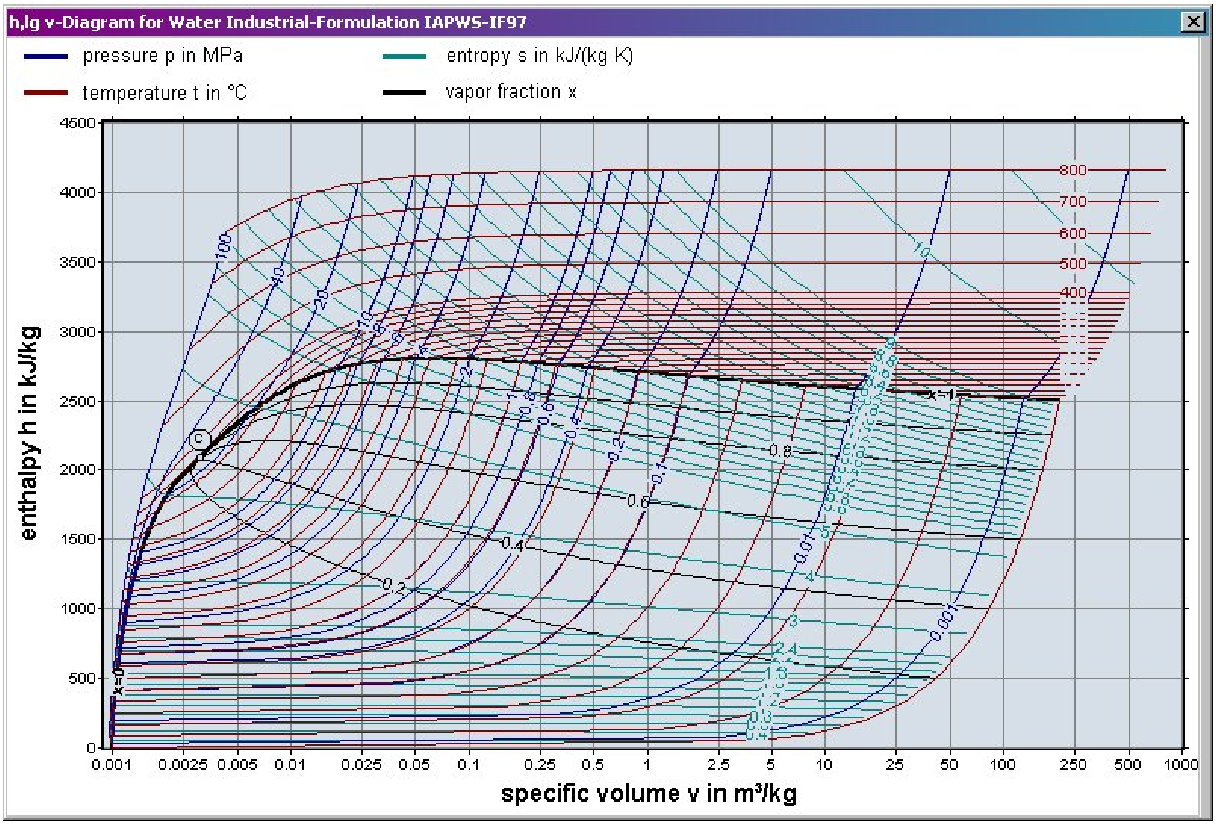

lg p,T-Diagram for Water Industrial-Formulation IAPWS-IF97
enthalpy h in kJ/kg
specific volume v in m³/kg
entropy s in kJ/(kg K)
pressure p in MPa
100
50
25
10
5
2.5
1
0.5
0.25
0.1
0.05
0.025
0.01
0.005
0.0025
0.001
temperature t in °C
0
100
200
300
400
500
600
700
800
C
ps=f(T)
100
200
300
400
500
600
700
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
3
5.5
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
8.8
9
10
11
0.001
0.002
0.01
0.1
1
10
100

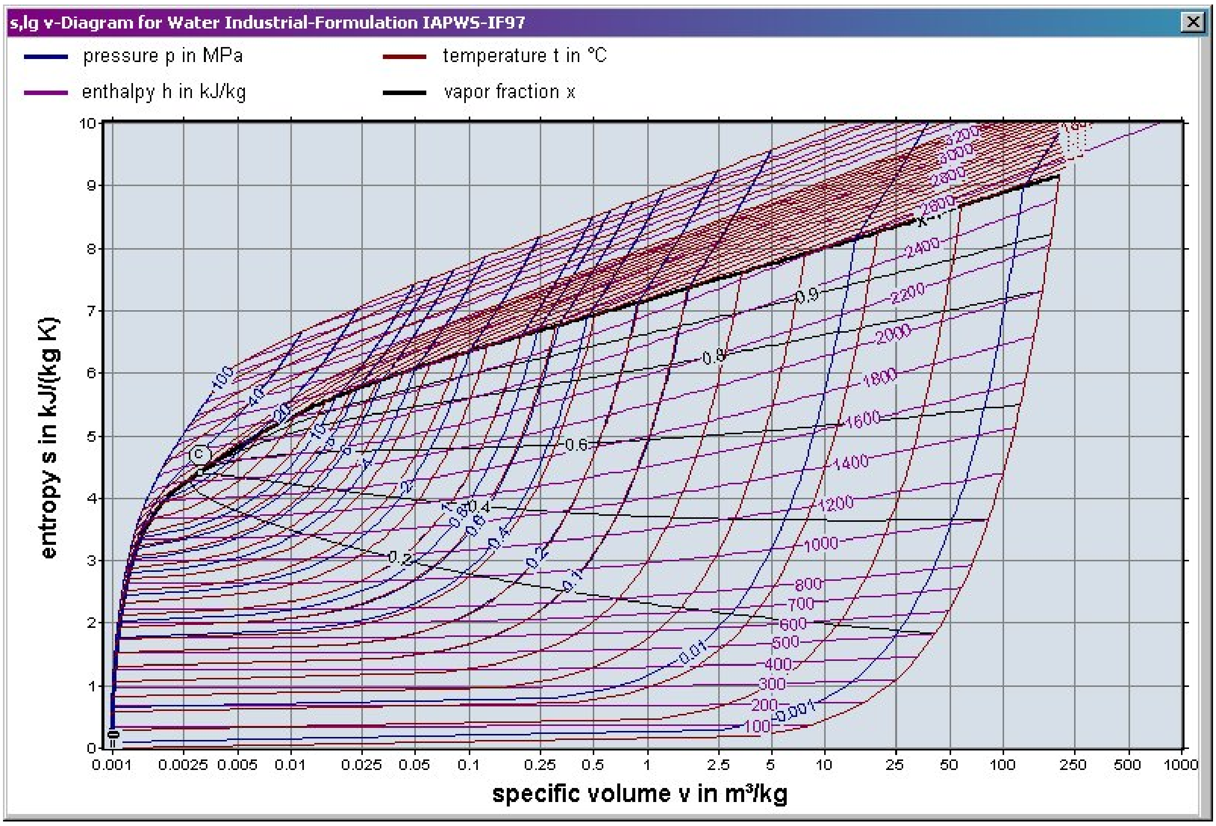

p,T-Diagram for Water Industrial-Formulation IAPWS-IF97
enthalpy h in kJ/kg
specific volume v in m³/kg
entropy s in kJ/(kg K)
pressure p in MPa
temperature t in °C
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
ps=f(T)
C
0.001
0.002
0.01
0.1
100
200
300
400
500
600
700
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
3
4
5
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4


T,h-Diagram for Water Industrial-Formulation IAPWS-IF97
pressure p in MPa
specific volume v in m³/kg
entropy s in kJ/(kg K)
vapor fraction x
temperature t in °C
enthalpy h in kJ/kg
0
100
200
300
400
500
600
700
800
0
500
1000
1500
2000
2500
3000
3500
4000
4500
C
100
40
20
10
0.01
1000
x=0
x=1
0.2
0.4
0.6
0.8
0.9


T,lg v-Diagram for Water Industrial-Formulation IAPWS-IF97
pressure p in MPa
entropy s in kJ/(kg K)
enthalpy h in kJ/kg
vapor fraction x
temperature t in °C
0
100
200
300
400
500
600
700
800
specific volume v in m³/kg
0.001
0.0025
0.005
0.01
0.025
0.05
0.1
0.25
0.5
1
2.5
5
10
25
50
100
250
500
1000
C
x=0
x=1
4000
3800
3600
3400
3200
3000
2800


lgp,s-Diagram for Water Industrial-Formulation IAPWS-IF97
enthalpy h in kJ/kg
specific volume v in m³/kg
temperature t in °C
vapor fraction x
pressure p in MPa
100
50
25
10
5
2.5
1
0.5
0.25
0.1
0.05
0.025
0.01
0.005
0.0025
0.001
entropy s in kJ/(kg K)
0
1
2
3
4
5
6
7
8
9
10
C
x=0
x=1
0.2
0.4
0.6
0.8
0.9
20
40
60
80
100
120
140
160
180
200
400
500
600
700
800


h,lg v-Diagram for Water Industrial-Formulation IAPWS-IF97
pressure p in MPa
entropy s in kJ/(kg K)
temperature t in °C
vapor fraction x
enthalpy h in kJ/kg
0
500
1000
1500
2000
2500
3000
3500
4000
4500
specific volume v in m³/kg
0.001
0.0025
0.005
0.01
0.025
0.05
0.1
0.25
0.5
1
2.5
5
10
25
50
100
250
500
1000
800
700
600
500
400
C
x=0
x=1
0.2
0.4
0.6
0.8
100
40
20
10
0.1
0.01
0.001


s,lg v-Diagram for Water Industrial-Formulation IAPWS-IF97
pressure p in MPa
temperature t in °C
enthalpy h in kJ/kg
vapor fraction x
entropy s in kJ/(kg K)
0
1
2
3
4
5
6
7
8
9
10
specific volume v in m³/kg
0.001
0.0025
0.005
0.01
0.025
0.05
0.1
0.25
0.5
1
2.5
5
10
25
50
100
250
500
1000
C
0.2
0.6
0.8
0.9
100
40
20
10
0.1
0.01
0.001
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
700
600
500
400
300
200
100

# 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 LibIF97 property library.

## 2.1 Installing FluidEXL*Graphics*

If FluidEXL*Graphics* has not yet been installed or if there is a version installed which has been delivered before June 2010, please complete the initial installation procedure described below.

If FluidEXL*Graphics* has already been installed in a version which has been delivered after June 2010, you simply need to copy the files which belong to the LibIF97 library. In this case, follow the subsection "Adding the LibIF97 Library" on page 2/11.

### Installing FluidEXL*Graphics* for 32-bit Office®

Complete the following steps for initial installation of FluidEXL*Graphics*.
Before you begin, it is best to uninstall any trial version or full version of FluidEXL*Graphics* delivered before June 2010.
After you have downloaded and extracted the zip-file

| | |
|---|---|
| "CD_FluidEXL_Graphics_LibIF97_Eng.zip" | (for English version of Windows) |
| "CD_FluidEXL_Graphics_LibIF97.zip" | (for German version of Windows) |

you will see the folder

| | |
|---|---|
| CD_FluidEXL_Graphics_LibIF97_Eng | (for English version of Windows) |
| CD_FluidEXL_Graphics_LibIF97 | (for German version of Windows) |

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files:

| | |
|---|---|
| FluidEXL_Graphics_Eng_Setup.exe | (for English version of Windows) |
| FluidEXL_Graphics_Setup.exe | (for German version of Windows) |
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla | (for German version of Windows) |
| FluidEXL_Graphics_LibIF97_Docu_Eng.pdf | |
| LibIF97.dll | |
| LibIF97.hlp. | |

In order to run the installation of FluidEXL*Graphics* double-click the file

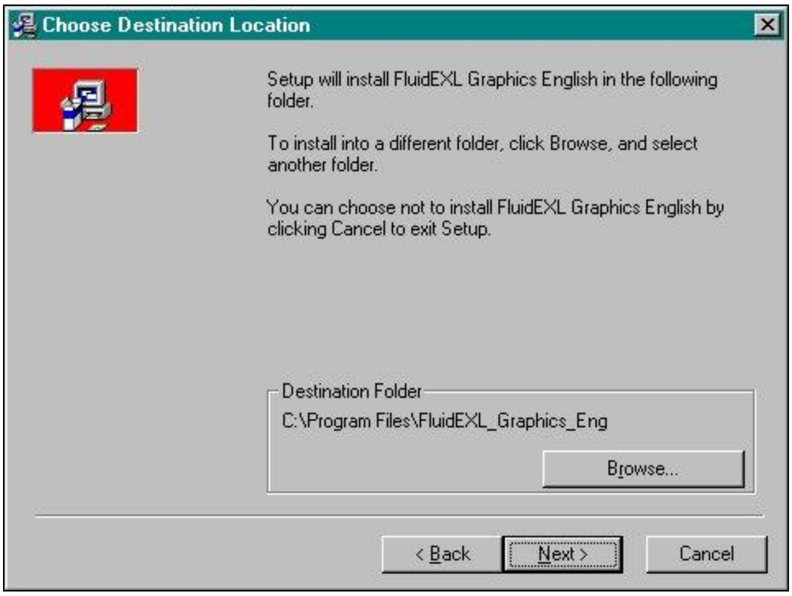
| | |
|---|---|
| FluidEXL_Graphics_Eng_Setup.exe | (for English version of Windows) |
| FluidEXL_Graphics_Setup.exe | (for German version of Windows). |

Installation may start with a window noting that all Windows programs should be closed. When this is the case, the installation can be continued. Click the "Continue" button.

In the following dialog box, "Choose Destination Location", the default path offered automatically for the installation of FluidEXL$^{\textit{Graphics}}$ is

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows). |

By clicking the "Browse…" button, you can change the installation directory before installation (see figure below).



Setup will install FluidEXL Graphics English in the following folder.

To install into a different folder, click Browse, and select another folder.

You can choose not to install FluidEXL Graphics English by clicking Cancel to exit Setup.

Destination Folder: C:\Program Files\FluidEXL_Graphics_Eng

**Figure 2.1:** Choose Destination Location

Finally, click on "Next" to continue installation; click "Next" again in the "Start Installation" window which follows in order to start the installation of FluidEXL$^{\textit{Graphics}}$.

After FluidEXL$^{\textit{Graphics}}$ has been installed, the sentence

> "FluidEXL Graphics English has been successfully installed."

will be shown. Confirm this by clicking the "Finish" button.

During the installation process the following files

- Advapi32.dll
- DFORMD.dll
- Dforrt.dll
- UNWISE.EXE
- INSTALL_EXL.LOG
- LC.dll
- Msvcp60.dll
- Msvcrt.dll
- UNWISE.INI

have been copied into the chosen destination folder, in the standard case

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows). |

In addition, the two subdirectories \FORMULATION97 and \FLuft have been compiled in the destination folder.

In the next step, the following files

| | |
|---|---|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla | (for German version of Windows) |
| LibIF97.dll | |
| LibIF97.hlp | |

from the extracted folder

CD_FluidEXL_Graphics_LibIF97_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibIF97 (for German version of Windows)

must be copied into the chosen destination folder (the standard being

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows),

using an appropriate program such as Explorer or Norton Commander.

## Installing FluidEXL$^{Graphics}$ for 64-bit Office®

Complete the following steps for initial installation of FluidEXL$^{Graphics}$.

Before you begin, it is best to uninstall any trial version or full version of FluidEXL$^{Graphics}$ delivered before June 2010.

After you have downloaded and extracted the zip-file

"CD_FluidEXL_Graphics_LibIF97_x64_Eng.zip" (for English version of Windows)
"CD_FluidEXL_Graphics_LibIF97_x64.zip" (for German version of Windows)

you will see the folder

CD_FluidEXL_Graphics_LibIF97_Eng (for English version of Windows)
CD_FluidEXL_Graphics_LibIF97 (for German version of Windows)

in your Windows Explorer, Norton Commander etc.

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

Within this folder you will see the following files

FluidEXL_Graphics_LibIF97_Docu_Eng

FluidEXL_Graphics_Eng.xla (for English version of Windows)
FluidEXL_Graphics.xla (for German version of Windows)

FluidEXL_Graphics_Eng_Setup_64.msi (for English version of Windows)
FluidEXL_Graphics_Setup_64.msi (for German version of Windows)

LibIF97.dll

LibIF97.hlp

Setup.exe

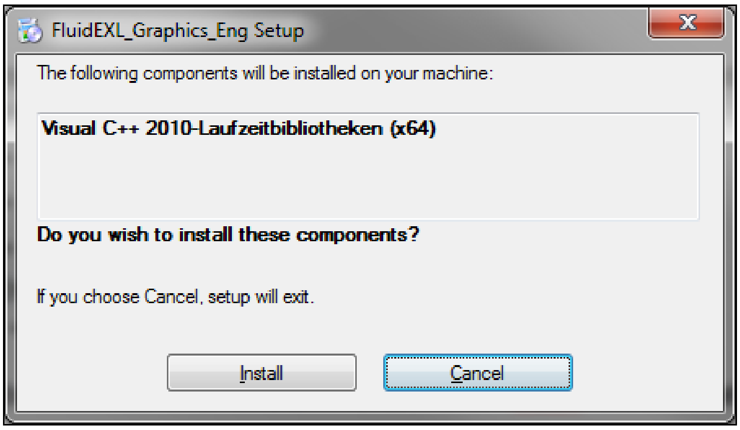
and the folders

vcredist_x64
WindowsInstaller3_1.

In order to run the installation of FluidEXL$^{Graphics}$ double-click the file

Setup.exe.

If the "Microsoft Visual C++ 2010 x64 Redistributable Pack" is not running on your computer yet, installation will start with a window noting that the "Visual C++ 2010 runtime library (x64)" will be installed on your machine (see figure below).


FluidEXL_Graphics_Eng Setup

The following components will be installed on your machine:

**Visual C++ 2010-Laufzeitbibliotheken (x64)**

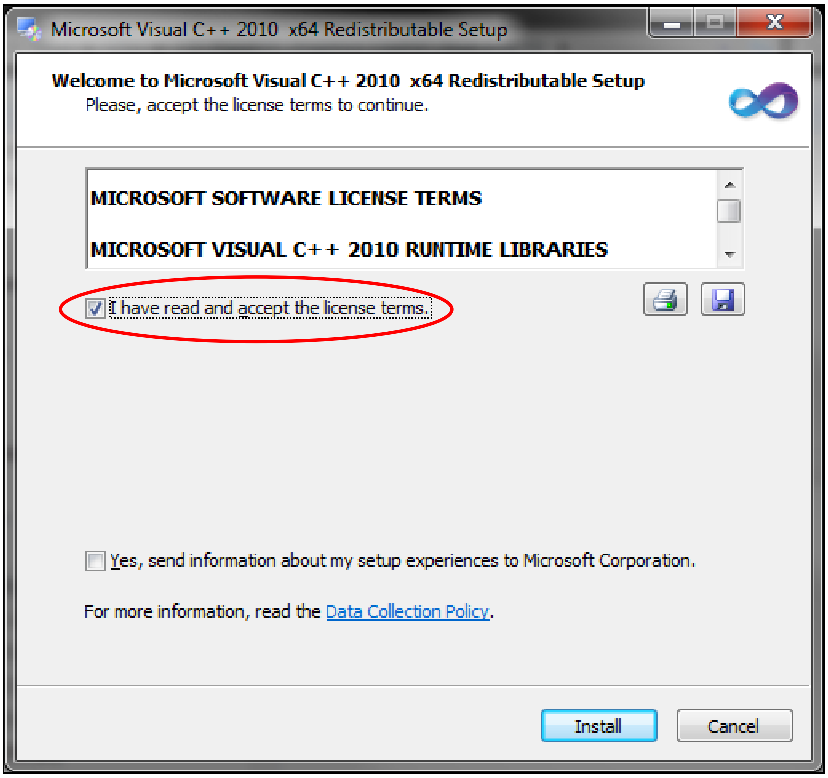
**Do you wish to install these components?**

If you choose Cancel, setup will exit.

**Figure 2.2:** Installing the "Visual C++ 2010 runtime library (x64)"

Click on "Install" to continue.

In the following window you are required to accept the Microsoft® license terms to install the "Microsoft Visual C++ 2010 x64 Redistributable Pack" by ticking the box next to "I have read and accept the license terms" (see figure below).


Microsoft Visual C++ 2010 x64 Redistributable Setup

**Welcome to Microsoft Visual C++ 2010 x64 Redistributable Setup**
Please, accept the license terms to continue.

**MICROSOFT SOFTWARE LICENSE TERMS**

**MICROSOFT VISUAL C++ 2010 RUNTIME LIBRARIES**

☑ I have read and accept the license terms.

☐ Yes, send information about my setup experiences to Microsoft Corporation.

For more information, read the Data Collection Policy.

**Figure 2.3:** Accepting the license terms

Now click on "Install" to continue installation.

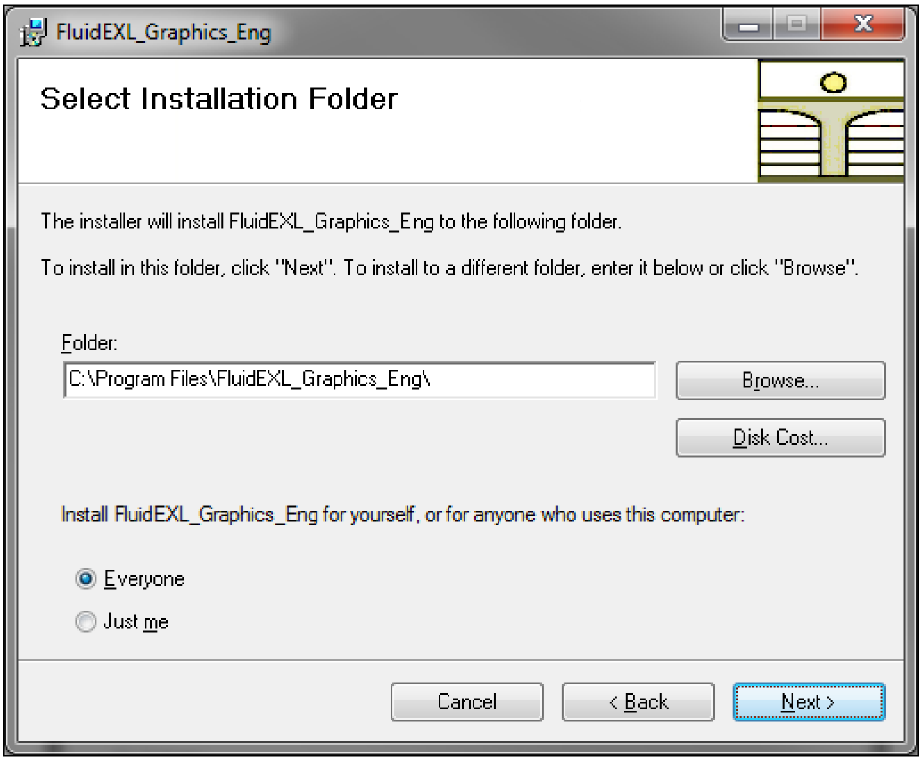
After the "Microsoft Visual C++ 2010 x64 Redistributable Pack" has been installed, you will see the sentence "Microsoft Visual C++ 2010 x64 Redistributable has been installed." Confirm this by clicking "Finish."

Now the installation of FluidEXL_Graphics_Eng_64 starts with a window noting that the installer will guide you through the installation. Click the "Next >" button to continue.

In the following dialog box, "Select Installation Folder," the default path offered automatically for the installation of FluidEXL$^{Graphics}$ is

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows). |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows). |

By clicking the "Browse…" button, you can change the installation directory before installation (see Figure 2.4).


FluidEXL_Graphics_Eng

Select Installation Folder

The installer will install FluidEXL_Graphics_Eng to the following folder.

