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

**FluidDYM  
with LibIF97  
for DYMOLA®**

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**Software for the Industrial Formulation IAPWS-IF97  
of Water and Steam  
Including DLL and Add-In for DYMOLA<sup>®</sup>**

**FluidDYM  
LibIF97**

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## 0. Package Contents

### Zip-file "CD\_FluidDYM\_LibIF97\_Eng.zip" for Dymola®

Including the following files:

|                               |                                                                 |
|-------------------------------|-----------------------------------------------------------------|
| FluidDYM_LibIF97_Setup.exe    | Installation Program for the FluidDYM Add-In for use in Dymola® |
| LibIF97.dll                   | Dynamic Link Library for water and steam for use in Dymola®     |
| Docu_FluidDYM_LibIF97_Eng.pdf | User's Guide                                                    |
| Folder "Users_Guide"          | Includes the complete User's Guide                              |

# 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.

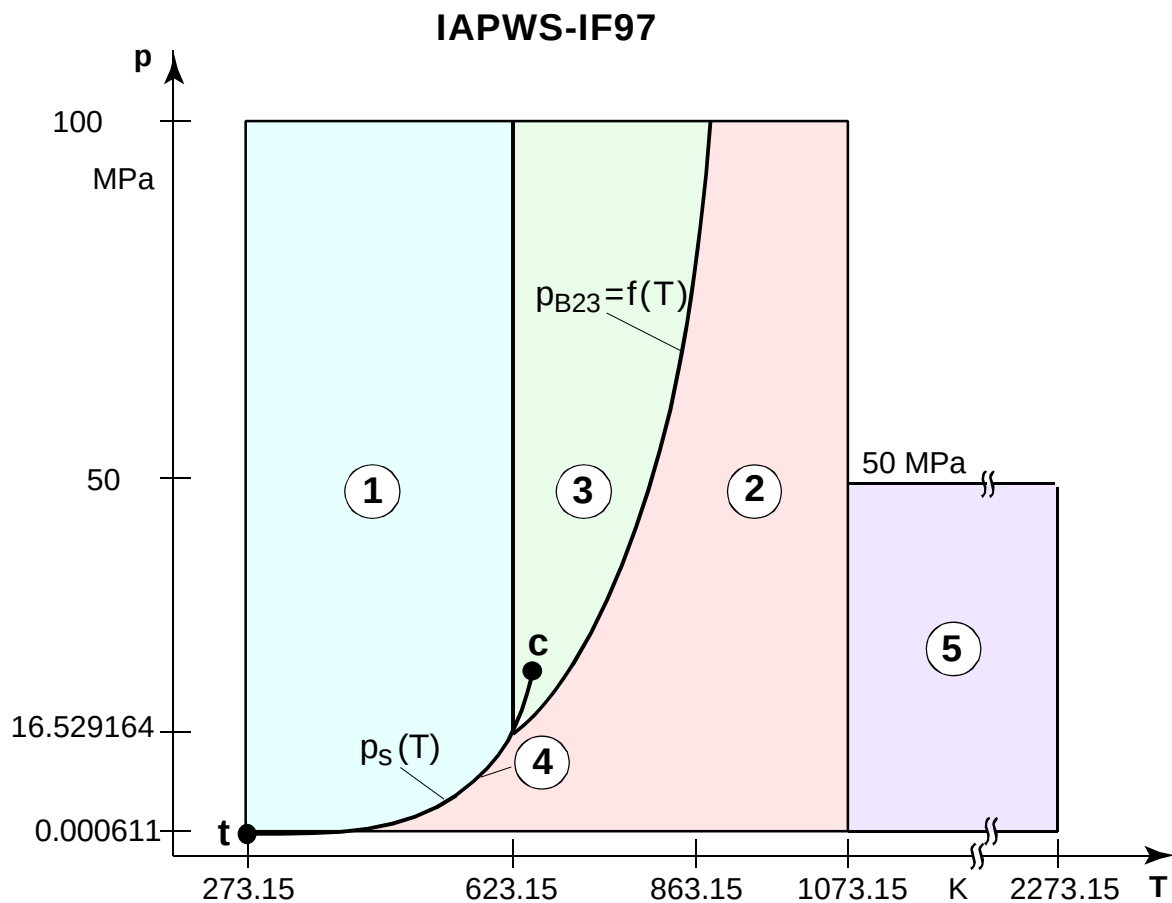


**Figure 1.1** Entire Range of Validity of the IF97

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           |
|-------------------------------------------------------------|----------------|-----------------------------------|--------------------------------------------|-------------------------------------------------------------------------------|------------------------------|
| $a = f(p, t, x)$                                            | a_ptx_97       | = APTX97(P, T, X)                 | = C_APTX97(A, P, T, X)                     | Thermal diffusivity                                                           | m <sup>2</sup> /s            |
| $\alpha_p = f(p, t, x)$                                     | alphap_ptx_97  | = ALPHAPPTX97(P, T, X)            | = C_ALPHAPPTX97(ALPHAP, P, T, X)           | Relative pressure coefficient                                                 | K <sup>-1</sup>              |
| $\alpha_v = f(p, t, x)$                                     | alphav_ptx_97  | = ALPHAVPTX97(P, T, X)            | = C_ALPHAVPTX97(ALPHAV, P, T, X)           | Isobaric cubic expansion coefficient                                          | K <sup>-1</sup>              |
| $b = f(p)$                                                  | b_p_97         | = BP97(P)                         | = C_BP97(B, P)                             | Laplace coefficient                                                           | m                            |
| $b = f(t)$                                                  | b_t_97         | = BT97(T)                         | = C_BT97(B, T)                             | Laplace coefficient                                                           | m                            |
| $\beta_p = f(p, t, x)$                                      | betap_ptx_97   | = BETAPPTX97(P, T, X)             | = C_BETAPPTX97(BETAP, P, T, X)             | Isothermal stress coefficient                                                 | kg/m <sup>3</sup>            |
| $c_p = f(p, t, x)$                                          | cp_ptx_97      | = CPPTX97(P, T, X)                | = C_CPPTX97(CP, P, T, X)                   | Specific isobaric heat capacity                                               | kJ/(kg · K)                  |
| $c_v = f(p, t, x)$                                          | cv_ptx_97      | = CVPTX97(P, T, X)                | = C_CVPTX97(CV, P, T, X)                   | Specific isochoric heat capacity                                              | kJ/(kg · K)                  |
| $\delta_T = f(p, t, x)$                                     | deltat_ptx_97  | = DELTATPTX97(P, T, X)            | = C_DELTATPTX97(DELTAT, P, T, X)           | Isothermal throttling coefficient                                             | kJ/(kg · kPa <sup>-1</sup> ) |