To install in this folder, click "Next". To install to a different folder, enter it below or click "Browse".

Folder: C:\Program Files\FluidEXL_Graphics_Eng\

Install FluidEXL_Graphics_Eng for yourself, or for anyone who uses this computer:

● Everyone

○ Just me

**Figure 2.4:** Choosing the Installation Folder of FluidEXL$^{Graphics}$

Finally, click on "Next >" to continue installation; click "Next >" again in the "Confirm Installation" window which follows in order to start the installation of FluidEXL$^{Graphics}$.

After FluidEXL$^{Graphics}$ has been installed, you will see the sentence "FluidEXL_Graphics_Eng has been successfully installed." Confirm this by clicking the "Close" button.

During the installation process the following files will have been copied into the destination folder chosen, the standard being C:\Program Files\FluidEXL_Graphics_Eng:

capt_ico_big.ico
libifcoremd.dll
libiomp5md.dll.
libmmd.dll
LC.dll

In addition, the two subdirectories \FORMULATION97 and \FLuft were created in the destination folder.

In the next step, the files below,

| | |
|---|---|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla | (for German version of Windows) |
| LibIF97.dll | |
| LibIF97.hlp | |

found in your CD folder, must be copied into the chosen destination folder (the standard being

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows)) |

using an appropriate program such as Explorer or Norton Commander.

## 2.2 Registering FluidEXL$^{Graphics}$ as Add-In in Excel®

### Registering FluidEXL$^{Graphics}$ as Add-In in Excel®, versions 2003 or earlier

After the installation of FluidEXL$^{Graphics}$, the program must be registered as an Add-In in Excel®. In order to do so, start Excel® and carry out the following steps:

- Click "Tools" in the upper menu bar of Excel®.
- Here, click the "Add-Ins..." menu item.
  After a short delay the "Add-Ins" dialog box will appear.
- Click "Browse...."
- In the following dialog box, choose your chosen destination folder (the standard being

  | | |
  |---|---|
  | C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
  | C:\Programme\FluidEXL_Graphics | (for German version of Windows)) |

  here select

  | | |
  |---|---|
  | "FluidEXL_Graphics_Eng.xla" | (for English version of Windows) |
  | "FluidEXL_Graphics.xla" | (for German version of Windows) |

  and afterwards click "OK".
- Now, the entry

  | | |
  |---|---|
  | "FluidEXL Graphics Eng" | (for English version of Windows) |
  | "FluidEXL Graphics" | (for German version of Windows) |

  will appear in the Add-Ins list.

***Note:***

*As long as the check box next to the file name "FluidEXL Graphics Eng" is checked, this Add-In will be loaded automatically every time you start Excel® until you unmark the box by clicking on it again.*

In order to register FluidEXL$^{Graphics}$ as an Add-In, click "OK" in the "Add-Ins" dialog box. Now, the new FluidEXL$^{Graphics}$ menu bar will appear in the upper menu area of your Excel® screen, marked with a red circle in Figure 2.5.

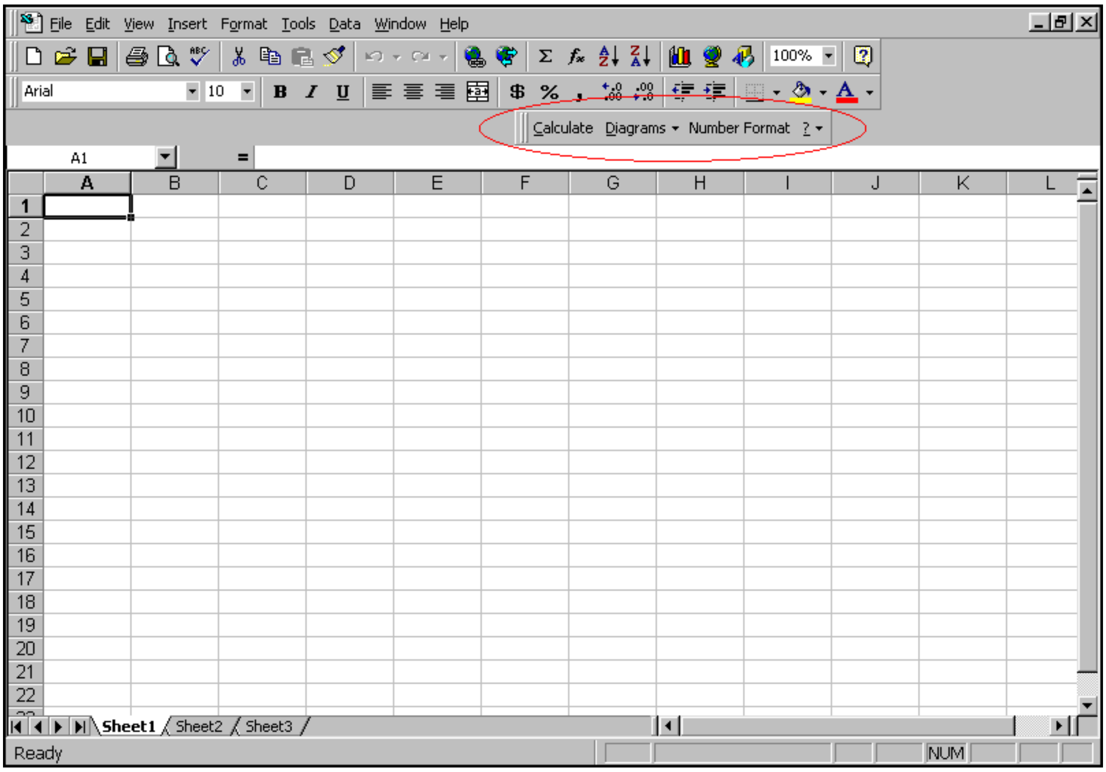


**Figure 2.5:** Menu bar of FluidEXL*Graphics*

From within Excel you can now select the "Water IAPWS-IF97" DLL library property functions via this menu bar (cf. part 2.5 on page 2/19).

## Registering FluidEXL$^{Graphics}$ as Add-In in Excel® 2007 (or later versions)

After installation in Windows®, FluidEXL$^{Graphics}$ must be registered in Excel® versions 2007 and later as an Add-In. To do this, start Excel® and carry out the following steps:

- Click the Windows Office® button in the upper left hand corner of Excel®
- Click on the "Excel Options" button in the menu which appears (see Figure 2.6)

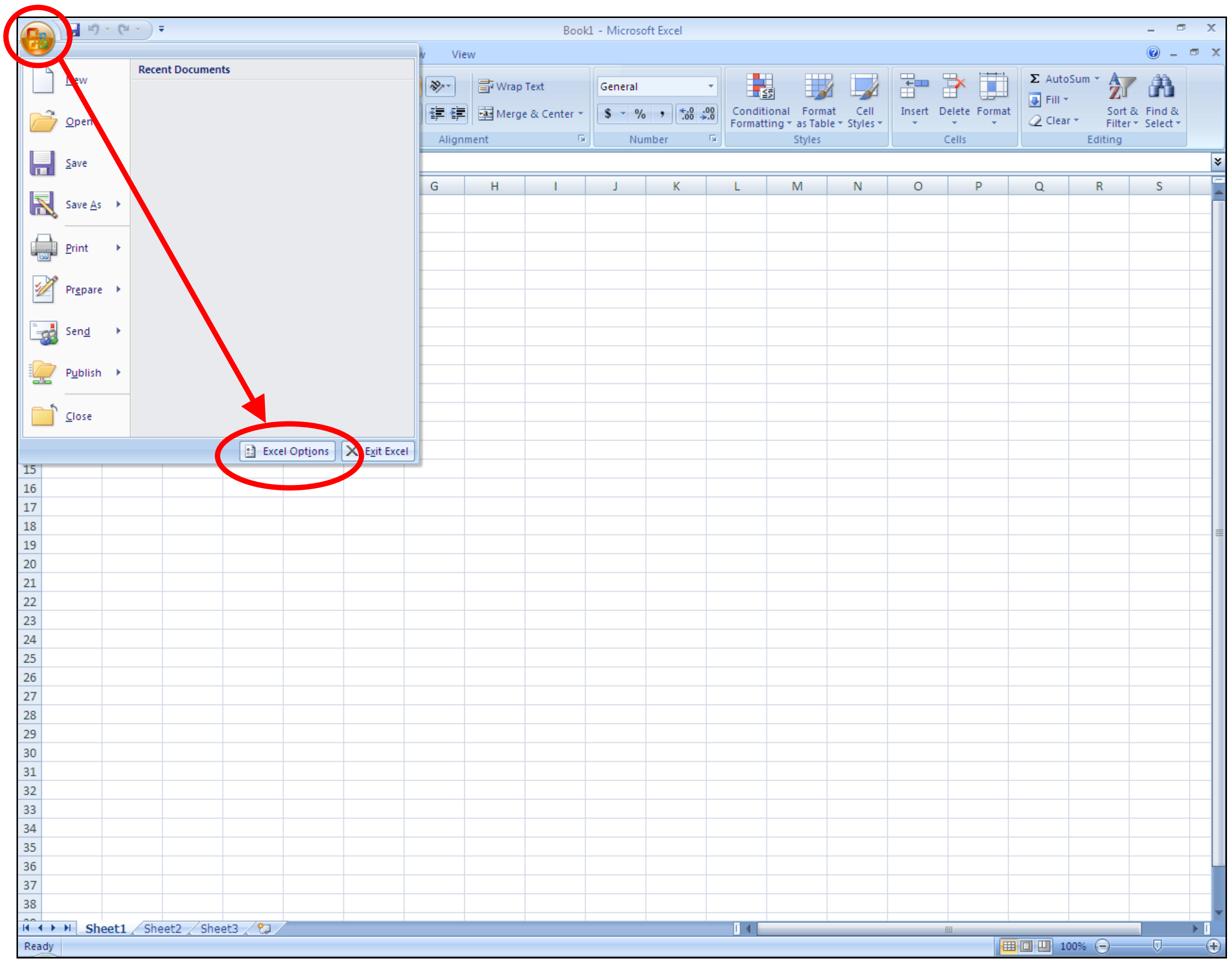
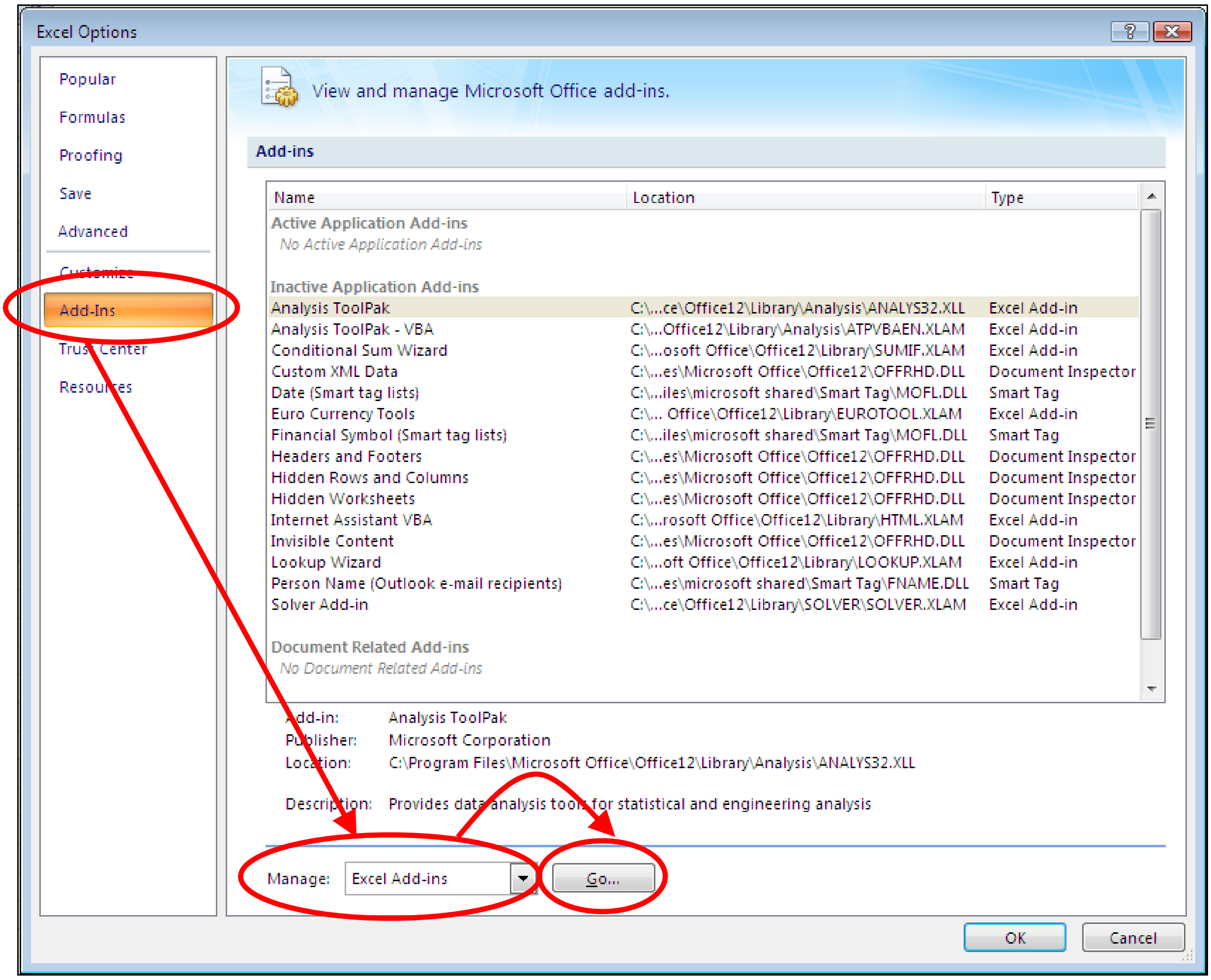


**Figure 2.6:** Registering FluidEXL$^{Graphics}$ as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu



| Name | Location | Type |
|---|---|---|
| Active Application Add-ins | | |
| *No Active Application Add-ins* | | |
| Inactive Application Add-ins | | |
| Analysis ToolPak | C:\...ce\Office12\Library\Analysis\ANALYS32.XLL | Excel Add-in |
| Analysis ToolPak - VBA | C:\...Office12\Library\Analysis\ATPVBAEN.XLAM | Excel Add-in |
| Conditional Sum Wizard | C:\...osoft Office\Office12\Library\SUMIF.XLAM | Excel Add-in |
| Custom XML Data | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Date (Smart tag lists) | C:\...iles\microsoft shared\Smart Tag\MOFL.DLL | Smart Tag |
| Euro Currency Tools | C:\... Office\Office12\Library\EUROTOOL.XLAM | Excel Add-in |
| Financial Symbol (Smart tag lists) | C:\...iles\microsoft shared\Smart Tag\MOFL.DLL | Smart Tag |
| Headers and Footers | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Hidden Rows and Columns | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Hidden Worksheets | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Internet Assistant VBA | C:\...rosoft Office\Office12\Library\HTML.XLAM | Excel Add-in |
| Invisible Content | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Lookup Wizard | C:\...oft Office\Office12\Library\LOOKUP.XLAM | Excel Add-in |
| Person Name (Outlook e-mail recipients) | C:\...es\microsoft shared\Smart Tag\FNAME.DLL | Smart Tag |
| Solver Add-in | C:\...ce\Office12\Library\SOLVER\SOLVER.XLAM | Excel Add-in |
| Document Related Add-ins | | |
| *No Document Related Add-ins* | | |

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Location: C:\Program Files\Microsoft Office\Office12\Library\Analysis\ANALYS32.XLL

Description: Provides data analysis tools for statistical and engineering analysis

Manage: Excel Add-ins

**Figure 2.7:** Dialog window "Excel Options"

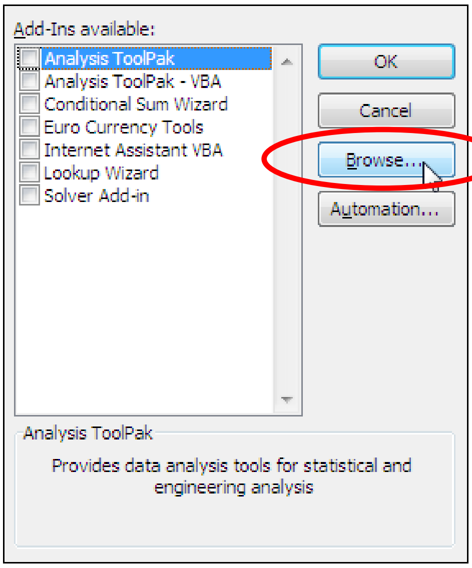
- Should it not be shown in the list automatically, select "Excel Add-ins" (found next to "Manage:" in the lower area of the menu)
- Then click the "Go…" button
- Click "Browse" in the following window and locate the destination folder, generally

  C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
  C:\Programme\FluidEXL_Graphics (for German version of Windows);

  within that folder click on the file named

  "FluidEXL_Graphics_Eng.xla" (for English version of Windows)
  "FluidEXL_Graphics.xla" (for German version of Windows)

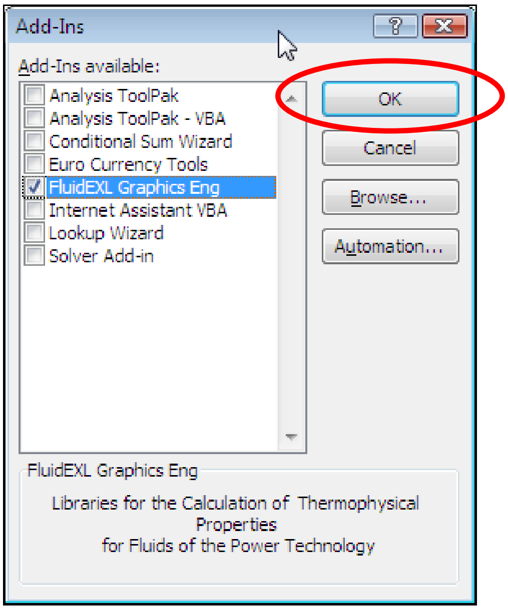
  and then hit "OK."



Provides data analysis tools for statistical and engineering analysis

**Figure 2.8:** Dialog window "Add-Ins available"

- Now, "FluidEXL Graphics Eng" will be shown in your list of Add-Ins.
  (If a check-mark is situated 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 check-mark is removed from the box by clicking on it.)



Libraries for the Calculation of Thermophysical Properties
for Fluids of the Power Technology

**Figure 2.9:** Dialog window "Add-Ins"

- In order to register the Add-In click the "OK" button in the "Add-Ins" window.

In order to use FluidEXL*Graphics* in the following example, click on the menu item "Add-Ins" shown in Figure 2.10.

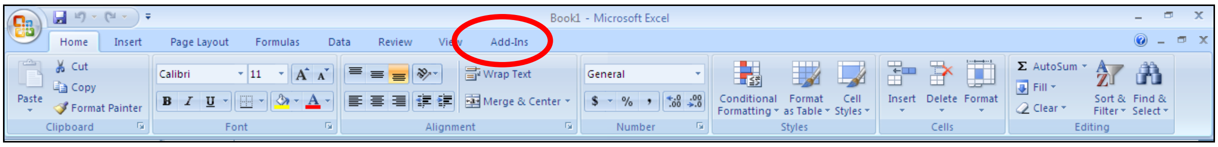


**Figure 2.10:** Menu item "Add-Ins"

In the upper menu region of Excel, the FluidEXL$^{\mathit{Graphics}}$ menu bar will appear as marked with the red circle in the next figure.

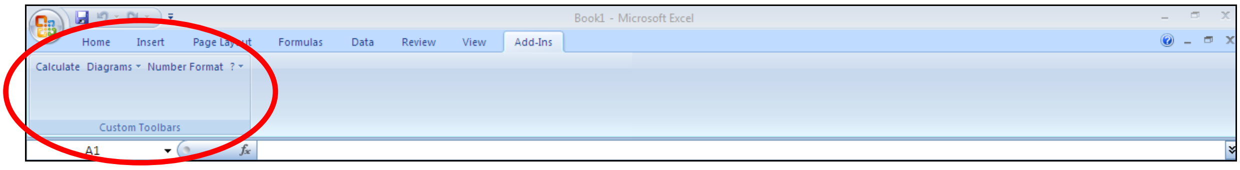


**Figure 2.11:** FluidEXL$^{\mathit{Graphics}}$ menu bar

Installation of FluidEXL$^{\mathit{Graphics}}$ in Excel® (versions 2007 and later) is now finished. FluidEXL$^{\mathit{Graphics}}$ can be used analogous to the description for using with earlier Excel® versions.

### Adding the LibIF97 Library (FluidEXL$^{\mathit{Graphics}}$ is already installed)

If FluidEXL$^{\mathit{Graphics}}$ has already been installed in the June 2010 version, you only have to copy the following files

| | |
|---|---|
| FluidEXL_Graphics_Eng.xla | (for English version of Windows) |
| FluidEXL_Graphics.xla | (for German version of Windows) |
| LibIF97.dll | |
| LibIF97.hlp | |

provided in the extracted folder

| | |
|---|---|
| CD_FluidEXL_Graphics_LibIF97_Eng | (for English version of Windows) |
| CD_FluidEXL_Graphics_LibIF97 | (for German version of Windows) |

into the folder you have chosen for the installation of FluidEXL$^{\mathit{Graphics}}$ (the standard being

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows) |

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

From within Excel you can now select the "Water IAPWS-IF97" DLL library property functions for water and steam via this menu bar (the example calculation can be found in chapter 2.5 on page 2/19).

## 2.3 The FluidEXL$^{\mathit{Graphics}}$ Help System

As mentioned earlier, FluidEXL$^{\mathit{Graphics}}$ also provides detailed online help functions.

If you are running Windows Vista or Windows 7, please note the paragraph

"Using the FluidEXL$^{\mathit{Graphics}}$ Online-Help in Windows Vista or Windows 7."

For general information in Excel®

- Click on "?" and then "Help" in the FluidEXL$^{\mathit{Graphics}}$ menu bar.

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

- Click "Calculate" in the FluidEXL$^{\mathit{Graphics}}$ menu bar.
- Click on the "Water IAPWS-IF97" 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.
- If the "Office Assistant" is active, first double-click "Help on this feature" and in the next menu click "Help on selected function".

If the LibIF97.hlp function help cannot be found, confirm the question whether you want to look for it yourself with "Yes". Select the LibIF97.hlp file in the installation folder of FluidEXL$^{\textit{Graphics}}$ in the window which is opened, in the standard case

C:\Program Files\FluidEXL_Graphics_Eng (for English version of Windows)
C:\Programme\FluidEXL_Graphics (for German version of Windows)

and click "Yes" in order to complete the search.

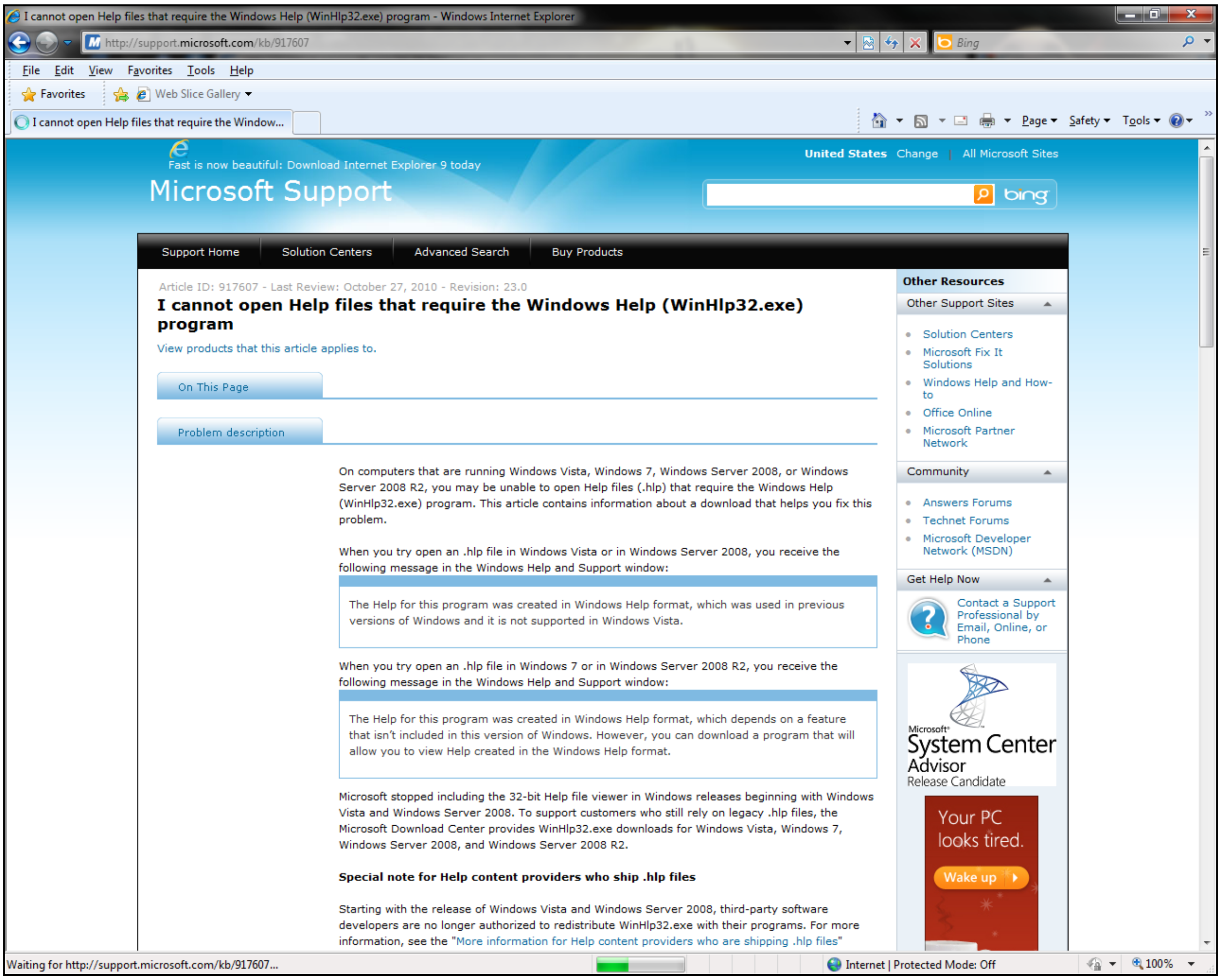
## Using the FluidEXL$^{\textit{Graphics}}$ Online Help in Windows Vista or Windows 7

If you are running Windows Vista or Windows 7 on your computer, you might not be able to open Help files. To view these files you have to install the Microsoft® Windows Help program which is provided by Microsoft®. Please carry out the following steps in order to download and install the Windows Help program.

Open Microsoft Internet Explorer® and go to the following address:

http://support.microsoft.com/kb/917607/

You will see the following web page:



Article ID: 917607 - Last Review: October 27, 2010 - Revision: 23.0

**I cannot open Help files that require the Windows Help (WinHlp32.exe) program**

View products that this article applies to.

On This Page

Problem description

On computers that are running Windows Vista, Windows 7, Windows Server 2008, or Windows Server 2008 R2, you may be unable to open Help files (.hlp) that require the Windows Help (WinHlp32.exe) program. This article contains information about a download that helps you fix this problem.

When you try open an .hlp file in Windows Vista or in Windows Server 2008, you receive the following message in the Windows Help and Support window:

> The Help for this program was created in Windows Help format, which was used in previous versions of Windows and it is not supported in Windows Vista.

When you try open an .hlp file in Windows 7 or in Windows Server 2008 R2, you receive the following message in the Windows Help and Support window:

> The Help for this program was created in Windows Help format, which depends on a feature that isn't included in this version of Windows. However, you can download a program that will allow you to view Help created in the Windows Help format.

Microsoft stopped including the 32-bit Help file viewer in Windows releases beginning with Windows Vista and Windows Server 2008. To support customers who still rely on legacy .hlp files, the Microsoft Download Center provides WinHlp32.exe downloads for Windows Vista, Windows 7, Windows Server 2008, and Windows Server 2008 R2.

**Special note for Help content providers who ship .hlp files**

Starting with the release of Windows Vista and Windows Server 2008, third-party software developers are no longer authorized to redistribute WinHlp32.exe with their programs. For more information, see the "More information for Help content providers who are shipping .hlp files"

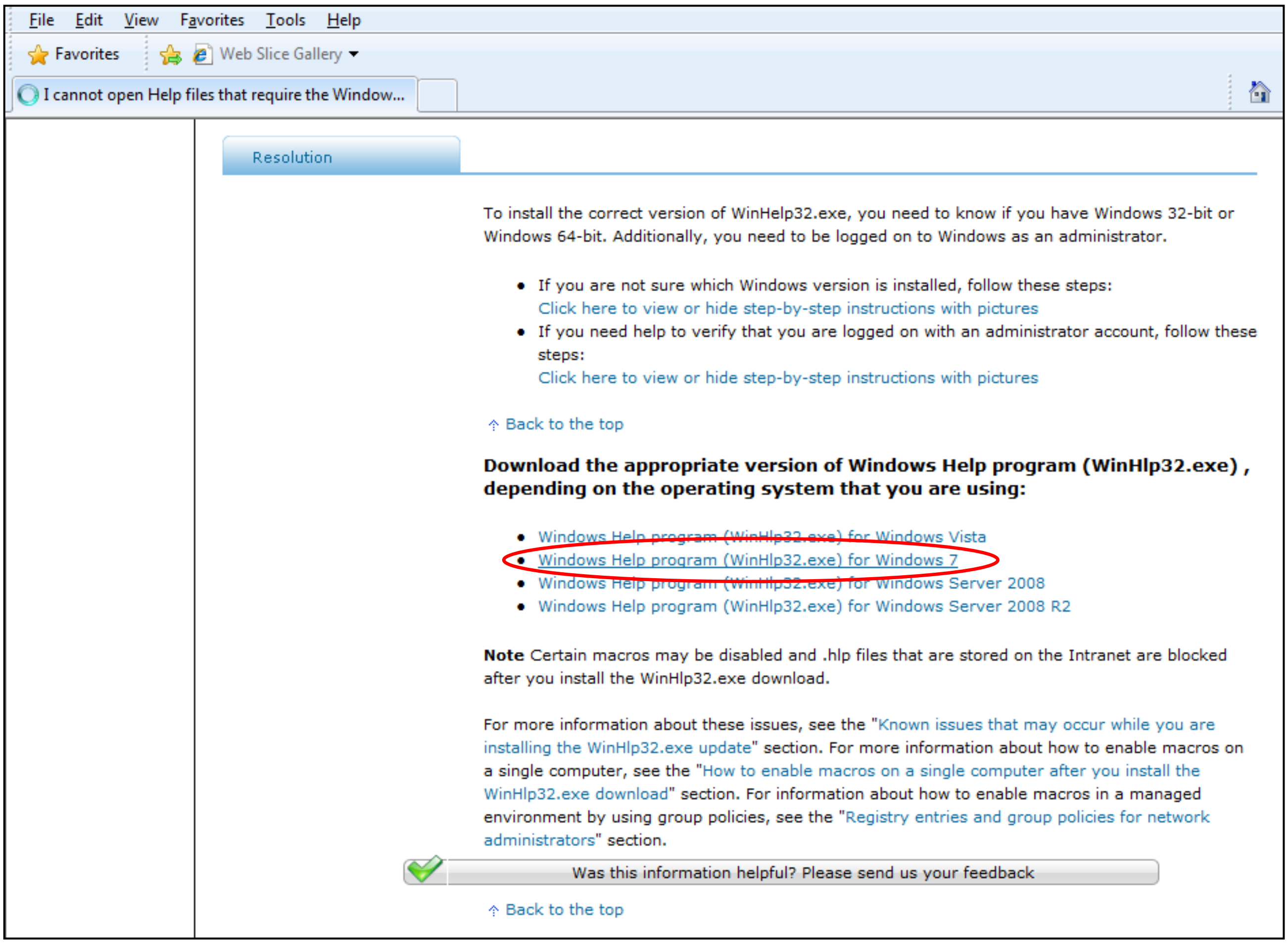
**Figure 2.12:** Microsoft® Support web page

Scroll down until you see the headline "Resolution." Here you can see the bold hint:

> "Download the appropriate version of Windows Help program (WinHlp32.exe), depending on the operating system that you are using:"

The following description relates to Windows® 7. The procedure is analogous for Windows® Vista.

Click on the link "Windows Help program (WinHlp32.exe) for Windows 7" (see Figure 2.13).



To install the correct version of WinHelp32.exe, you need to know if you have Windows 32-bit or Windows 64-bit. Additionally, you need to be logged on to Windows as an administrator.

- If you are not sure which Windows version is installed, follow these steps:
  Click here to view or hide step-by-step instructions with pictures
- If you need help to verify that you are logged on with an administrator account, follow these steps:
  Click here to view or hide step-by-step instructions with pictures

↑ Back to the top

**Download the appropriate version of Windows Help program (WinHlp32.exe) , depending on the operating system that you are using:**

- Windows Help program (WinHlp32.exe) for Windows Vista
- Windows Help program (WinHlp32.exe) for Windows 7
- Windows Help program (WinHlp32.exe) for Windows Server 2008
- Windows Help program (WinHlp32.exe) for Windows Server 2008 R2

**Note** Certain macros may be disabled and .hlp files that are stored on the Intranet are blocked after you install the WinHlp32.exe download.

For more information about these issues, see the "Known issues that may occur while you are installing the WinHlp32.exe update" section. For more information about how to enable macros on a single computer, see the "How to enable macros on a single computer after you install the WinHlp32.exe download" section. For information about how to enable macros in a managed environment by using group policies, see the "Registry entries and group policies for network administrators" section.

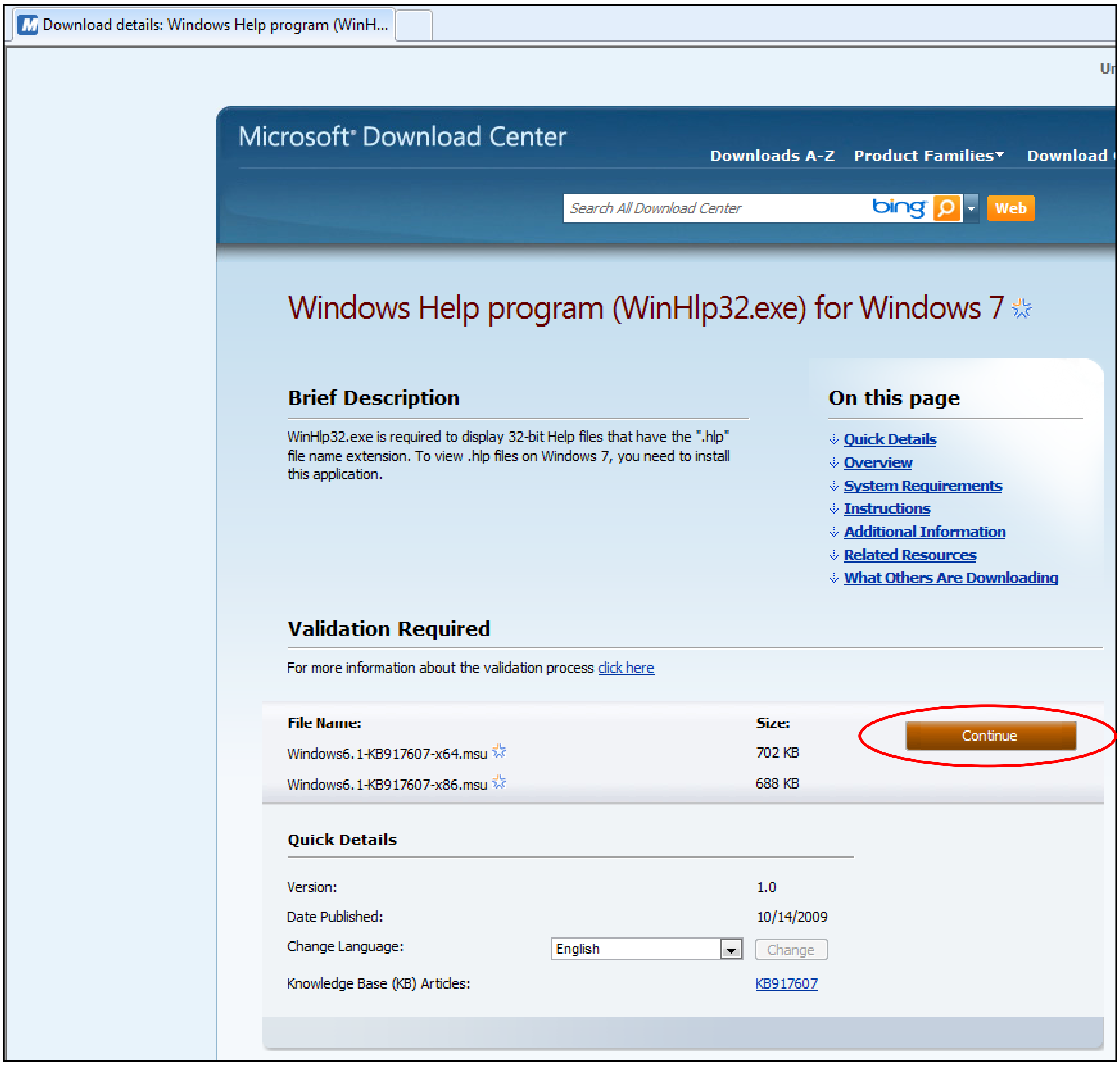
↑ Back to the top

**Figure 2.13:** Selecting your Windows version

You will be forwarded to the Microsoft Download Center where you can download the Microsoft Windows Help program.

First, a validation of your Windows License is required.

To do this click on the "Continue" button (see Figure 2.14).



Windows Help program (WinHlp32.exe) for Windows 7

**Brief Description**

WinHlp32.exe is required to display 32-bit Help files that have the ".hlp" file name extension. To view .hlp files on Windows 7, you need to install this application.

**Validation Required**

For more information about the validation process click here

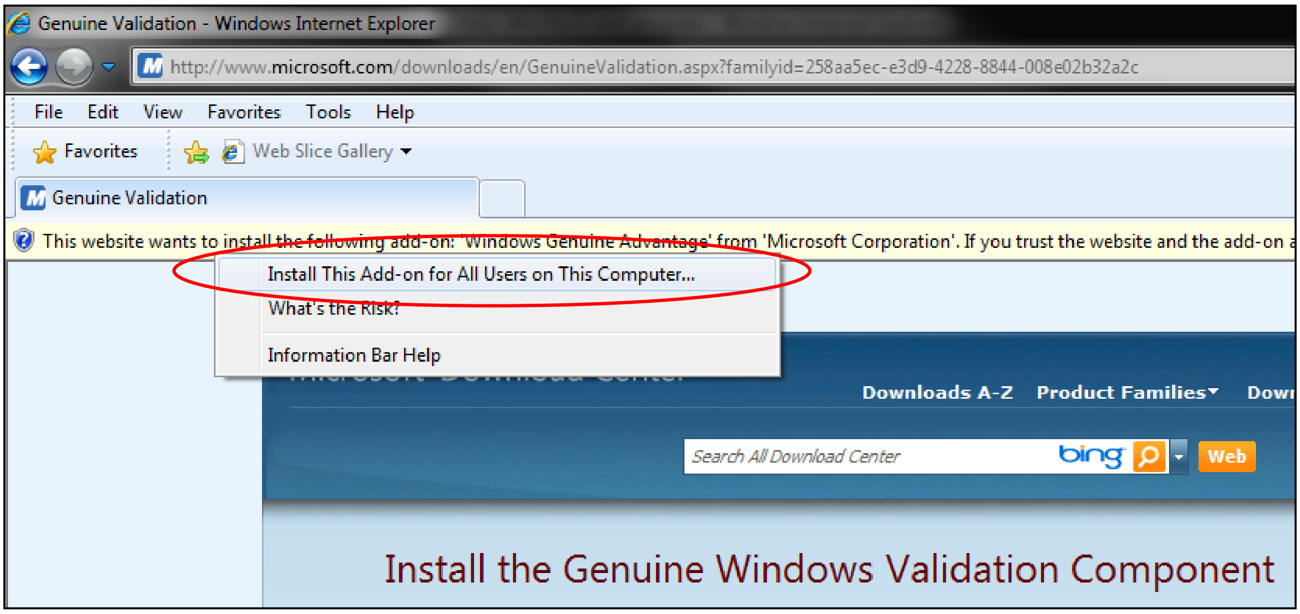
| File Name: | Size: |
|---|---|
| Windows6.1-KB917607-x64.msu | 702 KB |
| Windows6.1-KB917607-x86.msu | 688 KB |

**Quick Details**

| | |
|---|---|
| Version: | 1.0 |
| Date Published: | 10/14/2009 |
| Change Language: | English |
| Knowledge Base (KB) Articles: | KB917607 |

**Figure 2.14:** Microsoft® Download Center

You will be forwarded to a web page with instructions on how to install the Genuine Windows Validation Component.
At the top of your Windows Internet Explorer you will see a yellow information bar. Right-click this bar and select "Install ActiveX Control" in the context menu (see Figure 2.15).



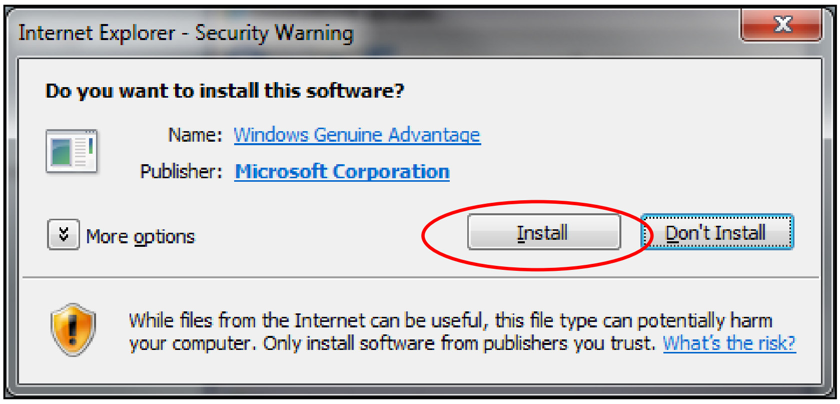
http://www.microsoft.com/downloads/en/GenuineValidation.aspx?familyid=258aa5ec-e3d9-4228-8844-008e02b32a2c

This website wants to install the following add-on: 'Windows Genuine Advantage' from 'Microsoft Corporation'. If you trust the website and the add-on a

Install the Genuine Windows Validation Component

**Figure 2.15:** Installing the Genuine Windows Validation Component

A dialog window appears in which you will be asked if you want to install the software. Click the "Install" button to continue (see Figure 2.16).



Do you want to install this software?

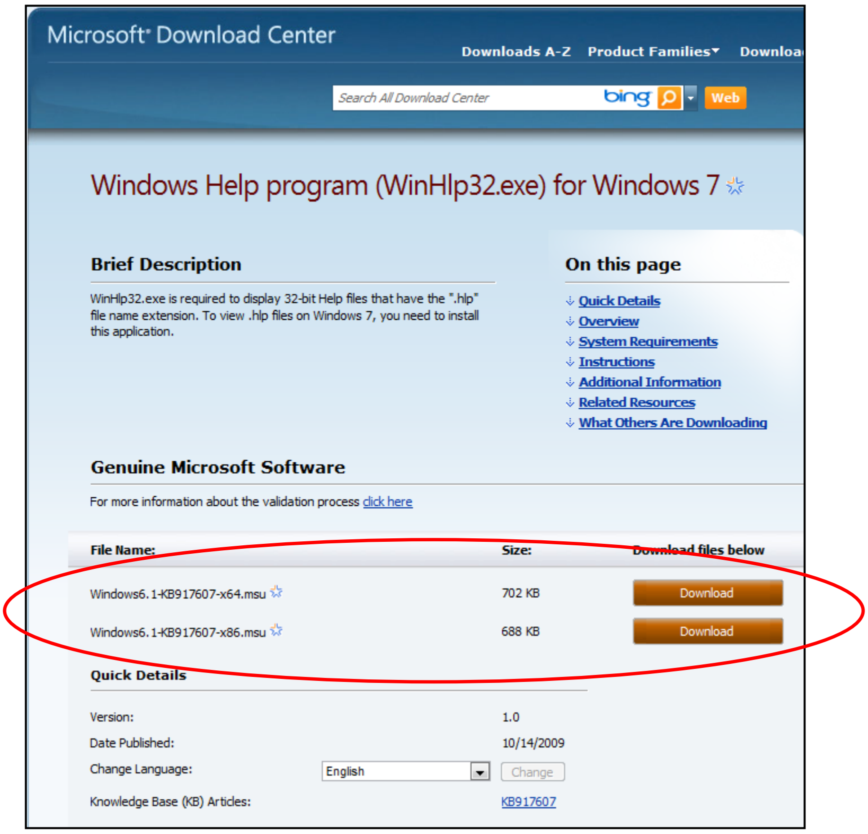
Name: Windows Genuine Advantage

Publisher: Microsoft Corporation

While files from the Internet can be useful, this file type can potentially harm your computer. Only install software from publishers you trust. What's the risk?

**Figure 2.16:** Internet Explorer – Security Warning

After the validation has been carried out you will be able to download the appropriate version of Windows Help program (see Figure 2.17).



Windows Help program (WinHlp32.exe) for Windows 7

**Brief Description**

WinHlp32.exe is required to display 32-bit Help files that have the ".hlp" file name extension. To view .hlp files on Windows 7, you need to install this application.

**Genuine Microsoft Software**

For more information about the validation process click here

| File Name: | Size: | Download files below |
|---|---|---|
| Windows6.1-KB917607-x64.msu | 702 KB | Download |
| Windows6.1-KB917607-x86.msu | 688 KB | Download |

**Quick Details**

| | |
|---|---|
| Version: | 1.0 |
| Date Published: | 10/14/2009 |
| Change Language: | English |
| Knowledge Base (KB) Articles: | KB917607 |

**Figure 2.17:** Downloading the Windows Help program

To download and install the correct file you need to know which Windows version (32-bit or 64-bit) you are running on your computer.

If you are running a 64-bit operating system, please download the file

Windows6.1-KB917607-x64.msu.

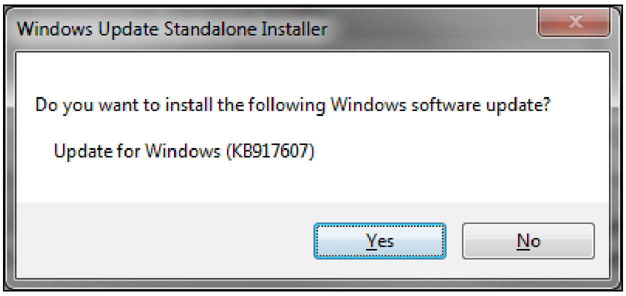
If you are running a 32-bit operating system, please download the file

Windows6.1-KB917607-x86.msu.

In order to run the installation of the Windows Help program double-click the file you have just downloaded on your computer:

Windows6.1-KB917607-x64.msu (for 64-bit operating system)
Windows6.1-KB917607-x86.msu. (for 32-bit operating system).

Installation starts with a window searching for updates on your computer. After the program has finished searching you may see the following window.