| $\left(\frac{\partial v}{\partial p}\right)_T = f(p, t, x)$ | dv_dp_T_ptx_97 | = DVDPT97(P, T, X)                | = C_DVDPT97(DVP, P, T, X)                  | Differential quotient $\left(\frac{\partial v}{\partial p}\right)_T(p, t, x)$ | m <sup>3</sup> /(kg · kPa)   |
| $\left(\frac{\partial v}{\partial T}\right)_p = f(p, t, x)$ | dv_dT_p_ptx_97 | = DVDTP97(P, T, X)                | = C_DVDTP97(DVT, P, T, X)                  | Differential quotient $\left(\frac{\partial v}{\partial T}\right)_p(p, t, x)$ | m <sup>3</sup> /(kg · K)     |
| $e = f(p, t, x, t_U)$                                       | e_ptx_tu_97    | = EPTXTU97(P, T, X, TU)           | = C_EPTXTU97(E, P, T, X, TU)               | Specific exergy                                                               | kJ/kg                        |
| $\varepsilon = f(p, t, x)$                                  | epsilon_ptx_97 | = EPSPTX97(P, T, X)               | = C_EPSPTX97(EPS, P, T, X)                 | Dielectric constant                                                           | -                            |
| $\eta = f(p, t, x)$                                         | eta_ptx_97     | = ETAPTX97(P, T, X)               | = C_ETAPTX97(ETA, P, T, X)                 | Dynamic viscosity                                                             | Pa · s = kg/(m · s)          |
| $f = f(p, t, x)$                                            | f_ptx_97       | = FPTX97(P, T, X)                 | = C_FPTX97(F, P, T, X)                     | Specific Helmholtz energy                                                     | kJ/kg                        |
| $f^* = f(p, t, x)$                                          | fug_ptx_97     | = FUGPTX97(P, T, X)               | = C_FUGPTX97(FUG, P, T, X)                 | Fugacity                                                                      | bar                          |
| $g = f(p, t, x)$                                            | g_ptx_97       | = GPTX97(P, T, X)                 | = C_GPTX97(G, P, T, X)                     | Specific Gibbs energy                                                         | kJ/kg                        |
| $h = f(p, s)$                                               | h_ps_97        | = HPS97(P, S)                     | = C_HPS97(HPS, P, S)                       | Backward function: Specific enthalpy from pressure and entropy                | kJ/kg                        |
| $h = f(p, t, x)$                                            | 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 <sup>-1</sup>   |
| $\lambda = f(p, t, x)$  | lambda_ptx_97 | = LAMPTX97(P, T, X)               | = C_LAMPTX97(LAM, P, T, X)                 | Heat conductivity                                              | W/(m · K)           |
| $\mu = f(p, t, x)$      | my_ptx_97     | = MYPTX97(P, T, X)                | = C_MYPTX97(MY, P, T, X)                   | Joule-Thomson coefficient                                      | K kPa <sup>-1</sup> |
| $n = f(p, t, x, wl)$    | 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 <sup>2</sup> /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)                   | <i>Prandtl</i> -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 <sup>3</sup>   |
| $s = f(p, h)$           | s_ph_97       | = SPH97(P, H)                     | = C_SPH97(SPH, P, H)                       | Backward function: Specific entropy from pressure and enthalpy | kJ/(kg · K)         |
| $s = f(p, t, x)$        | s_ptx_97      | = SPTX97(P, T, X)                 | = C_SPTX97(S, P, T, X)                     | Specific entropy                                               | kJ/(kg · K)         |