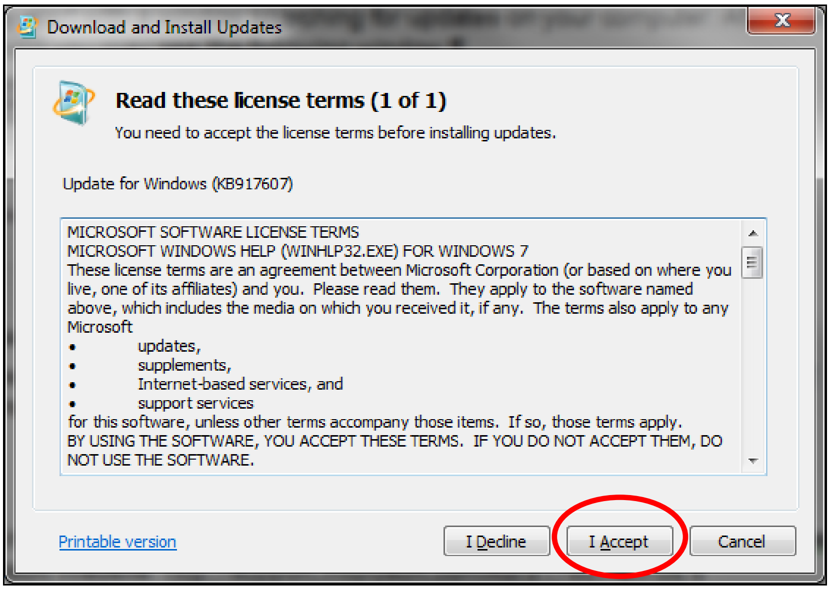
Do you want to install the following Windows software update?

Update for Windows (KB917607)

**Figure 2.18:** Windows Update Standalone Installer

In this case, the installation can be continued by clicking the "Yes" button.
(If you have already installed this update, you will see the message "Update for Windows (KB917607) is already installed on this computer.")

In the next window you have to accept the Microsoft license terms before installing the update by clicking on "I Accept" (see Figure 2.19)



**Read these license terms (1 of 1)**

You need to accept the license terms before installing updates.

Update for Windows (KB917607)

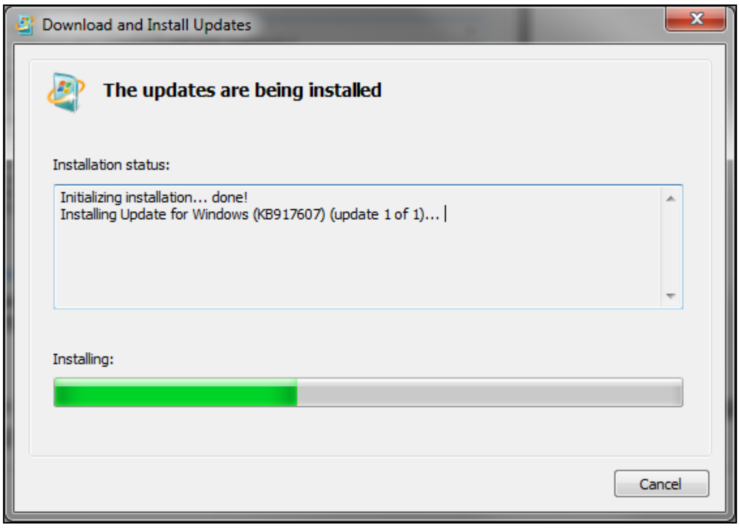
MICROSOFT SOFTWARE LICENSE TERMS
MICROSOFT WINDOWS HELP (WINHLP32.EXE) FOR WINDOWS 7
These license terms are an agreement between Microsoft Corporation (or based on where you live, one of its affiliates) and you. Please read them. They apply to the software named above, which includes the media on which you received it, if any. The terms also apply to any Microsoft

- updates,
- supplements,
- Internet-based services, and
- support services

for this software, unless other terms accompany those items. If so, those terms apply.
BY USING THE SOFTWARE, YOU ACCEPT THESE TERMS. IF YOU DO NOT ACCEPT THEM, DO NOT USE THE SOFTWARE.

**Figure 2.19:** Windows License Terms

Installation starts once you have clicked the "I Accept" button (see Figure 2.20).



**The updates are being installed**

Installation status:

```
Initializing installation... done!
Installing Update for Windows (KB917607) (update 1 of 1)...
```

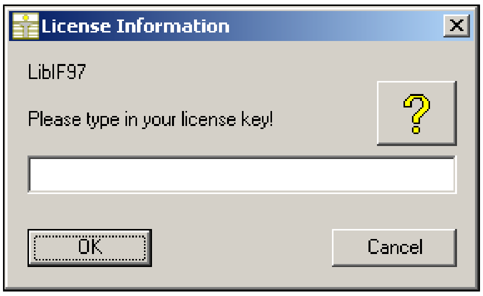
**Figure 2.20:** Installation process

After the Windows Help program has been installed, the notification "Installation complete" will appear. Confirm this by clicking the "Close" button.

The installation of the Windows Help program has been completed and you will now be able to open the Help files.

## 2.4 Licensing the LibIF97 Property Library

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).

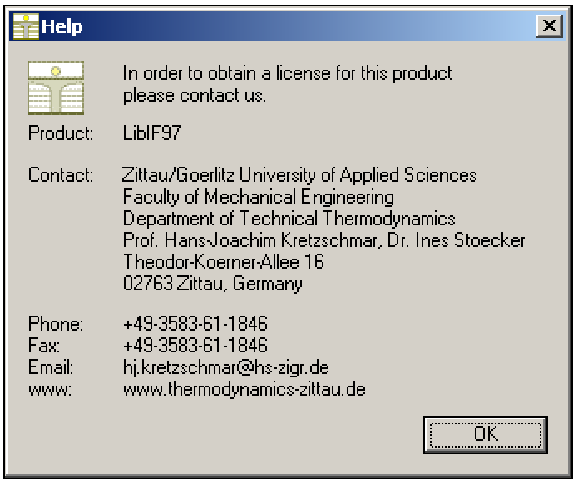

License Information

LibIF97

Please type in your license key!

**Figure 2.21:** "License Information" window

Here you will have to type in the license key which you have obtained from the Zittau/Goerlitz University of Applied Sciences. 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:


Help

In order to obtain a license for this product please contact us.

Product: LibIF97

Contact: Zittau/Goerlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar, Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

Phone: +49-3583-61-1846
Fax: +49-3583-61-1846
Email: hj.kretzschmar@hs-zigr.de
www: www.thermodynamics-zittau.de

**Figure 2.22:** "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 LibIF97 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 2.7 of this User's Guide.

Should you not wish to license the LibIF97 property library, you have to delete the files

LibIF97.dll
LibIF97.hlp

in the installation folder of FluidEXL*Graphics* (the standard being

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows) |

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

## 2.5 Example: Calculation of *h* = f(*p*,*t*,*x*) and *s* = f(*p*,*t*,*x*)

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

- Start Excel®
- Enter a value for *p* in bar in a cell
  (Range of validity of the IF97: p = 0.00611 ... 1000 bar
  p = 0.00611 ... 500 bar for high temperature region)

  ⇒ e. g.: Enter the value 100 into cell A2

- Enter a value for *t* in °C in a cell
  (Range of validity of the IF97: t = 0 ... 800 °C
  high temperature region up to 2000 °C

  ⇒ e. g.: Enter the value 400 into cell B2

- Enter a value for *x* in kg saturated steam/kg wet steam in a cell

  Since the wet steam region is calculated automatically by the subprograms, the following fixed details on the vapor fraction *x* are to be considered when the value for *x* is entered:

  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.

  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 it is not the case the calculation for the property of the chosen function to be calculated results in –1.

  Wet steam region of the IAPWS-IF97:

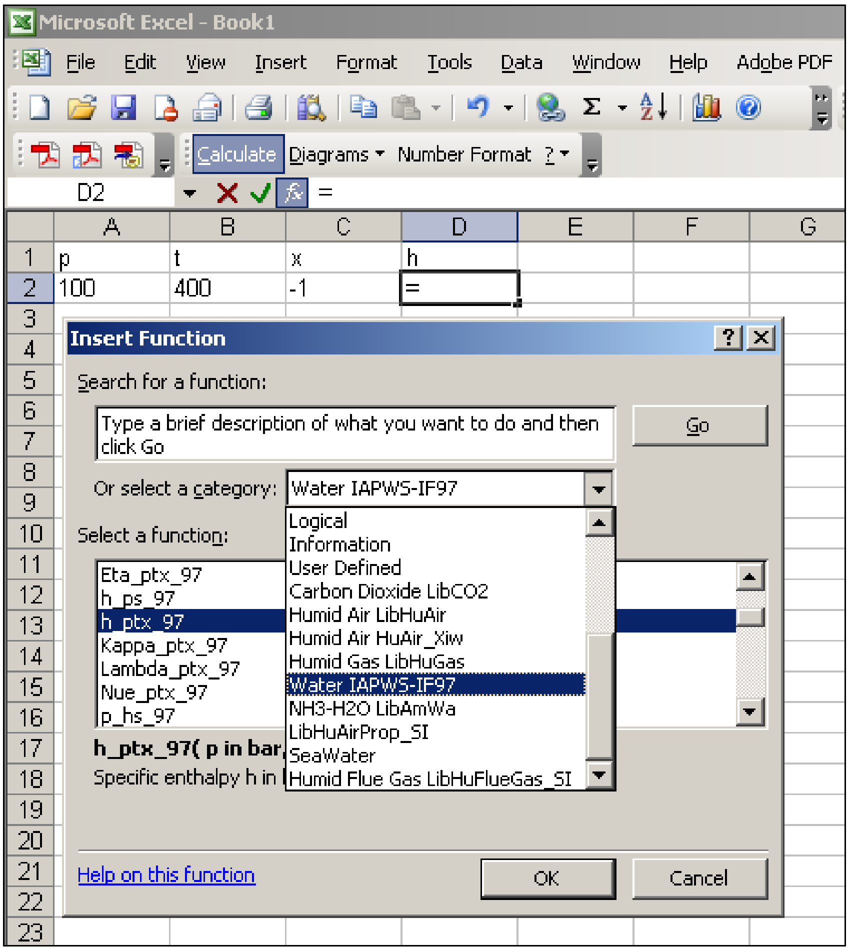
  $t_t$ = 0 °C ... $t_c$ = 373.946 °C
  $p_t$ = 0.00611 bar ... $p_c$ = 220.64 bar (c – critical point)

  ⇒ e.g.: Enter –1 into the C2 cell.

- Click the cell in which the enthalpy *h* in kJ/kg is to be displayed.

  ⇒ e.g.: Click the D2 cell.

- Click "Calculate" in the menu bar of FluidEXL*Graphics*.
  Now the "Insert Function" window appears (see next figure).



D2 =

| | A | B | C | D |
|---|---|---|---|---|
| 1 | p | t | x | h |
| 2 | 100 | 400 | -1 | = |

Search for a function: Type a brief description of what you want to do and then click Go

Or select a category: Water IAPWS-IF97

Select a function: h_ptx_97

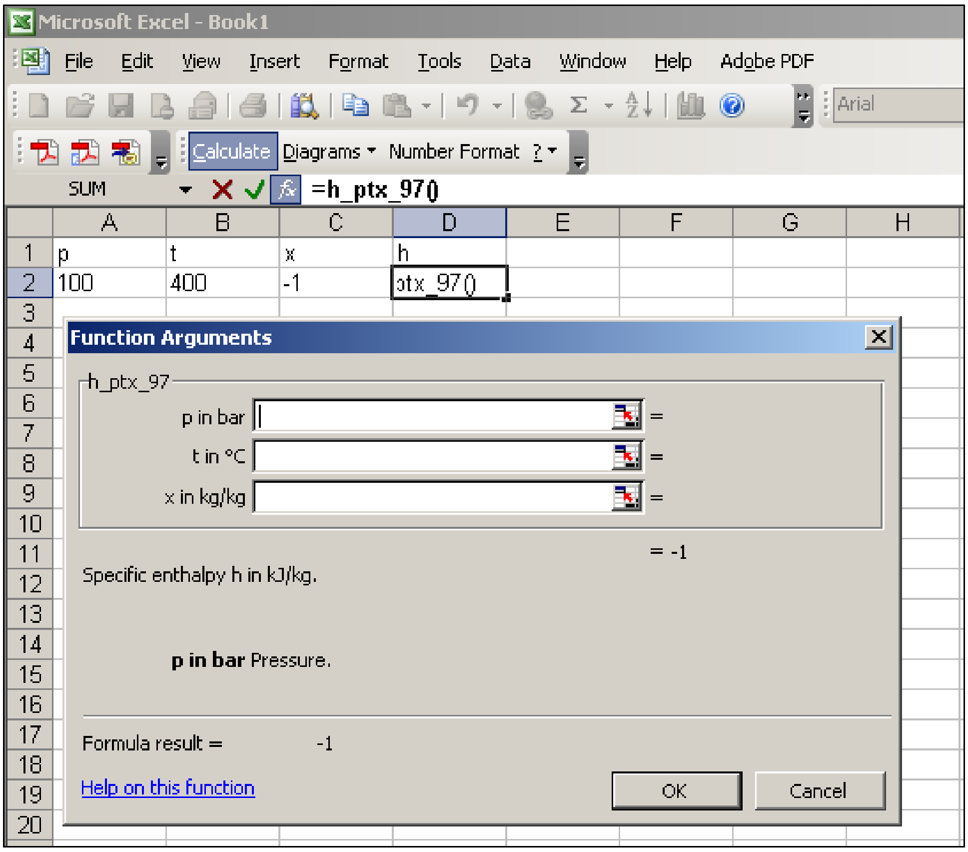
**h_ptx_97( p in bar,**

Specific enthalpy h in

**Figure 2.23:** Choice of library and function name

- Search and click the "Water IAPWS-IF97" library under "Or select a category:" in the upper part of the window.
- Search and click the h_ptx_97 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.



=h_ptx_97()

|  | A | B | C | D |
|---|---|---|---|---|
| 1 | p | t | x | h |
| 2 | 100 | 400 | -1 | ptx_97() |

h_ptx_97

p in bar =

t in °C =

x in kg/kg =

= -1

Specific enthalpy h in kJ/kg.

**p in bar** Pressure.

Formula result = -1

**Figure 2.24:** 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

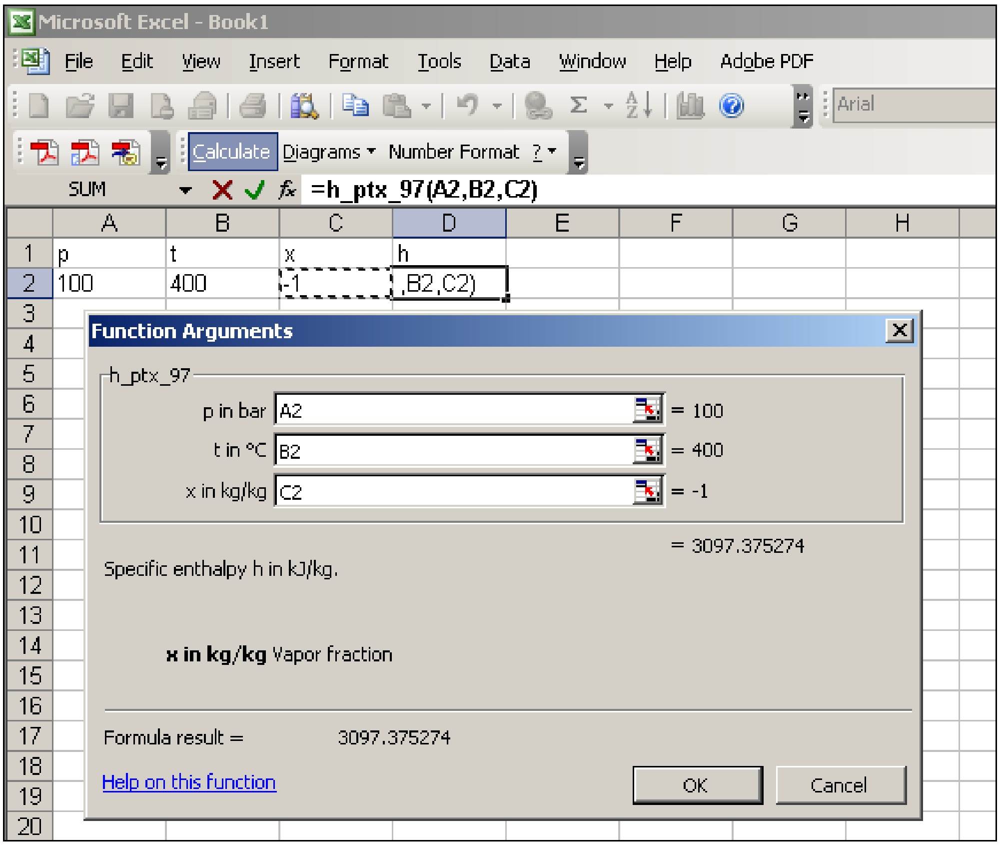
- Situate the cursor next to "t in °C" and enter the value for *t* by clicking the cell with the value for *t*, by entering the name of the cell with the value for *t*, or by entering the value for *t* directly.

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

- Situate the cursor next to "x in kg/kg" and enter the value for *x* by clicking the cell with the value for *x*, by entering the name of the cell with the value for *x*, or by entering the value for *x* directly.

  ⇒ e. g.: Click on the cell C2

The window should now look like the following figure:



=h_ptx_97(A2,B2,C2)

| | A | B | C | D |
|---|---|---|---|---|
| 1 | p | t | x | h |
| 2 | 100 | 400 | -1 | ,B2,C2) |

h_ptx_97

p in bar A2 = 100

t in °C B2 = 400

x in kg/kg C2 = -1

= 3097.375274

Specific enthalpy h in kJ/kg.

**x in kg/kg** Vapor fraction

Formula result = 3097.375274

**Figure 2.25:** 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 = 3097.375274 in kJ/kg.

The calculation of *h* = f(*p*,*t*,*x*) has thus been completed. Correspondingly, the specific entropy *s* = f(*p*,*t*,*x*) can be calculated with the same values for *p*, *t*, and *x*.

- Click the cell in which the entropy *s* in kJ/(kg K) is to be displayed.

  ⇒ e.g.: Click the cell E2.
- Click "Calculate" in the menu bar of FluidEXL$^{Graphics}$.
  The "Insert Function" window will appear.
- Because of the previous calculation, the "Water IAPWS-IF97" library under "Or select a category:" will be marked automatically.
- Search for and click on the s_ptx_97 function under "Select a function:" in the center of the window.
- Click "OK".
  The "Function Arguments" window appears.
- Enter the cell name with the value of *p* next to "p in bar", or click on the cell with the value of *p*.
- Situate the cursor next to "t in °C", click and enter the cell name with the value of *t*, or click on the cell with the value of *t*.

- Situate the cursor next to "x in kg/kg", click and enter the cell name with the value of *x,* or click on the cell with the value of *x*.
- Click "OK".

The result for *s* in kJ/kg K appears in the cell selected above.

⇒ The result in our sample calculation here is: 6.213928894 in kJ/kg K.

The calculation of *s* = f(*p*,*T*,*x*) has been carried out. You can now arbitrarily change the values for *p*, *T*, or *x* in the appropriate cells. The specific enthalpy and the specific entropy are 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 IF97. 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.

## 2.6 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.

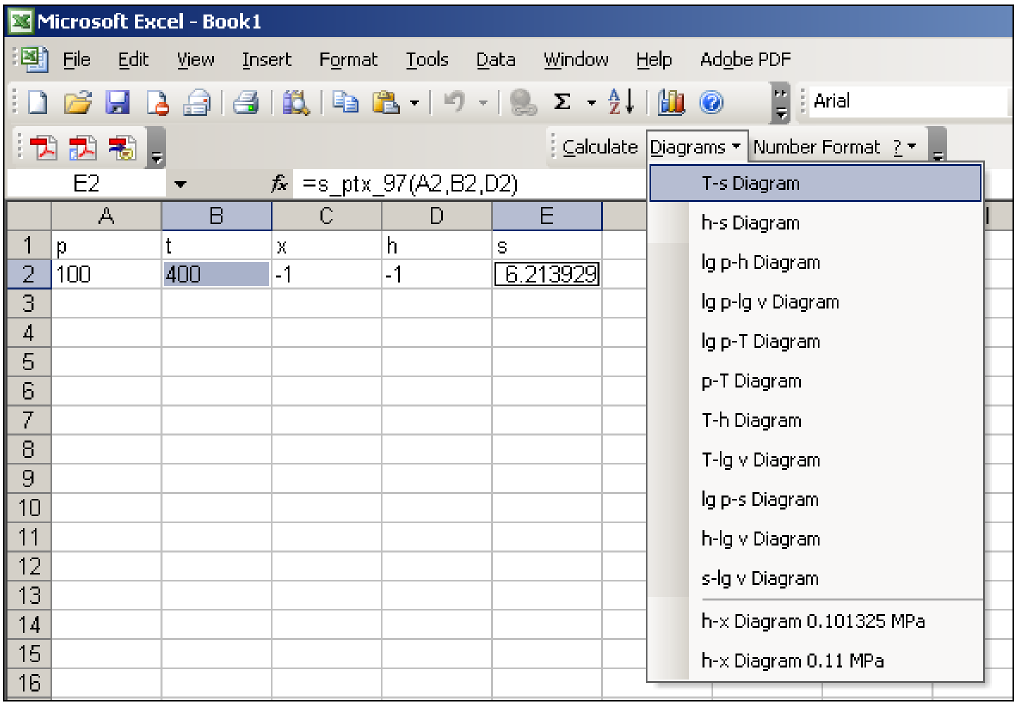
Hold down the "Ctrl" key and simultaneously click the cell with the value for *s* (as *s* is the abscissa in the diagram). Release the "Ctrl" key.

**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.



E2 =s_ptx_97(A2,B2,D2)

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | p | t | x | h | s |
| 2 | 100 | 400 | -1 | -1 | 6.213929 |

**Figure 2.26:** 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.

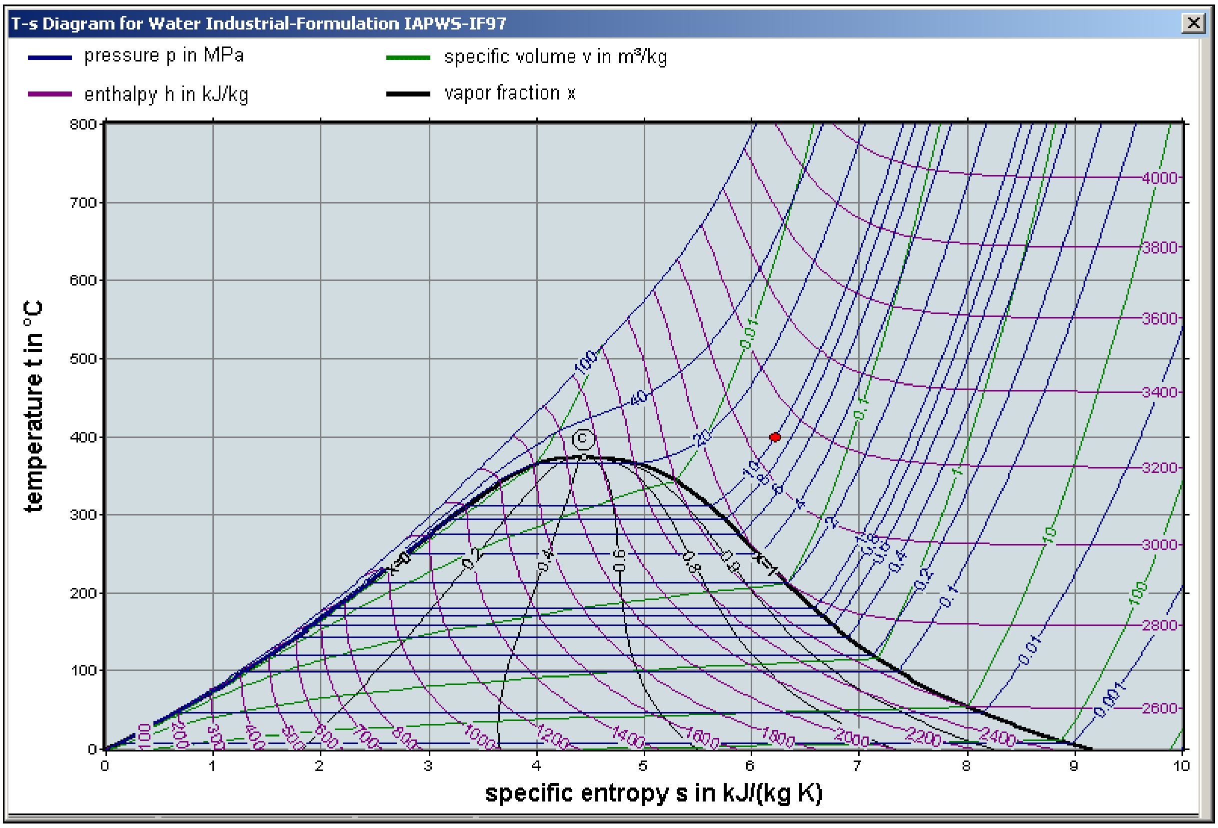


**Figure 2.27:** *T-s* Diagram including the state point

**Note:**

If the coloring is distorted you need to increase the amount of colors displayed on the screen by Windows® to more than 256 colors. The preferences can be set within Windows by going to "Control Panel" and then under "Screen".

In order to close the *T-s* diagram, click on the "x" in the upper-right hand corner of the *T-s* Diagram window.

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.

## 2.7 Removing FluidEXL*Graphics*

Should you wish to remove only the LibIF97 library, delete the files

LibIF97.dll
LibIF97.hlp

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

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows) |

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

### Unregistering 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 | (for English version of Windows) |
| FluidEXL_Graphics.xla | (for German version of Windows) |

has to be cancelled in Excel®.

In order to do that, 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" | (for English version of Windows) |
| "FluidEXL Graphics" | (for German version of Windows) |

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" | (for English version of Windows) |
| "FluidEXL Graphics" | (for German version of Windows) |

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

LibIF97.dll
LibIF97.hlp

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

| | |
|---|---|
| C:\Program Files\FluidEXL_Graphics_Eng | (for English version of Windows) |
| C:\Programme\FluidEXL_Graphics | (for German version of Windows), |

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

In order to remove FluidEXL*Graphics* from Windows and the hard disk 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" | (for English version of Windows) |
| "FluidEXL Graphics" | (for German version of Windows) |

by clicking on it and click the "Add/Remove…" button. In the following dialog box click "Automatic" and thereafter "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.

## Unregistering FluidEXL*Graphics* as Add-In in Excel® 2007 (or later versions)

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

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

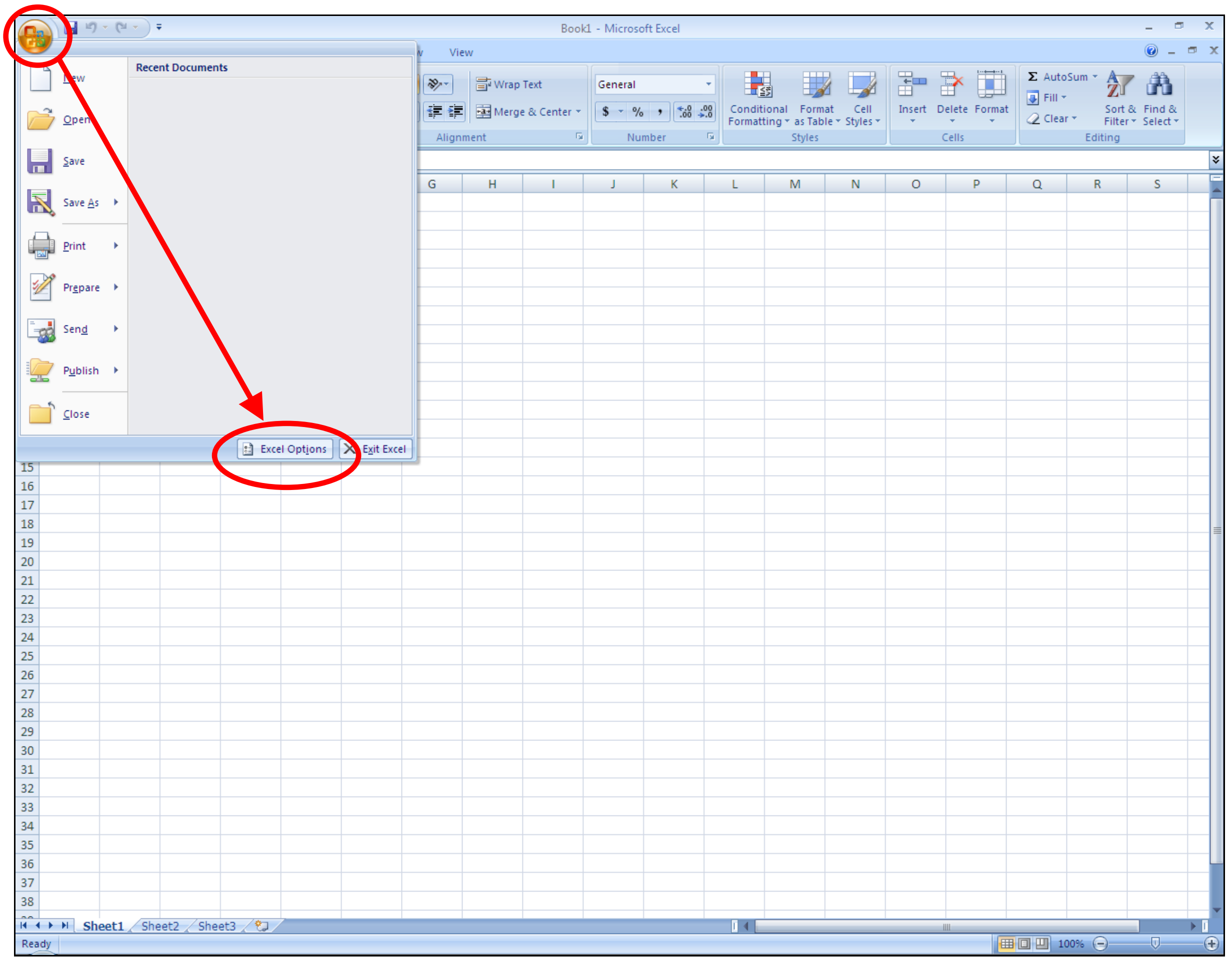
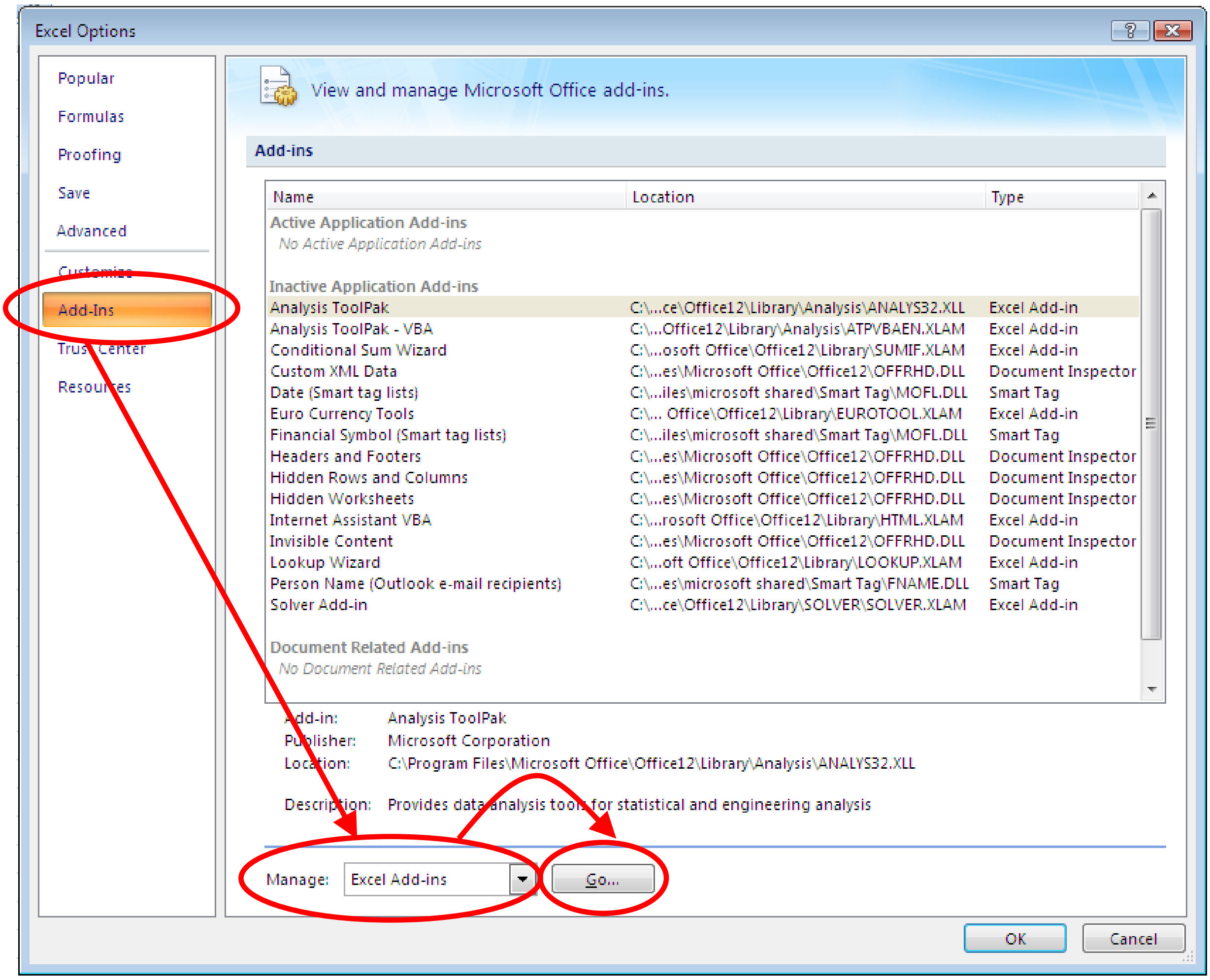


**Figure 2.28:** Unregistering FluidEXL*Graphics* as Add-In in Excel® 2007

- Click on "Add-Ins" in the next menu



| Name | Location | Type |
|---|---|---|
| **Active Application Add-ins** | | |
| *No Active Application Add-ins* | | |
| **Inactive Application Add-ins** | | |
| Analysis ToolPak | C:\...ce\Office12\Library\Analysis\ANALYS32.XLL | Excel Add-in |
| Analysis ToolPak - VBA | C:\...Office12\Library\Analysis\ATPVBAEN.XLAM | Excel Add-in |
| Conditional Sum Wizard | C:\...osoft Office\Office12\Library\SUMIF.XLAM | Excel Add-in |
| Custom XML Data | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Date (Smart tag lists) | C:\...iles\microsoft shared\Smart Tag\MOFL.DLL | Smart Tag |
| Euro Currency Tools | C:\... Office\Office12\Library\EUROTOOL.XLAM | Excel Add-in |
| Financial Symbol (Smart tag lists) | C:\...iles\microsoft shared\Smart Tag\MOFL.DLL | Smart Tag |
| Headers and Footers | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Hidden Rows and Columns | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Hidden Worksheets | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Internet Assistant VBA | C:\...rosoft Office\Office12\Library\HTML.XLAM | Excel Add-in |
| Invisible Content | C:\...es\Microsoft Office\Office12\OFFRHD.DLL | Document Inspector |
| Lookup Wizard | C:\...oft Office\Office12\Library\LOOKUP.XLAM | Excel Add-in |
| Person Name (Outlook e-mail recipients) | C:\...es\microsoft shared\Smart Tag\FNAME.DLL | Smart Tag |
| Solver Add-in | C:\...ce\Office12\Library\SOLVER\SOLVER.XLAM | Excel Add-in |
| **Document Related Add-ins** | | |
| *No Document Related Add-ins* | | |

Add-in: Analysis ToolPak
Publisher: Microsoft Corporation
Location: C:\Program Files\Microsoft Office\Office12\Library\Analysis\ANALYS32.XLL

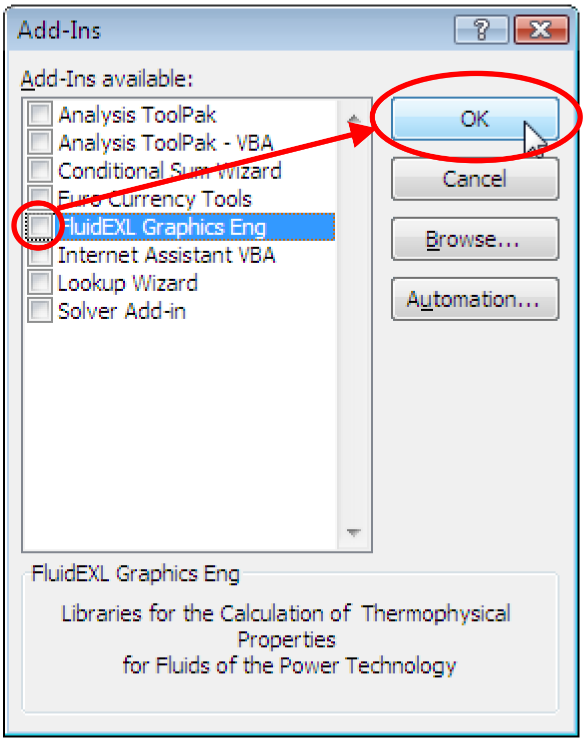
Description: Provides data analysis tools for statistical and engineering analysis

**Figure 2.29:** 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" (for English version of Windows)
"FluidEXL Graphics" (for German version of Windows)

in the window which now appears. Click the "OK" button to confirm your entry.



Libraries for the Calculation of Thermophysical Properties
for Fluids of the Power Technology

**Figure 2.30:** 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" | (for English version of Windows) |
| "FluidEXL Graphics" | (for German version of Windows) |

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.

# 3. Program Documentation

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

| | |
|---|---|
| Function Name: | **a_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION APTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_APTX97(A,P,T,X)**<br>REAL*8 A,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

**APTX97**, **A** or **a_ptx_97** - Thermal diffusivity $a = \frac{\lambda}{\rho \cdot c_p} = \frac{\lambda \cdot v}{c_p}$ 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

### Results for wrong input values

Result **APTX97, A = –1** or **a_ptx_97 = –1** for input values:

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

### References:

Internal calculation from $\rho$ or $v$ and $c_p$ [1], [2], [3] and $\lambda$ [6]

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

| | |
|---|---|
| Function Name: | **alphap_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION ALPHAPPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ALPHAPPTX97 (ALPHAP,P,T,X)**<br>REAL*8 ALPHAP,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

**ALPHAPPTX97**, **ALPHAP** or **alphap_ptx_97** - Relative pressure coefficient $\alpha_p$ in $\mathrm{K}^{-1}$

## 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **ALPHAPPTX97, ALPHAP = –1** or **alphap_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 800 °C or $t$ < 0 °C |
| 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<br>or $p$ < 0.00611 bar or at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>or $|t-t_s(p)|$ > 0.1 K |

## References:

Internal calculation from $\rho$ or $v$ and $c_p$ [1], [2], [3] and $\lambda$ [6]

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

| | |
|---|---|
| Function Name: | **alphav_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION ALPHAVPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ ALPHAVPTX97 (ALPHAV,P,T,X)**<br>REAL*8 ALPHAV,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

**ALPHAVPTX97**, **ALPHAV** or **alphav_ptx_97** - Isobaric cubic expansioncoefficient $\alpha_V$ 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **ALPHAVPTX97, ALPHAV = –1** or **alphav_ptx_97 = –1** for input values:

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

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

# Laplace Coefficient b = f(*p*)

| | |
|---|---|
| Function Name: | **b_p_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION BP97(P)**<br>REAL*8 P |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ BP97 (B,P)**<br>REAL*8 B,P |

## Input values

**P** - Pressure *p* in bar

## Result

**BPTX97**, **B** or **b_pt_97** - 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 **BP97, B = –1** or **b_p_97 = –1** 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION BT97(T)**<br>REAL*8 T |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ BT97 (B,T)**<br>REAL*8 B,T |

## Input values

**T -** Temperature *t* in °C

## Result

**BPTX97**, **B** or **b_pt_97** - Laplace coefficient *b* in m

## Range of validity

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

## Results for wrong input values

Result **BT97, B = –1** or **b_t_97 = –1** for input values:

Saturation lines: *t* > 373.946 °C or *t* < 0 °C

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

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

| | |
|---|---|
| Function Name: | **betap_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION BETAPPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ BETAPPTX97 (BETAP,P,T,X)**<br>REAL*8 BETAP,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

**BETAPPTX97**, **BETAP** or **betap_ptx_97** - Isothermal stress coefficient $\beta_p$ 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 | $t_t = 0$ °C to $t_c = 373.946$ °C |
| Pressure ranges from | $p_t = 0.00611$ bar to $p_c = 220.64$ bar) |

## Results for wrong input values

Result **BETAPPTX97, BETAP = –1** or **betap_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x = -1$) | $p > 1000$ bar or $p < 0.00611$ bar or<br>$t > 2000$ °C or $t < 0$ °C or<br>$t > 800$ °C at $p > 500$ bar |
| Saturation lines:<br>($x = 0$ or $x = 1$) | at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or<br>at $t = -1$ and $p > 220.64$ bar or $p < 0.00611$ bar or<br>at $p > 220.64$ bar or $p < 0.00611$ bar<br>and $t > 373.946$ °C or $t < 0$ °C<br>at $\lvert t-t_s(p)\rvert > 0.1$ K |

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

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

| | |
|---|---|
| Function Name: | **cp_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION CPPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_CPPTX97(CP,P,T,X)**<br>REAL*8 CP,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

**CPPTX97**, **CP** or **cp_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **CPPTX97, CP = –1** or **cp_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($x$ = 0 or $x$ = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $|t-t_s(p)| > 0.1$ K |

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

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

| | |
|---|---|
| Function Name: | **cv_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION CVPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_CVPTX97(CV,P,T,X)**<br>REAL*8 CV,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

**CVPTX97**, **CV** or **cv_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

### Results for wrong input values

Result **CVPTX97, CV = –1** or **cv_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($x$ = 0 or $x$ = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $|t-t_s(p)|$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **deltat_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION DELTATPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_DELTATPTX97 (DELTAT,P,T,X)**<br>REAL*8 DELTAT,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

**DELTATPTX97**, **DELTAT** or **deltat_ptx_97** - Isothermal throttling coefficient $\delta_T$ in kJ $kg^{-1}$ $kPa^{-1}$

## 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **DELTATPTX97, DELTAT = –1** or **deltat_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\|t-t_s(p)\|$ > 0.1 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION DVDPT97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_DVDPT97(DVDPT,P,T,X)**<br>REAL*8 DVDPT,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

**DVDPT97** - Differential quotient $\left(\frac{\partial v}{\partial p}\right)_T$ in $m^3 \cdot kg^{-1} \cdot kPa^{-1}$

### 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

### Results for wrong input values

Result **dv_dp_T_ptx_97** or **DVDPT97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | *p* > 1000 bar or *p* < 0.00611 bar or<br>*t* > 2000 °C or *t* < 0 °C or<br>*t* > 800 °C at *p* > 500 bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at *p* = –1 and *t* > 373.946 °C or *t* < 0 °C or<br>at *t* = –1 and *p* > 220.64 bar or *p* < 0.00611 bar or<br>at *p* > 220.64 bar or *p* < 0.00611 bar<br>and *t* > 373.946 °C or *t* < 0 °C<br>at $\lvert t-t_s(p)\rvert$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **dv_dT_p_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION DVDTP97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_DVDTP97(DVDTP,P,T,X)**<br>REAL*8 DVDTP,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

**DVDTP97** - Differential quotient $\left(\frac{\partial v}{\partial T}\right)_p$ in $\mathrm{m}^3 \cdot \mathrm{kg}^{-1} \cdot \mathrm{K}^{-1}$

## 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **dv_dT_p_ptx_97** or **DVDTP97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($x$ = 0 or $x$ = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\lvert t-t_s(p)\rvert$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **e_ptx_tu_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION EPTXTU97(P,T,X,TU)**<br>REAL*8 P,T,X,TU |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_EPTXTU97(E,P,T,X,TU)**<br>REAL*8 E,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

**EPTXTU97, E** or **e_ptx_tu_97** - 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 **EPTXTU97, E = –1** or **e_ptx_tu_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **epsilon_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION EPSPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ EPSPTX97 (BETAP,P,T,X)**<br>REAL*8 EPS,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

**EPSPTX97**, **EPS** or **epsilon_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **EPSPTX97, EPS = –1** or **epsilon_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\|t-t_s(p)\|$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **f_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION FPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ FPTX97 (F,P,T,X)**<br>REAL*8 F,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

**FPTX97**, **F** or **f_ptx_97** - 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **FPTX97, F = –1** or **f_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($0 \le x \le 1$) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\lvert t-t_s(p)\rvert$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **fug_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION FUGPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ FUGPTX97 (FUG,P,T,X)**<br>REAL*8 DELTAT,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

**FUGPTX97**, **FUG** or **fug_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **FUGPTX97, FUG = –1** or **fug_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($0 \le x \le 1$) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\lvert t-t_s(p)\rvert$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **g_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION GPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ GPTX97 (G,P,T,X)**<br>REAL*8 G,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

**GPTX97**, **G** or **g_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **GPTX97, G = –1** or **g_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($0 \le x \le 1$) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $|t - t_s(p)|$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **Eta_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION ETAPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ETAPTX97(ETA,P,T,X)**<br>REAL*8 ETA,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

**ETAPTX97**, **ETA** or **eta_ptx_97** - Dynamic viscosity $\eta$ 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

### Results for wrong input values

Result **ETAPTX97, ETA = –1** or **eta_ptx_97 = –1** for input values:

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

### References:

[7], internal calculation from $\rho$ or $v$ [1], [2], [3]

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

| | |
|---|---|
| Function Name: | **h_ps_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION HPS97(P,S)**<br>REAL*8 P,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_HPS97(H,P,S)**<br>REAL*8 H,P,S |

## Input values

**P -** Pressure $p$ in bar

**S** - Specific entropy $s$ in kJ/kg K

## Result

**HPS97, H** or **h_ps_97** - 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 **HPS97, H = –1** or **h_ps_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Wet steam region: | $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION HPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_HPTX97(H,P,T,X)**<br>REAL*8 H,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

**HPTX97, H** or **h_ptx_97** - 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: $t_t = 0$ °C ... $t_c = 373.946$ °C
$p_t = 0.00611$ bar ... $p_c = 220.64$ bar)

### Results for wrong input values

Result **HPTX97, H = –1** or **h_ptx_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **Kappa_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION KAPPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_KAPPTX97(KAPPA,P,T,X)**<br>REAL*8 KAPPA,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

**KAPPTX97**, **KAPPA** or **kappa_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **KAPPTX97, KAPPA = –1** or **kappa_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | *p* > 1000 bar or *p* < 0.00611 bar or<br>*t* > 2000 °C or *t* < 0 °C or<br>*t* > 800 °C at *p* > 500 bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at *p* = –1 and *t* > 373.946 °C or *t* < 0 °C or<br>at *t* = –1 and *p* > 220.64 bar or *p* < 0.00611 bar or<br>at *p* > 220.64 bar or *p* < 0.00611 bar<br>and *t* > 373.946 °C or *t* < 0 °C<br>at $\lvert t - t_s(p)\rvert$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **kappat_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION KAPPATPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ KAPPATPTX97 (KAPPAT,P,T,X)**<br>REAL*8 KAPPAT,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

**KAPPATPTX97**, **KAPPAT** or **kappat_ptx_97** - Isothermal compressibility $\kappa_T$ in $\text{kPa}^{-1}$

## 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **KAPPATPTX97, KAPPAT = –1** or **kappat_ptx_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **Lambda_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION LAMPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_LAMPTX97(LAM,P,T,X)**<br>REAL*8 LAM,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

**LAMPTX97**, **LAM** or **lambda_ptx_97** - Thermal conductivity $\lambda$ 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **LAMPTX97, LAM = –1** or **lambda_ptx_97 = –1** for input values:

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

## References:

[6], Internal calculation from $\rho$ or v [1], [2], [3]

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

| | |
|---|---|
| Function Name: | **my_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION MYPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_MYPTX97 (MY,P,T,X)**<br>REAL*8 MY,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

**MYPTX97**, **MY** or **my_ptx_97** - Joule-Thomson coefficient $\mu$ 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **MYPTX97, MY = –1** or **my_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x$ = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>($x$ = 0 or $x$ = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $|t-t_s(p)|$ > 0.1 K |

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

# Refractive Index *n* = f(*p*,*t*,*x*,*wl*)

| | |
|---|---|
| Function Name: | **n_ptxwl_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION NPTXWL97(P,T,X,WL)**<br>REAL*8 P,T,X,WL |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ NPTXWL97 (N,P,T,X,WL)**<br>REAL*8 N,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)

## Result

**NPTXWL97**, **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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **NPTXWL97, N = –1** or **n_ptxwl_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>$t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at $p$ = –1 and $t$ > 373.946 °C or $t$ < 0 °C or<br>at $t$ = –1 and $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at $p$ > 220.64 bar or $p$ < 0.00611 bar<br>and $t$ > 373.946 °C or $t$ < 0 °C<br>at $\|t-t_s(p)\|$ > 0.1 K |

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

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

| | |
|---|---|
| Function Name: | **Ny_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION NYPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_NYPTX97(NY,P,T,X)**<br>REAL*8 NY,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

**NYPTX97**, **NY** or **ny_ptx_97** - Kinematic viscosity $\nu = \frac{\eta}{\rho} = \eta \cdot v$ 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 $t_t$ = 0 °C to $t_c$ = 373.946 °C

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

### Results for wrong input values

Result **NYPTX97, NY = –1** or **ny_ptx_97 = –1** for input values:

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

### References:

Internal calculation from $\eta$ [7] and $\rho$ or v [1], [2], [3]

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

| | |
|---|---|
| Function Name: | **p_hs_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION PHS97(H,S)**<br>REAL*8 H,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_PHS97(P,H,S)**<br>REAL*8 P,H,S |

## Input values

**H** - Specific enthalpy *h* in kJ/kg

**S** - Specific entropy *s* in kJ/kg K

## Result

**PHS97, p** or **p_hs_97** - 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 **PHS97, P = –1** or **p_hs_97 = –1** for input values:

*s* < - 0.009 kJ/kg K
*h* < *h*(0.00611 bar, *x*) at *h'*(0.00611 bar) < *h* < *h''*(0.00611 bar)

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

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

| | |
|---|---|
| Function Name: | **p_vh_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION PVH97(V,H)**<br>REAL*8 V,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_PVH97(P,H)**<br>REAL*8 P,V,H |

### Input values

**V** - Specific volume $v$ in $m^3$/kg

**H** - Specific enthalpy $h$ in kJ/kg

### Result

**PVH97, p** or **p_vh_97 -** 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 **PVH97, P = –1** or **p_vh_97 = –1** for input values:

$v < 0.0009$ $m^3$/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*,*u*)

Function Name: **p_vu_97**

Sub-program with function value: **REAL*8 FUNCTION PVU97(V,U)**
for call from Fortran REAL*8 V,U

Sub-program with parameter: **INTEGER*4 FUNCTION C_VU97(P,V,U)**
for call from DLL REAL*8 P,V,U

## Input values

**V** - Specific volume *h* in kJ/kg

**U** - Specific internal energy *u* in kJ/kg

## Result

**PVU97, p** or **p_vu_97** - 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 *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 **PVU97, P = –1** or **p_vu_97 = –1** for input values:

$v < 0.0009$ m$^3$/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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION PRPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_PRPTX97(PR,P,T,X)**<br>REAL*8 PR,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

**PRPTX97**, **Pr** or **Pr_ptx_97** - 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 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **PRPTX97, Pr = –1** or **Pr_ptx_97 = –1** for input values:

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

## References:

Internal calculation of $\eta$ [7], [6], and $\rho$ or $v$ and $c_p$ [1], [2], [3]

## Vapor Pressure $p_s$ = f($t$)

| | |
|---|---|
| Function Name: | **ps_t_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION PST97(T)**<br>REAL*8 T |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_PST97(PS,T)**<br>REAL*8 PS,T |

### Input values

**T -** Temperature $t$ in °C

### Result

**PST97**, **PS** or **ps_t_97** **-** Vapor pressure $p_s$ in bar

### Range of validity

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

### Results for wrong input values

Result **PST97, PS = –1** or **ps_t_97 = –1** for input values:
$t < 0$ °C or $t > 373.946$ °C

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

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

| | |
|---|---|
| Function Name: | **Rho_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION RHOPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_RHOPTX97(RHO,P,T,X)**<br>REAL*8 RHO,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

**RHOPTX97**, **RHO** or **rho_ptx_97** - Density $\rho = \frac{1}{v}$ in $\mathrm{kg/m^3}$

## 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 **RHOPTX97, RHO = –1** or **rho_ptx_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **s_ph_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION SPH97(P,H)**<br>REAL*8 P,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_SPH97(S,P,H)**<br>REAL*8 S,P,H |

### Input values

**P -** Pressure *p* in bar

**H** - Specific enthalpy *h* in kJ/kg

### Result

**SPH97, S** or **s_ph_97** - 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 **SPH97, S = –1** or **s_ph_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Wet steam region: | $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION SPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_SPTX97(S,P,T,X)**<br>REAL*8 S,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

**SPTX97, S** or **s_ptx_97** - 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: $t_t$ = 0 °C ... $t_c$ = 373.946 °C
$p_t$ = 0.00611 bar ... $p_c$ = 220.64 bar)

## Results for wrong input values

Result **SPTX97, S = –1** or **s_ptx_97 = –1** for input values:

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

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

# Surface Tension $\sigma$ = f($p$)

| | |
|---|---|
| Function Name: | **Sigma_p_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION SIGMAP97(P)**<br>REAL*8 P |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_SIGMAP97(SIGMA,P)**<br>REAL*8 SIGMA,P |

## Input values

**P -** Pressure $p$ in bar

## Result

**SIGMAP97**, **SIGMA** or **sigma_p_97** - Surface tension $\sigma$ in mN/m = mPa$\cdot$m

## Range of validity

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

## Results for wrong input values

Result **SIGMAP97, SIGMA = –1** or **sigma_p_97 = –1** 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION SIGMAT97(T)**<br>REAL*8 T |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_SIGMAT97(SIGMA,T)**<br>REAL*8 SIGMA,T |

### Input values

**T -** Temperature $t$ in °C

### Result

**SIGMAT97**, **SIGMA** or **sigma_t_97** **-** Surface tension $\sigma$ in mN/m = mPa$\cdot$m

### Range of validity

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

### Results for wrong input values

Result **SIGMAT97, SIGMA = –1** or **sigma_t_97 = –1** for input values:

$t$ < 0 °C or $t$ > 373.946 °C

**References:** [8]

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

| | |
|---|---|
| Function Name: | **t_hs_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION THS97(H,S)**<br>REAL*8 H,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_THS97(T,H,S)**<br>REAL*8 T,H,S |

### Input values

**H** - Specific enthalpy *h* in kJ/kg

**S** - Specific entropy *s* in kJ/kg K

### Result

**THS97, T** or **t_hs_97** - 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 **THS97, T = –1** or **t_hs_97 = –1** 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]

# [#][K][$][+] Backward Function: Temperature *t* = f(*p*,*h*)

| | |
|---|---|
| Function Name: | **t_ph_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION TPH97(P,H)**<br>REAL*8 P,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_TPH97(T,P,H)**<br>REAL*8 T,P,H |

### Input values

**P -** Pressure $p$ in bar

**H** - Specific enthalpy $h$ in kJ/kg

### Result

**TPH97, T** or **t_ph_97** - 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 **TPH97, T = –1** or **t_ph_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Wet steam region: | $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 373.946 °C or $t$ < 0 °C |

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

---

[#] FUNC_97_200

[K] Backward function: Temperature t = f(p,h)

[$] Backward function: Temperature, t = f(p,h)

[+] SUCH:200

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

| | |
|---|---|
| Function Name: | **t_ps_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION TPS97(P,S)**<br>REAL*8 P,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_TPS97(T,P,S)**<br>REAL*8 T,P,S |

## Input values

**P -** Pressure *p* in bar

**S** - Specific entropy *s* in kJ/kg K

## Result

**TPS97, T** or **t_ps_97** - 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 **TPS97, T = –1** or **t_ps_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Wet steam region: | $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 373.946 °C or $t$ < 0 °C |

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

# [#][K][$][+] Backward Function: Temperature *t* = f(*v*,*h*)

| | |
|---|---|
| Function Name: | **t_vh_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION TVH97(V,H)**<br>REAL*8 V,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_TVH97(T,V,H)**<br>REAL*8 T,V,H |

## Input values

**V** - Specific volume *v* in $m^3$/kg

**H** - Specific enthalpy *h* in kJ/kg

## Result

**TVH97, T** or **t_vh_97** - 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 *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 **TVH97, T = –1** or **t_vh_97 = –1** for input values:

$v < 0.0009$ $m^3$/kg

$h < h$(0.00611 bar, $x$) at $h'$(0.00611 bar) $< h < h''$(0.00611 bar)

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

---

[#] FUNC_97_212

[K] Backward function: Temperature t = f(v,h)

[$] Backward function: Temperature, t = f(v,h)

[+] SUCH:212

# [#][K][$][+] Backward Function: Temperature *t* = f(*v*,*u*)

| | |
|---|---|
| Function Name: | **t_vu_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION TVU97(V,U)**<br>REAL*8 V,U |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_TVU97(T,V,U)**<br>REAL*8 T,V,U |

### Input values

**V** - Specific volume $v$ in $m^3/kg$

**U** - Specific internal energy $u$ in kJ/kg

### Result

**TVU97, T** or **t_vu_97** - 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 $v$ 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 **TVU97, T = –1** or **t_vu_97 = –1** for input values:

$v < 0.0009\ m^3/kg$

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

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

---

[#] FUNC_97_214

[K] Backward function: Temperature t = f(v,u)

[$] Backward function: Temperature, t = f(v,u)

[+] SUCH:214

# Saturation Temperature $t_s$ = f($p$)

| | |
|---|---|
| Function Name: | **ts_p_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION TSP97(P)**<br>REAL*8 P |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_TSP97(TS,P)**<br>REAL*8 TS,P |

## Input values

**P -** Pressure $p$ in bar

## Result

**TSP97**, **T** or **ts_p_97** - 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 **TSP97, T = –1** or **ts_p_97 = –1** 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION UPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_UPTX97(U,P,T,X)**<br>REAL*8 U,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

**UPTX97, U** or **u_ptx_97** - 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: $t_t = 0$ °C ... $t_c = 373.946$ °C
$p_t = 0.00611$ bar ... $p_c = 220.64$ bar)

## Results for wrong input values

Result **UPTX97, U = –1** or **u_ptx_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **v_ph_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION VPH97(P,H)**<br>REAL*8 P,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_VPH97(V,P,H)**<br>REAL*8 V,P,H |

### Input values

**P -** Pressure $p$ in bar

**H** - Specific enthalpy $h$ in kJ/kg

### Result

**VPH97**, **V** or **v_ph_97** - Specific volume $v$ in $m^3$/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 **VPH97, V = –1** or **v_ph_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p > 1000$ bar or $p < 0.00611$ bar or<br>at internal calculation result $t > 2000$ °C or $t < 0$ °C or<br>$t > 800$ °C at $p > 500$ bar |
| Wet steam region: | $p > 220.64$ bar or $p < 0.00611$ bar or<br>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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION VPS97(P,S)**<br>REAL*8 P,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_VPS97(V,P,S)**<br>REAL*8 V,P,S |

## Input values

**P** - Pressure $p$ in bar

**S** - Specific entropy $s$ in kJ/kg K

## Result

**VPS97**, **V** or **v_ps_97** - Specific volume $v$ in $\mathrm{m^3/kg}$

## 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 **VPS97, V = –1** or **v_ps_97 = –1** for input values:

| | |
|---|---|
| Single phase region: | $p$ > 1000 bar or $p$ < 0.00611 bar or<br>at internal calculation result $t$ > 2000 °C or $t$ < 0 °C or<br>$t$ > 800 °C at $p$ > 500 bar |
| Wet steam region: | $p$ > 220.64 bar or $p$ < 0.00611 bar or<br>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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION VPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_VPTX97(V,P,T,X)**<br>REAL*8 V,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

**VPTX97**, **V** or **v_ptx_97** - Specific volume $v$ in $m^3/kg$

### 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 **VPTX97, V = –1** or **v_ptx_97 = –1** for input values:

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

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

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

| | |
|---|---|
| Function Name: | **w_ptx_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION WPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_WPTX97(W,P,T,X)**<br>REAL*8 W,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

**WPTX97, W** or **w_ptx_97** - 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 | $t_t = 0$ °C to $t_c = 373.946$ °C |
| Pressure ranges from | $p_t = 0.00611$ bar to $p_c = 220.64$ bar) |

### Results for wrong input values

Result **WPTX97, W = –1** or **w_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>($x = -1$) | $p > 1000$ bar or $p < 0.00611$ bar or<br>$t > 2000$ °C or $t < 0$ °C or<br>$t > 800$ °C at $p > 500$ bar |
| Saturation lines:<br>($x = 0$ or $x = 1$) | at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or<br>at $t = -1$ and $p > 220.64$ bar or $p < 0.00611$ bar or<br>at $p > 220.64$ bar or $p < 0.00611$ bar<br>and $t > 373.946$ °C or $t < 0$ °C<br>at $\|t - t_s(p)\| > 0.1$ K |

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

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

| | |
|---|---|
| Function Name: | **x_hs_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION XHS97(H,S)**<br>REAL*8 H,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_XHS97(X,H,S)**<br>REAL*8 X,H,S |

### Input values

**H** - Specific enthalpy *h* in kJ/kg

**S** - Specific entropy *s* in kJ/kg K

### Result

**XHS97, X** or **x_hs_97 -** 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 **XHS97, X = –1** or **x_hs_97 = –1** 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION XPH97(P,H)**<br>REAL*8 P,H |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_XPH97(X,P,H)**<br>REAL*8 X,P,H |

### Input values

**P -** Pressure *p* in bar

**H** - Specific enthalpy *h* in kJ/kg

### Result

**XPH97, X** or **x_ph_97** - 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 **XPH97, X = –1** or **x_ph_97 = –1** 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(*v*,*h*)

Function Name: **x_vh_97**

Sub-program with function value: for call from Fortran
**REAL*8 FUNCTION XVH97(V,H)**
REAL*8 V,H

Sub-program with parameter: for call from DLL
**INTEGER*4 FUNCTION C_XVH97(X,V,H)**
REAL*8 X,V,H

### Input values

**V** - Specific volume *v* in $m^3$/kg

**H** - Specific enthalpy *h* in kJ/kg

### Result

**XVH97, X** or **x_vh_97** - 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 *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 **XVH97, X = –1** or **x_vh_97 = –1** 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(*v*,*u*)

| | |
|---|---|
| Function Name: | **x_vu_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION XVU97(V,U)**<br>REAL*8 V,U |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_XVU97(X,V,U)**<br>REAL*8 X,V,U |

### Input values

**V** - Specific volume *v* in $m^3$/kg

**U** - Specific internal energy *u* in kJ/kg

### Result

**XVU97, X** or **x_vu_97** - 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 **XVU97, X = –1** or **x_vu_97 = –1** 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*,*s*)

| | |
|---|---|
| Function Name: | **x_ps_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION XPS97(P,S)**<br>REAL*8 P,S |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_XPS97(X,P,S)**<br>REAL*8 X,P,S |

## Input values

**P -** Pressure *p* in bar

**S** - Specific entropy *s* in kJ/kg K

## Result

**XPS97, X** or **x_ps_97** - 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 **XPS97, X = –1** or **x_ps_97 = –1** 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_97** |
| Sub-program with function value:<br>for call from Fortran | **REAL*8 FUNCTION ZPTX97(P,T,X)**<br>REAL*8 P,T,X |
| Sub-program with parameter:<br>for call from DLL | **INTEGER*4 FUNCTION C_ ZPTX97 (Z,P,T,X)**<br>REAL*8 Z,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

**ZPTX97**, **Z** or **z_ptx_97** - 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 | $t_t$ = 0 °C to $t_c$ = 373.946 °C |
| Pressure ranges from | $p_t$ = 0.00611 bar to $p_c$ = 220.64 bar) |

## Results for wrong input values

Result **ZPTX97, Z = –1** or **z_ptx_97 = –1** for input values:

| | |
|---|---|
| Single phase region:<br>(*x* = –1) | $p > 1000$ bar or $p < 0.00611$ bar or<br>$t > 2000$ °C or $t < 0$ °C or<br>$t > 800$ °C at $p > 500$ bar |
| Saturation lines:<br>(*x* = 0 or *x* = 1) | at $p = -1$ and $t > 373.946$ °C or $t < 0$ °C or<br>at $t = -1$ and $p > 220.64$ bar or $p < 0.00611$ bar or<br>at $p > 220.64$ bar or $p < 0.00611$ bar<br>and $t > 373.946$ °C or $t < 0$ °C<br>at $\|t-t_s(p)\| > 0.1$ K |

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

# 4. 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
  - IAPWS-IF97-S03rev
  - IAPWS-IF97-S04
  - IAPWS-IF97-S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

## Humid Combustion Gas Mixtures

### Library LibHuGas

Model: Ideal mixture of the real fluids:

$CO_2$ - Span and Wagner
$H_2O$ - IAPWS-95
$N_2$ - Span et al.
$O_2$ - Schmidt and Wagner
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 and 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 the VDI 4670
- Poynting effect from ASHRAE RP-1485

## Carbon Dioxide including Dry Ice

### Library LibCO2

Formulation of Span and Wagner (1994)

## Seawater

### Library LibSeaWa

IAPWS Formulation 2008 of Feistel and IAPWS-IF97

## 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
Ne
$N_2$
$O_2$
CO
$CO_2$
Air
NO
$H_2O$
$SO_2$
$H_2$
$H_2S$
OH
He
$F_2$
$NH_3$
Methane
Ethane
Ethylene
Propylene
Propane
Iso-Butane
n-Butane
Benzene
Methanol

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

## Dry Air including Liquid Air

### Library LibRealAir

Formulation of Lemmon et al. (2000)

## Nitrogen

### Library LibN2

Formulation of Span et al. (2000)

## Hydrogen

### Library LibH2

Formulation of Leachman et al. (2007)

## Refrigerants

### Ammonia

### Library LibNH3

Formulation of Tillner-Roth (1995)

### R134a

### Library LibR134a

Formulation of Tillner-Roth and Baehr (1994)

### Iso-Butane

### Library LibButane_Iso

Formulation of Bücker et al. (2003)

### n-Butane

### Library LibButane_n

Formulation of Bücker et al. (2003)

## 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 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

| | |
|---|---|
| $C_2H_6O_2$ | Ethylene glycol |
| $C_3H_8O_2$ | Propylene glycol |
| $C_2H_5OH$ | Ethyl alcohol |
| $CH_3OH$ | Methyl alcohol |
| $C_3H_8O_3$ | Glycerol |
| $K_2CO_3$ | Potassium carbonate |
| $CaCl_2$ | Calcium chloride |
| $MgCl_2$ | Magnesium chloride |
| NaCl | Sodium chloride |
| $C_2H_3KO_2$ | Potassium acetate |

Formulation of the International Institute of Refrigeration (1997)

## 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 **$C_{14}H_{42}O_5Si_6$** **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)

## Propane

**Library LibPropane**

Formulation of Lemmon et al. (2007)

## Methanol

**Library LibCH3OH**

Formulation of de Reuck and Craven (1993)

## Ethanol

**Library LibC2H5OH**

Formulation of Schroeder et al. (2012)

## 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 **$C_5H_{14}$** **Library LibC5H14**

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 **$H_2S$** **Library LibH2S**

Dinitrogen monooxide **$N_2O$** **Library LibN2O**

Sulfur dioxide **$SO_2$** **Library LibSO2**

Acetone **$C_3H_6O$** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

## For more information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker

Theodor-Koerner-Allee 16
02763 Zittau, Germany

Internet: www.thermodynamics-zittau.de
E-mail: hj.kretzschmar@hs-zigr.de
Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

## The following thermodynamic and transport properties can be calculated[a]:

### Thermodynamic Properties

- Vapor pressure $p_s$
- Saturation temperature $T_s$
- Density $\rho$
- Specific volume $v$
- Enthalpy $h$
- Internal energy $u$
- Entropy $s$
- Exergy $e$
- Isobaric heat capacity $c_p$
- Isochoric heat capacity $c_v$
- Isentropic exponent $\kappa$
- Speed of sound $w$
- Surface tension $\sigma$

### Transport Properties

- Dynamic viscosity $\eta$
- Kinematic viscosity $\nu$
- Thermal conductivity $\lambda$
- Prandtl-number $Pr$

### 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 can be calculated.

---

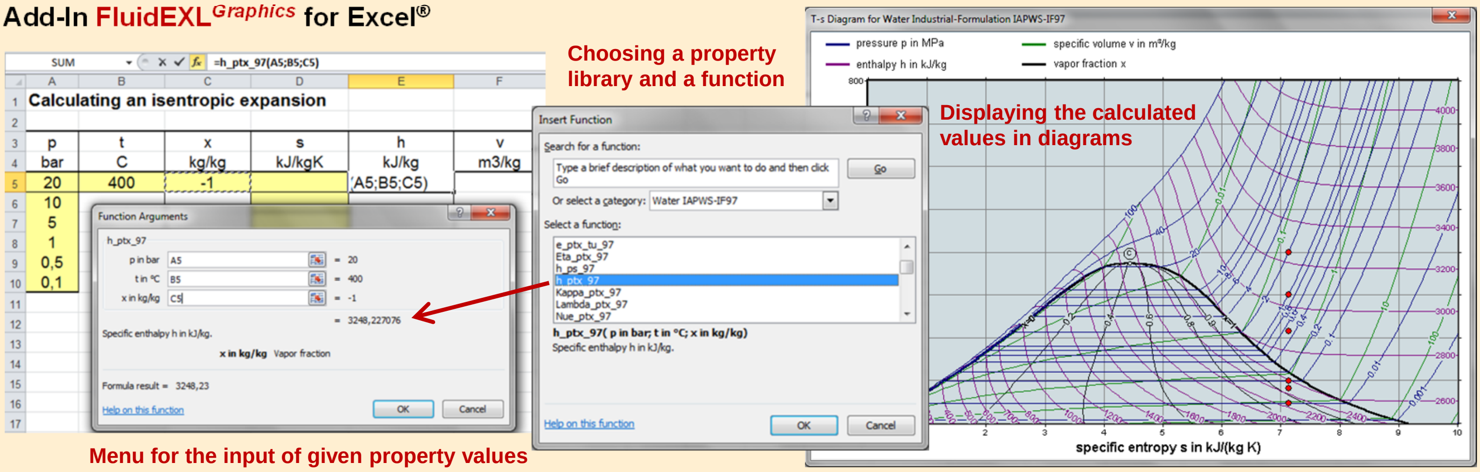
[a] Not all of these property functions are available in all property libraries.

**www.thermodynamic-property-libraries.com**

ZITTAU/GOERLITZ UNIVERSITY OF APPLIED SCIENCES
Department of Technical Thermodynamics
www.thermodynamics-zittau.de

# Property Software for Calculating Heat Cycles, Boilers, Turbines, and Refrigerators

## Add-In FluidEXL$^{Graphics}$ for Excel®



=h_ptx_97(A5;B5;C5)

|  | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Calculating an isentropic expansion |  |  |  |  |  |
| 2 |  |  |  |  |  |  |
| 3 | p | t | x | s | h | v |
| 4 | bar | C | kg/kg | kJ/kgK | kJ/kg | m3/kg |
| 5 | 20 | 400 | -1 |  | (A5;B5;C5) |  |
| 6 | 10 |  |  |  |  |  |
| 7 | 5 |  |  |  |  |  |
| 8 | 1 |  |  |  |  |  |
| 9 | 0,5 |  |  |  |  |  |
| 10 | 0,1 |  |  |  |  |  |

Function Arguments

h_ptx_97
p in bar: A5 = 20
t in °C: B5 = 400
x in kg/kg: C5 = -1
= 3248,227076

Specific enthalpy h in kJ/kg.

**x in kg/kg** Vapor fraction

Formula result = 3248,23

Help on this function

Insert Function

Search for a function: Type a brief description of what you want to do and then click Go

Or select a category: Water IAPWS-IF97

Select a function:
- e_ptx_tu_97
- Eta_ptx_97
- h_ps_97
- h_ptx_97
- Kappa_ptx_97
- Lambda_ptx_97
- Nue_ptx_97

**h_ptx_97( p in bar; t in °C; x in kg/kg)**
Specific enthalpy h in kJ/kg.

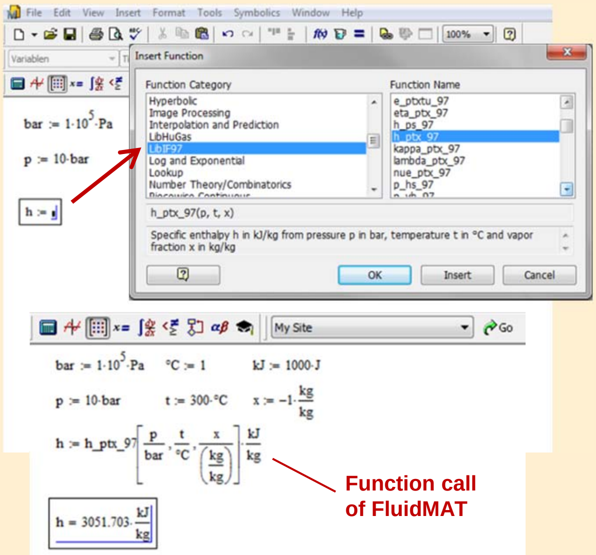
Choosing a property library and a function

Displaying the calculated values in diagrams

Menu for the input of given property values

## Add-In FluidMAT for Mathcad®

The property libraries can be used in Mathcad®.



Insert Function

Function Category:
- Hyperbolic
- Image Processing
- Interpolation and Prediction
- LibHuGas
- LibIF97
- Log and Exponential
- Lookup
- Number Theory/Combinatorics

Function Name:
- e_ptxtu_97
- eta_ptx_97
- h_ps_97
- h_ptx_97
- kappa_ptx_97
- lambda_ptx_97
- nue_ptx_97
- p_hs_97

h_ptx_97(p, t, x)

Specific enthalpy h in kJ/kg from pressure p in bar, temperature t in °C and vapor fraction x in kg/kg

$\text{bar} := 1\cdot 10^5\cdot\text{Pa}$ $\quad$ $°C := 1$ $\quad$ $kJ := 1000\cdot J$

$p := 10\cdot\text{bar}$ $\quad$ $t := 300\cdot°C$ $\quad$ $x := -1\cdot\frac{kg}{kg}$

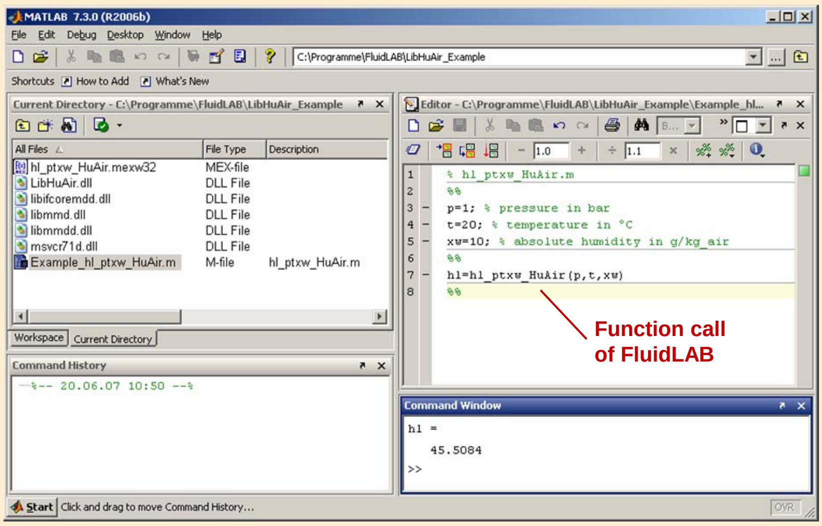
$$h := h\_ptx\_97\left[\frac{p}{\text{bar}},\frac{t}{°C},\frac{x}{\left(\frac{kg}{kg}\right)}\right]\cdot\frac{kJ}{kg}$$

$$h = 3051.703\cdot\frac{kJ}{kg}$$

Function call of FluidMAT

## Add-In FluidLAB for MATLAB®

Using the Add-In FluidLAB the property functions can be called in MATLAB®.



| All Files | File Type | Description |
|---|---|---|
| hl_ptxw_HuAir.mexw32 | MEX-file |  |
| LibHuAir.dll | DLL File |  |
| libifcoremd.dll | DLL File |  |
| libmmd.dll | DLL File |  |
| libmmdd.dll | DLL File |  |
| msvcr71d.dll | DLL File |  |
| Example_hl_ptxw_HuAir.m | M-file | hl_ptxw_HuAir.m |

```
%-- 20.06.07 10:50 --%
```

```
% hl_ptxw_HuAir.m
%%
p=1; % pressure in bar
t=20; % temperature in °C
xw=10; % absolute humidity in g/kg_air
%%
hl=hl_ptxw_HuAir(p,t,xw)
%%
```

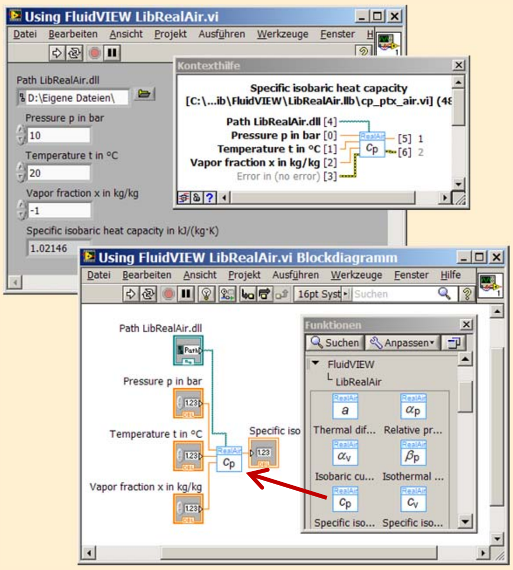
Command Window

```
hl =

   45.5084

>>
```

Function call of FluidLAB

## Add-On FluidVIEW for LabVIEW®

The property functions can be calculated in LabVIEW®.



Path LibRealAir.dll: D:\Eigene Dateien\

Pressure p in bar: 10

Temperature t in °C: 20

Vapor fraction x in kg/kg: -1

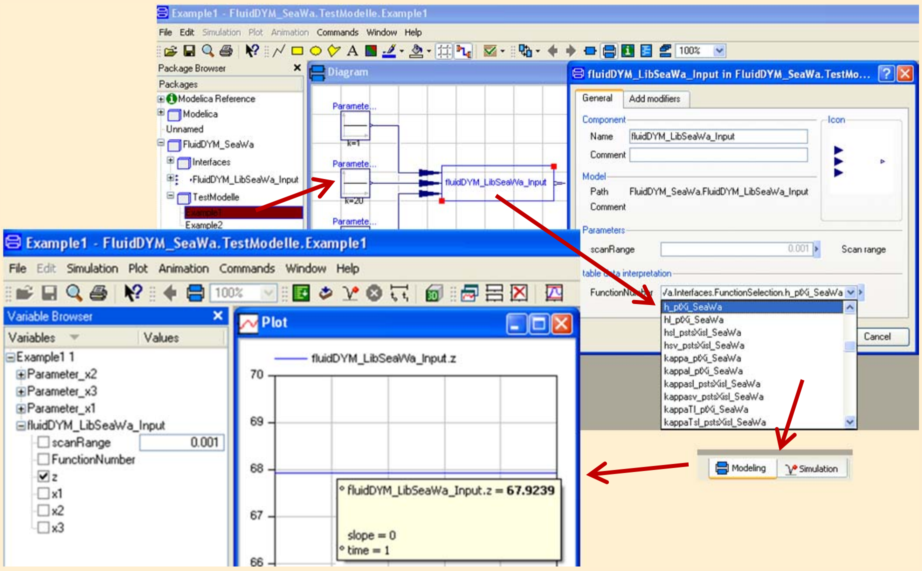
Specific isobaric heat capacity in kJ/(kg·K): 1.02146

**Specific isobaric heat capacity**
**[C:\...ib\FluidVIEW\LibRealAir.llb\cp_ptx_air.vi] (48**

**Path LibRealAir.dll** [4]
**Pressure p in bar** [0]
**Temperature t in °C** [1]
**Vapor fraction x in kg/kg** [2]
Error in (no error) [3]
[5] 1
[6] 2

## Add-In FluidDYM for DYMOLA® (Modelica) and SimulationX®

The property functions can be called in DYMOLA® and SimulationX®



fluidDYM_LibSeaWa_Input in FluidDYM_SeaWa.TestMo...

General | Add modifiers

Component
Name: fluidDYM_LibSeaWa_Input
Comment:

Model
Path: FluidDYM_SeaWa.FluidDYM_LibSeaWa_Input
Comment:

Parameters
scanRange: 0.001 Scan range

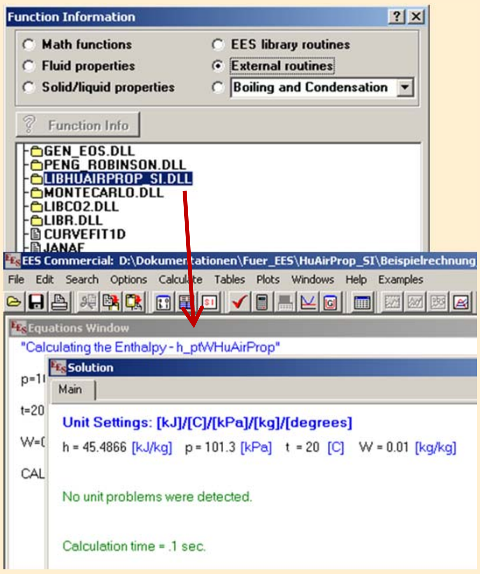
table data interpretation
FunctionNumber: √a.Interfaces.FunctionSelection.h_pXi_SeaWa
- h_pXi_SeaWa
- hl_pXi_SeaWa
- hsl_pstsXisl_SeaWa
- hsv_pstsXisl_SeaWa
- kappa_pXi_SeaWa
- kappal_pXi_SeaWa
- kappasl_pstsXisl_SeaWa
- kappasv_pstsXisl_SeaWa
- kappaTl_pXi_SeaWa
- kappaTsl_pstsXisl_SeaWa

| Variables | Values |
|---|---|
| Example1 1 |  |
| Parameter_x2 |  |
| Parameter_x3 |  |
| Parameter_x1 |  |
| fluidDYM_LibSeaWa_Input |  |
| ☐ scanRange | 0.001 |
| ☐ FunctionNumber |  |
| ☑ z |  |
| ☐ x1 |  |
| ☐ x2 |  |
| ☐ x3 |  |

fluidDYM_LibSeaWa_Input.z = **67.9239**

slope = 0
time = 1

## Add-In **FluidEES** for Engineering Equation Solver®



Function Information

○ Math functions
○ Fluid properties
○ Solid/liquid properties
○ EES library routines
● External routines
○ Boiling and Condensation

GEN_EOS.DLL
PENG_ROBINSON.DLL
LIBHUAIRPROP_SI.DLL
MONTECARLO.DLL
LIBCO2.DLL
LIBR.DLL
CURVEFIT1D
JANAF

EES Commercial: D:\Dokumentationen\Fuer_EES\HuAirProp_SI\Beispielrechnung

Equations Window

"Calculating the Enthalpy - h_ptWHuAirProp"

p=1
t=20
W=(
CAL

Solution

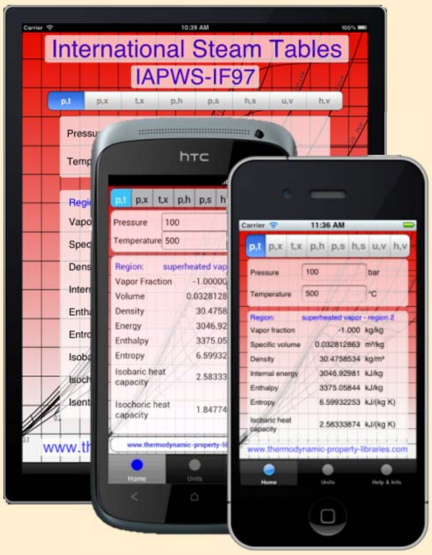
Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

h = 45.4866 [kJ/kg] p = 101.3 [kPa] t = 20 [C] W = 0.01 [kg/kg]

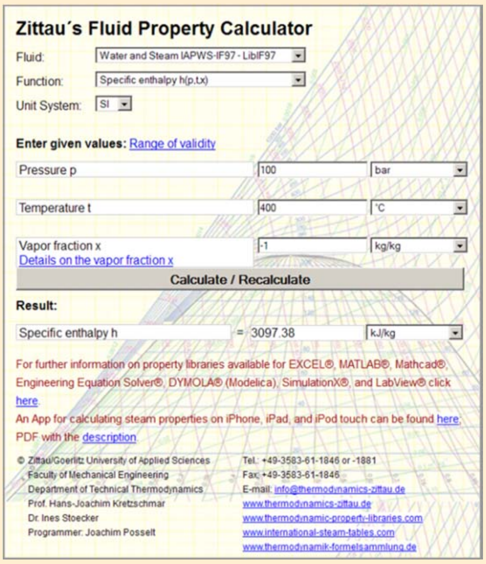
No unit problems were detected.

Calculation time = .1 sec.

## App International Steam Tables for iPhone, iPad, iPod touch, Android smart phones and tablets



## Online Property Calculator at www.thermodynamics-zittau.de



Zittau´s Fluid Property Calculator

Fluid: Water and Steam IAPWS-IF97 - LibIF97
Function: Specific enthalpy h(p,t,x)
Unit System: SI

Enter given values: Range of validity

Pressure p 100 bar
Temperature t 400 °C
Vapor fraction x -1 kg/kg
Details on the vapor fraction x

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/Goerlitz University of Applied Sciences
Faculty of Mechanical Engineering
Department of Technical Thermodynamics
Prof. Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Programmer: Joachim Posselt

Tel.: +49-3583-61-1846 or -1881
Fax: +49-3583-61-1846
E-mail: info@thermodynamics-zittau.de
www.thermodynamics-zittau.de
www.thermodynamic-property-libraries.com
www.international-steam-tables.com
www.thermodynamik-formelsammlung.de

## 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 83
TI 84
TI 89

TI Voyage 200

TI 92

## For more information please contact:

Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
Professor Hans-Joachim Kretzschmar
Dr. Ines Stoecker
Theodor-Koerner-Allee 16
02763 Zittau, Germany

E-mail: hj.kretzschmar@hs-zigr.de
Internet: www.thermodynamics-zittau.de
Phone: +49-3583-61-1846
Fax.: +49-3583-61-1846

**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 $\rho$
- Specific volume $v$
- Enthalpy $h$
- Internal energy $u$
- Entropy $s$
- Exergy $e$
- Isobaric heat capacity $c_p$
- Isochoric heat capacity $c_v$
- Isentropic exponent $\kappa$
- Speed of sound $w$
- Surface tension $\sigma$

### Transport Properties

- Dynamic viscosity $\eta$
- Kinematic viscosity $\nu$
- Thermal conductivity $\lambda$
- Prandtl-number $Pr$

### 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 can be calculated.

---

[a] Not all of these property functions are available in all property libraries.

**www.thermodynamic-property-libraries.com**

# 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] Wagner, W.; Kretzschmar, H.-J.:
International Steam Tables.
Springer-Verlag, Berlin (2008)

[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.
Journal of Eng. for Gas Turbines and 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] Kretzschmar, H.-J.:
Mollier h-s Diagram.
Springer-Verlag, Berlin (1998, 2008)

[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] Supplementary Release on Backward Equations for Specific Volume as a Function of Pressure and Temperature v(p,T) for Region 3 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam 2005. Available at the IAPWS website http://www.iapws.org

[10] Supplementary Release on Backward Equations p(h,s) for Region 3, Equations as a Function of h and s for the Region Boundaries, and an Equation $T_{sat}$(h,s) for Region 4 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam 2004. Available at the IAPWS website http://www.iapws.org

[11] 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

[12] Grigull, U.:
Properties of Water and Steam in SI Units.
Springer-Verlag, Berlin (1989)

[13] Kretzschmar, H.-J.:
Zur Aufbereitung und Darbietung thermophysikalischer Stoffdaten für die Energietechnik.
Habilitation, TU Dresden, Fakultät Maschinenwesen (1990)

[14] Baehr, H.D.; Diederichsen, Ch.:
Berechnungsgleichungen für Enthalpie und Entropie der Komponenten von Luft und Verbrennungsgasen.
BWK 40 (1988) No 1/2, pp. 30-33

[15] Brandt, F.:
Wärmeübertragung in Dampferzeugern und Wärmetauschern.
FDBR-Fachbuchreihe, 2nd edition, Vulkan Verlag Essen (1995)

[16] VDI-Wärmeatlas, 7. Auflage.
VDI-Verlag, Düsseldorf (1995)

[17] Blanke, W.:
Thermophysikalische Stoffgrößen.
Springer-Verlag, Berlin (1989)

[18] VDI-Richtlinie 4670
Thermodynamische Stoffwerte von feuchter Luft und Verbrennungsgasen.
VDI-Handbuch Energietechnik, VDI-Gesellschaft Energietechnik, Düsseldorf (2000)

[19] Lemmon, E. W.; Jacobsen, R. T.; Penoncello, S. G.; Friend, D. G.:
Thermodynamic Properties of Air and Mixtures of Nitrogen, Argon and Oxygen from 60 to 2000 K at Pressures to 2000 MPa.
J. Phys. Chem. Ref. Data 29 (2000) No 2, pp. 331-385

[20] Lemmon, E. W.; Jacobsen, R. T:
Transport Properties of Air.
National Institute of Standards and Technology, Boulder CO, (2000),
private communication

[21] Revised Supplementary Release on Saturation Properties of Ordinary Water Substance 1992. Available at the IAPWS website http://www.iapws.org

[22] Hyland, R. W.; Wexler, A.:
Formulations for the Thermodynamic Properties of Saturated Phases of $H_2O$ from 173.15 K to 473.15 K.
Report No. 2793 (RP-216), National Bureau of Standards, Washington, D.C. (1983)

# 6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

- FluidEXL$^{\mathit{Graphics}}$ for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica)
- FluidVIEW for LabVIEW®:

**2011**

| | |
|---|---|
| Lopez, Munguia, Spain | 10/2011 |
| University of KwaZulu-Natal, Westville, South Africa | 10/2011 |
| Voith, Heidenheim | 09/2011 |
| SpgBe Montreal, Canada | 09/2011 |
| SPG TECH, Montreuil Cedex, France | 09/2011 |
| Voith, Heidenheim-Mergelstetten | 09/2011 |
| MTU Aero Engines, Munich | 08/2011 |
| MIBRAG, Zeitz | 08/2011 |
| RWE, Essen | 07/2011 |
| Fels, Elingerode | 07/2011 |
| Weihenstephan University of Applied Sciences | 07/2011, 09/2011, 10/2011 |
| Forschungszentrum Juelich | 07/2011 |
| RWTH Aachen University | 07/2011, 08/2011 |
| INNEO Solutions, Ellwangen | 06/2011 |
| Caliqua, Basel, Switzerland | 06/2011 |
| Technical University of Freiberg | 06/2011 |
| Fichtner IT Consulting, Stuttgart | 05/2011, 06/2011, 08/2011 |
| Salzgitter Flachstahl, Salzgitter | 05/2011 |
| Helbling Beratung & Bauplanung, Zurich, Switzerland | 05/2011 |
| INEOS, Cologne | 04/2011 |
| Enseleit Consulting Engineers, Siebigerode | 04/2011 |
| Witt Consulting Engineers, Stade | 03/2011 |

| | |
|---|---|
| Helbling, Zurich, Switzerland | 03/2011 |
| MAN Diesel, Copenhagen, Denmark | 03/2011 |
| AGO, Kulmbach | 03/2011 |
| University of Duisburg | 03/2011, 06/2011 |
| CCP, Marburg | 03/2011 |
| BASF, Ludwigshafen | 02/2011 |
| ALSTOM Power, Baden, Switzerland | 02/2011 |
| Universität der Bundeswehr, Munich | 02/2011 |
| Calorifer, Elgg, Switzerland | 01/2011 |
| STRABAG, Vienna, Austria | 01/2011 |
| TUEV Sued, Munich | 01/2011 |
| ILK Dresden | 01/2011 |
| Technical University of Dresden | 01/2011, 05/2011, 06/2011, 08/2011 |

**2010**

| | |
|---|---|
| Umweltinstitut Neumarkt | 12/2010 |
| YIT Austria, Vienna, Austria | 12/2010 |
| MCI Innsbruck, Austria | 12/2010 |
| University of Stuttgart | 12/2010 |
| HS Cooler, Wittenburg | 12/2010 |
| Visteon, Novi Jicin, Czech Republic | 12/2010 |
| CompuWave, Brunntal | 12/2010 |
| Stadtwerke Leipzig | 12/2010 |
| MCI Innsbruck, Austria | 12/2010 |
| EVONIK Energy Services, Zwingenberg | 12/2010 |
| Caliqua, Basel, Switzerland | 11/2010 |
| Shanghai New Energy Resources Science & Technology, China | 11/2010 |
| Energieversorgung Halle | 11/2010 |
| Hochschule für Technik Stuttgart, University of Applied Sciences | 11/2010 |
| Steinmueller, Berlin | 11/2010 |
| Amberg-Weiden University of Applied Sciences | 11/2010 |
| AREVA NP, Erlangen | 10/2010 |
| MAN Diesel, Augsburg | 10/2010 |
| KRONES, Neutraubling | 10/2010 |
| Vaillant, Remscheid | 10/2010 |

| | |
|---|---|
| PC Ware, Leipzig | 10/2010 |
| Schubert Consulting Engineers, Weißenberg | 10/2010 |
| Fraunhofer Institut UMSICHT, Oberhausen | 10/2010 |
| Behringer Consulting Engineers, Tagmersheim | 09/2010 |
| Saacke, Bremen | 09/2010 |
| WEBASTO, Neubrandenburg | 09/2010 |
| Concordia University, Montreal, Canada | 09/2010 |
| Compañía Eléctrica de Sochagota, Bogota, Colombia | 08/2010 |
| Hannover University of Applied Sciences | 08/2010 |
| ERGION, Mannheim | 07/2010 |
| Fichtner IT Consulting, Stuttgart | 07/2010 |
| TF Design, Matieland, South Africa | 07/2010 |
| MCE, Berlin | 07/2010, 12/2010 |
| IPM, Zittau/Goerlitz University of Applied Sciences | 06/2010 |
| TUEV Sued, Dresden | 06/2010 |
| RWE IT, Essen | 06/2010 |
| Glen Dimplex, Kulmbach | 05/2010, 07/2010 10/2010 |
| Hot Rock, Karlsruhe | 05/2010 |
| Darmstadt University of Applied Sciences | 05/2010 |
| Voith, Heidenheim | 04/2010 |
| CombTec, Zittau | 04/2010 |
| University of Glasgow, Great Britain | 04/2010 |
| Universitaet der Bundeswehr, Munich | 04/2010 |
| Technical University of Hamburg-Harburg | 04/2010 |
| Vattenfall Europe, Berlin | 04/2010 |
| HUBER Consulting Engineers, Berching | 04/2010 |
| VER, Dresden | 04/2010 |
| CCP, Marburg | 03/2010 |
| Offenburg University of Applied Sciences | 03/2010 |
| Technical University of Berlin | 03/2010 |
| NIST Boulder CO, USA | 03/2010 |
| Technical University of Dresden | 02/2010 |
| Siemens Energy, Nuremberg | 02/2010 |
| Augsburg University of Applied Sciences | 02/2010 |

| | |
|---|---|
| ALSTOM Power, Baden, Switzerland | 02/2010, 05/2010 |
| MIT Massachusetts Institute of Technology Cambridge MA, USA | 02/2010 |
| Wieland Werke, Ulm | 01/2010 |
| Siemens Energy, Goerlitz | 01/2010, 12/2010 |
| Technical University of Freiberg | 01/2010 |
| ILK, Dresden | 01/2010, 12/2010 |
| Fischer-Uhrig Consulting Engineers, Berlin | 01/2010 |

**2009**

| | |
|---|---|
| ALSTOM Power, Baden, Schweiz | 01/2009, 03/2009, 05/2009 |
| Nordostschweizerische Kraftwerke AG, Doettingen, Switzerland | 02/2009 |
| RWE, Neurath | 02/2009 |
| Brandenburg University of Technology, Cottbus | 02/2009 |
| Hamburg University of Applied Sciences | 02/2009 |
| Kehrein, Moers | 03/2009 |
| EPP Software, Marburg | 03/2009 |
| Bernd Münstermann, Telgte | 03/2009 |
| Suedzucker, Zeitz | 03/2009 |
| CPP, Marburg | 03/2009 |
| Gelsenkirchen University of Applied Sciences | 04/2009 |
| Regensburg University of Applied Sciences | 05/2009 |
| Gatley & Associates, Atlanta, USA | 05/2009 |
| BOSCH, Stuttgart | 06/2009, 07/2009 |
| Dr. Nickolay, Consulting Engineers, Gommersheim | 06/2009 |
| Ferrostal Power, Saarlouis | 06/2009 |
| BHR Bilfinger, Essen | 06/2009 |
| Intraserv, Wiesbaden | 06/2009 |
| Lausitz University of Applied Sciences, Senftenberg | 06/2009 |
| Nuernberg University of Applied Sciences | 06/2009 |
| Technical University of Berlin | 06/2009 |
| Fraunhofer Institut UMSICHT, Oberhausen | 07/2009 |
| Bischoff, Aurich | 07/2009 |
| Fichtner IT Consulting, Stuttgart | 07/2009 |
| Techsoft, Linz, Austria | 08/2009 |
| DLR, Stuttgart | 08/2009 |

| | |
|---|---|
| Wienstrom, Vienna, Austria | 08/2009 |
| RWTH Aachen University | 09/2009 |
| Vattenfall, Hamburg | 10/2009 |
| AIC, Chemnitz | 10/2009 |
| Midiplan, Bietigheim-Bissingen | 11/2009 |
| Institute of Air Handling and Refrigeration ILK, Dresden | 11/2009 |
| FZD, Rossendorf | 11/2009 |
| Techgroup, Ratingen | 11/2009 |
| Robert Sack, Heidelberg | 11/2009 |
| EC, Heidelberg | 11/2009 |
| MCI, Innsbruck, Austria | 12/2009 |
| Saacke, Bremen | 12/2009 |
| ENERKO, Aldenhoven | 12/2009 |

**2008**

| | |
|---|---|
| Pink, Langenwang | 01/2008 |
| Fischer-Uhrig, Berlin | 01/2008 |
| University of Karlsruhe | 01/2008 |
| MAAG, Kuesnacht, Switzerland | 02/2008 |
| M&M Turbine Technology, Bielefeld | 02/2008 |
| Lentjes, Ratingen | 03/2008 |
| Siemens Power Generation, Goerlitz | 04/2008 |
| Evonik, Zwingenberg (general EBSILON program license) | 04/2008 |
| WEBASTO, Neubrandenburg | 04/2008 |
| CFC Solutions, Munich | 04/2008 |
| RWE IT, Essen | 04/2008 |
| Rerum Cognitio, Zwickau | 04/2008, 05/2008 |
| ARUP, Berlin | 05/2008 |
| Research Center, Karlsruhe | 07/2008 |
| AWECO, Neukirch | 07/2008 |
| Technical University of Dresden, Professorship of Building Services | 07/2008 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 07/2008, 10/2008 |
| Ingersoll-Rand, Unicov, Czech Republic | 08/2008 |
| Technip Benelux BV, Zoetermeer, Netherlands | 08/2008 |
| Fennovoima Oy, Helsinki, Finland | 08/2008 |

| | |
|---|---|
| Fichtner Consulting & IT, Stuttgart | 09/2008 |
| PEU, Espenhain | 09/2008 |
| Poyry, Dresden | 09/2008 |
| WINGAS, Kassel | 09/2008 |
| TUEV Sued, Dresden | 10/2008 |
| Technical University of Dresden, Professorship of Thermic Energy Machines and Plants | 10/2008, 11/2008 |
| AWTEC, Zurich, Switzerland | 11/2008 |
| Siemens Power Generation, Erlangen | 12/2008 |

## 2007

| | |
|---|---|
| Audi, Ingolstadt | 02/2007 |
| ANO Abfallbehandlung Nord, Bremen | 02/2007 |
| TUEV NORD SysTec, Hamburg | 02/2007 |
| VER, Dresden | 02/2007 |
| Technical University of Dresden, Chair in Jet Propulsion Systems | 02/2007 |
| Redacom, Nidau, Switzerland | 02/2007 |
| Universität der Bundeswehr, Munich | 02/2007 |
| Maxxtec, Sinsheim | 03/2007 |
| University of Rostock, Chair in Technical Thermodynamics | 03/2007 |
| AGO, Kulmbach | 03/2007 |
| University of Stuttgart, Chair in Aviation Propulsions | 03/2007 |
| Siemens Power Generation, Duisburg | 03/2007 |
| ENTHAL Haustechnik, Rees | 05/2007 |
| AWECO, Neukirch | 05/2007 |
| ALSTOM, Rugby, Great Britain | 06/2007 |
| SAAS, Possendorf | 06/2007 |
| Grenzebach BSH, Bad Hersfeld | 06/2007 |
| Reichel Engineering, Haan | 06/2007 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 06/2007 |
| Voith Paper Air Systems, Bayreuth | 06/2007 |
| Egger Holzwerkstoffe, Wismar | 06/2007 |
| Tissue Europe Technologie, Mannheim | 06/2007 |
| Dometic, Siegen | 07/2007 |
| RWTH Aachen University, Institute for Electrophysics | 09/2007 |
| National Energy Technology Laboratory, Pittsburg, USA | 10/2007 |

| | |
|---|---|
| Energieversorgung Halle | 10/2007 |
| AL-KO, Jettingen | 10/2007 |
| Grenzebach BSH, Bad Hersfeld | 10/2007 |
| Wiesbaden University of Applied Sciences, Department of Engineering Sciences | 10/2007 |
| Endress+Hauser Messtechnik, Hannover | 11/2007 |
| Munich University of Applied Sciences, Department of Mechanical Engineering | 11/2007 |
| Rerum Cognitio, Zwickau | 12/2007 |
| Siemens Power Generation, Erlangen | 11/2007 |
| University of Rostock, Chair in Technical Thermodynamics | 11/2007, 12/2007 |

**2006**

| | |
|---|---|
| STORA ENSO Sachsen, Eilenburg | 01/2006 |
| Technical University of Munich, Chair in Energy Systems | 01/2006 |
| NUTEC Engineering, Bisikon, Switzerland | 01/2006, 04/2006 |
| Conwel eco, Bochov, Czech Republic | 01/2006 |
| Offenburg University of Applied Sciences | 01/2006 |
| KOCH Transporttechnik, Wadgassen | 01/2006 |
| BEG Bremerhavener Entsorgungsgesellschaft | 02/2006 |
| Deggendorf University of Applied Sciences, Department of Mechanical Engineering and Mechatronics | 02/2006 |
| University of Stuttgart, Department of Thermal Fluid Flow Engines | 02/2006 |
| Technical University of Munich, Chair in Apparatus and Plant Engineering | 02/2006 |
| Energietechnik Leipzig (company license), | 02/2006 |
| Siemens Power Generation, Erlangen | 02/2006, 03/2006 |
| RWE Power, Essen | 03/2006 |
| WAETAS, Pobershau | 04/2006 |
| Siemens Power Generation, Goerlitz | 04/2006 |
| Technical University of Braunschweig, Department of Thermodynamics | 04/2006 |
| EnviCon & Plant Engineering, Nuremberg | 04/2006 |
| Brassel Engineering, Dresden | 05/2006 |
| University of Halle-Merseburg, Department of USET Merseburg incorporated society | 05/2006 |
| Technical University of Dresden, Professorship of Thermic Energy Machines and Plants | 05/2006 |

| | |
|---|---|
| Fichtner Consulting & IT Stuttgart<br>(company licenses and distribution) | 05/2006 |
| Suedzucker, Ochsenfurt | 06/2006 |
| M&M Turbine Technology, Bielefeld | 06/2006 |
| Feistel Engineering, Volkach | 07/2006 |
| ThyssenKrupp Marine Systems, Kiel | 07/2006 |
| Caliqua, Basel, Switzerland (company license) | 09/2006 |
| Atlas-Stord, Rodovre, Denmark | 09/2006 |
| Konstanz University of Applied Sciences,<br>Course of Studies Construction and Development | 10/2006 |
| Siemens Power Generation, Duisburg | 10/2006 |
| Hannover University of Applied Sciences,<br>Department of Mechanical Engineering | 10/2006 |
| Siemens Power Generation, Berlin | 11/2006 |
| Zikesch Armaturentechnik, Essen | 11/2006 |
| Wismar University of Applied Sciences, Seafaring Department | 11/2006 |
| BASF, Schwarzheide | 12/2006 |
| Enertech Energie und Technik, Radebeul | 12/2006 |

**2005**

| | |
|---|---|
| TUEV Nord, Hannover | 01/2005 |
| J.H.K Plant Engineering and Service, Bremerhaven | 01/2005 |
| Electrowatt-EKONO, Zurich, Switzerland | 01/2005 |
| FCIT, Stuttgart | 01/2005 |
| Energietechnik Leipzig (company license) | 02/2005, 04/2005,<br>07/2005 |
| eta Energieberatung, Pfaffenhofen | 02/2005 |
| FZR Forschungszentrum, Rossendorf/Dresden | 04/2005 |
| University of Saarbruecken | 04/2005 |
| Technical University of Dresden<br>Professorship of Thermic Energy Machines and Plants | 04/2005 |
| Grenzebach BSH, Bad Hersfeld | 04/2005 |
| TUEV Nord, Hamburg | 04/2005 |
| Technical University of Dresden, Waste Management | 05/2005 |
| Siemens Power Generation, Goerlitz | 05/2005 |
| Duesseldorf University of Applied Sciences,<br>Department of Mechanical Engineering and Process Engineering | 05/2005 |

| | |
|---|---|
| Redacom, Nidau, Switzerland | 06/2005 |
| Dumas Verfahrenstechnik, Hofheim | 06/2005 |
| Alensys Engineering, Erkner | 07/2005 |
| Stadtwerke Leipzig | 07/2005 |
| SaarEnergie, Saarbruecken | 07/2005 |
| ALSTOM ITC, Rugby, Great Britain | 08/2005 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 08/2005 |
| Vattenfall Europe, Berlin (group license) | 08/2005 |
| Technical University of Berlin | 10/2005 |
| Basel University of Applied Sciences, Department of Mechanical Engineering, Switzerland | 10/2005 |
| Midiplan, Bietigheim-Bissingen | 11/2005 |
| Technical University of Freiberg, Chair in Hydrogeology | 11/2005 |
| STORA ENSO Sachsen, Eilenburg | 12/2005 |
| Energieversorgung Halle (company license) | 12/2005 |
| KEMA IEV, Dresden | 12/2005 |

**2004**

| | |
|---|---|
| Vattenfall Europe (group license) | 01/2004 |
| TUEV Nord, Hamburg | 01/2004 |
| University of Stuttgart, Institute of Thermodynamics and Heat Engineering | 02/2004 |
| MAN B&W Diesel A/S, Copenhagen, Denmark | 02/2004 |
| Siemens AG Power Generation, Erlangen | 02/2004 |
| Ulm University of Applied Sciences | 03/2004 |
| Visteon, Kerpen | 03/2004, 10/2004 |
| Technical University of Dresden, Professorship of Thermic Energy Machines and Plants | 04/2004 |
| Rerum Cognitio, Zwickau | 04/2004 |
| University of Saarbruecken | 04/2004 |
| Grenzebach BSH, Bad Hersfeld | 04/2004 |
| SOFBID Zwingenberg (general EBSILON program license) | 04/2004 |
| EnBW Energy Solutions, Stuttgart | 05/2004 |
| HEW-Kraftwerk, Tiefstack | 06/2004 |
| h s energieanlagen, Freising | 07/2004 |
| FCIT, Stuttgart | 08/2004 |
| Physikalisch Technische Bundesanstalt (PTB), Braunschweig | 08/2004 |
| Mainova Frankfurt | 08/2004 |

| | |
|---|---|
| Rietschle Energieplaner, Winterthur, Switzerland | 08/2004 |
| MAN Turbo Machines, Oberhausen | 09/2004 |
| TUEV Sued, Dresden | 10/2004 |
| STEAG Kraftwerk, Herne | 10/2004, 12/2004 |
| University of Weimar | 10/2004 |
| energeticals (e-concept), Munich | 11/2004 |
| SorTech, Halle | 11/2004 |
| Enertech EUT, Radebeul (company license) | 11/2004 |
| Munich University of Applied Sciences | 12/2004 |
| STORA ENSO Sachsen, Eilenburg | 12/2004 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 12/2004 |
| Freudenberg Service, Weinheim | 12/2004 |

**2003**

| | |
|---|---|
| Paper Factory, Utzenstorf, Switzerland | 01/2003 |
| MAB Plant Engineering, Vienna, Austria | 01/2003 |
| Wulff Energy Systems, Husum | 01/2003 |
| Technip Benelux BV, Zoetermeer, Netherlands | 01/2003 |
| ALSTOM Power, Baden, Switzerland | 01/2003, 07/2003 |
| VER, Dresden | 02/2003 |
| Rietschle Energieplaner, Winterthur, Switzerland | 02/2003 |
| DLR, Leupholdhausen | 04/2003 |
| Emden University of Applied Sciences, Department of Technology | 05/2003 |
| Petterssson+Ahrends, Ober-Moerlen | 05/2003 |
| SOFBID ,Zwingenberg (general EBSILON program license) | 05/2003 |
| Ingenieurbuero Ostendorf, Gummersbach | 05/2003 |
| TUEV Nord, Hamburg | 06/2003 |
| Muenstermann GmbH, Telgte-Westbevern | 06/2003 |
| University of Cali, Colombia | 07/2003 |
| Atlas-Stord, Rodovre, Denmark | 08/2003 |
| ENERKO, Aldenhoven | 08/2003 |
| STEAG RKB, Leuna | 08/2003 |
| eta Energieberatung, Pfaffenhofen | 08/2003 |
| exergie, Dresden | 09/2003 |
| AWTEC, Zurich, Switzerland | 09/2003 |
| Energie, Timelkam, Austria | 09/2003 |

| | |
|---|---|
| Electrowatt-EKONO, Zurich, Switzerland | 09/2003 |
| LG, Annaberg-Buchholz | 10/2003 |
| FZR Forschungszentrum, Rossendorf/Dresden | 10/2003 |
| EnviCon & Plant Engineering, Nuremberg | 11/2003 |
| Visteon, Kerpen | 11/2003 |
| VEO Vulkan Energiewirtschaft Oderbruecke, Eisenhuettenstadt | 11/2003 |
| Stadtwerke Hannover | 11/2003 |
| SaarEnergie, Saarbruecken | 11/2003 |
| Fraunhofer-Gesellschaft, Munich | 12/2003 |
| Erfurt University of Applied Sciences, Department of Supply Engineering | 12/2003 |
| SorTech, Freiburg | 12/2003 |
| Mainova, Frankfurt | 12/2003 |
| Energieversorgung Halle | 12/2003 |

## 2002

| | |
|---|---|
| Hamilton Medical AG, Rhaezuens, Switzerland | 01/2002 |
| Bochum University of Applied Sciences, Department of Thermo- and Fluid Dynamics | 01/2002 |
| SAAS, Possendorf/Dresden | 02/2002 |
| Siemens, Karlsruhe (general license for the WinIS information system) | 02/2002 |
| FZR Forschungszentrum, Rossendorf/Dresden | 03/2002 |
| CompAir, Simmern | 03/2002 |
| GKS Gemeinschaftskraftwerk, Schweinfurt | 04/2002 |
| ALSTOM Power Baden, Switzerland (group licenses) | 05/2002 |
| InfraServ, Gendorf | 05/2002 |
| SoftSolutions, Muehlhausen (company license) | 05/2002 |
| DREWAG, Dresden (company license) | 05/2002 |
| SOFBID, Zwingenberg (general EBSILON program license) | 06/2002 |
| Kleemann Engineering, Dresden | 06/2002 |
| Caliqua, Basel, Switzerland (company license) | 07/2002 |
| PCK Raffinerie, Schwedt (group license) | 07/2002 |
| Fischer-Uhrig Engineering, Berlin | 08/2002 |
| Fichtner Consulting & IT, Stuttgart (company licenses and distribution) | 08/2002 |
| Stadtwerke Duisburg | 08/2002 |

| | |
|---|---|
| Stadtwerke Hannover | 09/2002 |
| Siemens Power Generation, Goerlitz | 10/2002 |
| Energieversorgung Halle (company license) | 10/2002 |
| Bayer, Leverkusen | 11/2002 |
| Dillinger Huette, Dillingen | 11/2002 |
| G.U.N.T. Geraetebau, Barsbuettel<br>(general license and training test benches) | 12/2002 |
| VEAG, Berlin (group license) | 12/2002 |

**2001**

| | |
|---|---|
| ALSTOM Power, Baden, Switzerland | 01/2001, 06/2001, 12/2001 |
| KW2 B. V., Amersfoot, Netherlands | 01/2001, 11/2001 |
| Eco Design, Saitamaken, Japan | 01/2001 |
| M&M Turbine Technology, Bielefeld | 01/2001, 09/2001 |
| MVV Energie, Mannheim | 02/2001 |
| Technical University of Dresden, Department of<br>Power Machinery and Plants | 02/2001 |
| PREUSSAG NOELL, Wuerzburg | 03/2001 |
| Fichtner Consulting & IT Stuttgart<br>(company licenses and distribution) | 04/2001 |
| Muenstermann GmbH, Telgte-Westbevern | 05/2001 |
| SaarEnergie, Saarbruecken | 05/2001 |
| Siemens, Karlsruhe<br>(general license for the WinIS information system) | 08/2001 |
| Neusiedler AG, Ulmerfeld, Austria | 09/2001 |
| h s energieanlagen, Freising | 09/2001 |
| Electrowatt-EKONO, Zurich, Switzerland | 09/2001 |
| IPM Zittau/Goerlitz University of Applied Sciences (general license) | 10/2001 |
| eta Energieberatung, Pfaffenhofen | 11/2001 |
| ALSTOM Power Baden, Switzerland | 12/2001 |
| VEAG, Berlin (group license) | 12/2001 |

**2000**

| | |
|---|---|
| SOFBID, Zwingenberg<br>(general EBSILON program license) | 01/2000 |
| AG KKK - PGW Turbo, Leipzig | 01/2000 |
| PREUSSAG NOELL, Wuerzburg | 01/2000 |
| M&M Turbine Technology, Bielefeld | 01/2000 |

| | |
|---|---|
| IBR Engineering Reis, Nittendorf-Undorf | 02/2000 |
| GK, Hannover | 03/2000 |
| KRUPP-UHDE, Dortmund (company license) | 03/2000 |
| UMAG W. UDE, Husum | 03/2000 |
| VEAG, Berlin (group license) | 03/2000 |
| Thinius Engineering, Erkrath | 04/2000 |
| SaarEnergie, Saarbruecken | 05/2000, 08/2000 |
| DVO Data Processing Service, Oberhausen | 05/2000 |
| RWTH Aachen University | 06/2000 |
| VAUP Process Automation, Landau | 08/2000 |
| Knuerr-Lommatec, Lommatzsch | 09/2000 |
| AVACON, Helmstedt | 10/2000 |
| Compania Electrica, Bogota, Colombia | 10/2000 |
| G.U.N.T. Geraetebau, Barsbuettel<br>(general license for training test benches) | 11/2000 |
| Steinhaus Informationssysteme, Datteln<br>(general license for process data software) | 12/2000 |

## 1999

| | |
|---|---|
| Bayernwerk, Munich | 01/1999 |
| DREWAG, Dresden (company license) | 02/1999 |
| KEMA IEV, Dresden | 03/1999 |
| Regensburg University of Applied Sciences | 04/1999 |
| Fichtner Consulting & IT, Stuttgart<br>(company licenses and distribution) | 07/1999 |
| Technical University of Cottbus, Chair in Power Plant Engineering | 07/1999 |
| Technical University of Graz, Department of Thermal Engineering, Austria | 11/1999 |
| Ostendorf Engineering, Gummersbach | 12/1999 |

## 1998

| | |
|---|---|
| Technical University of Cottbus, Chair in Power Plant Engineering | 05/1998 |
| Fichtner Consulting & IT (CADIS information systems) Stuttgart<br>(general KPRO program license) | 05/1998 |
| M&M Turbine Technology Bielefeld | 06/1998 |
| B+H Software Engineering Stuttgart | 08/1998 |
| Alfa Engineering, Switzerland | 09/1998 |
| VEAG Berlin (group license) | 09/1998 |
| NUTEC Engineering, Bisikon, Switzerland | 10/1998 |

| | |
|---|---|
| SCA Hygiene Products, Munich | 10/1998 |
| RWE Energie, Neurath | 10/1998 |
| Wilhelmshaven University of Applied Sciences | 10/1998 |
| BASF, Ludwigshafen (group license) | 11/1998 |
| Energieversorgung, Offenbach | 11/1998 |

### 1997

| | |
|---|---|
| Gerb, Dresden | 06/1997 |
| Siemens Power Generation, Goerlitz | 07/1997 |