| $\sigma = f(p)$         | sigma_p_97    | = SIGMAP97(P)                     | = C_SIGMAP97(SIG, P)                       | Surface tension from pressure                                  | mN/m = mPa · m      |
| $\sigma = f(t)$         | sigma_t_97    | = SIGMAT97(T)                     | = C_SIGMAT97(SIG, T)                       | Surface tension from temperature                               | mN/m = mPa · 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 |
|-----------------------|---------------|-----------------------------------|--------------------------------------------|-------------------------------------------------------------------|--------------------|
| $t = f(v, h)$         | t_vh_97       | = TVH97(P,H)                      | = C_TVH97(TPH,P,H)                         | Backward function: Temperature from volume and enthalpy           | °C                 |
| $t = f(v, u)$         | t_vu_97       | = TVU97(P,H)                      | = C_TVU97(TPH,P,H)                         | Backward function: Temperature from volume and internal energy    | °C                 |
| $t_s = f(p)$          | ts_p_97       | = TSP97(P)                        | = C_TSP97(TS,P)                            | Saturation temperature                                            | °C                 |
| $u = f(p, t, x)$      | u_ptx_97      | = UPTX97(P,T,X)                   | = C_UPTX97(U,P,T,X)                        | Specific internal energy                                          | kJ/kg              |
| $v = f(p, h)$         | v_ph_97       | = VPH97(P,S)                      | = C_VPH97(VPS,P,S)                         | Backward function: Specific volume from pressure and enthalpy     | m³/kg              |
| $v = f(p, s)$         | v_ps_97       | = VPS97(P,S)                      | = C_VPS97(VPS,P,S)                         | Backward function: Specific volume from pressure and entropy      | m³/kg              |
| $v = f(p, t, x)$      | v_ptx_97      | = VPTX97(P,T,X)                   | = C_VPTX97(V,P,T,X)                        | Specific volume                                                   | m³/kg              |
| $w = f(p, t, x)$      | w_ptx_97      | = WPTX97(P,T,X)                   | = C_WPTX97(W,P,T,X)                        | Isentropic speed of sound                                         | m/s                |
| $x = f(h, s)$         | x_hs_97       | = XHS97(H,S)                      | = C_XHS97(XHS,H,S)                         | Backward function: Vapor fraction from enthalpy and entropy       | kg/kg              |
| $x = f(p, h)$         | x_ph_97       | = XPH97(P,H)                      | = C_XPH97(XPH,P,H)                         | Backward function: Vapor fraction from pressure and enthalpy      | kg/kg              |
| $x = f(p, s)$         | x_ps_97       | = XPS97(P,S)                      | = C_XPS97(XPS,P,S)                         | Backward function: Vapor fraction from pressure and entropy       | kg/kg              |
| $x = f(v, h)$         | x_vh_97       | = XVH97(P,H)                      | = C_XVH97(XPH,P,H)                         | Backward function: Vapor fraction from volume and enthalpy        | kg/kg              |
| $x = f(v, u)$         | x_vu_97       | = XVU97(P,H)                      | = C_XVU97(XPH,P,H)                         | Backward function: Vapor fraction from volume and internal energy | kg/kg              |
| $z = f(p, t, x)$      | 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                                          |
|                          | Exception to 900°C for the functions for $\alpha$ , $\eta$ , $\lambda$ , $\nu$ , 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:  $t_t = 0\text{ °C} \dots t_c = 373.946\text{ °C}$   
 $p_t = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$  (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.*

## 2. Application of FluidDYM in Dymola®

The FluidDYM Add-In has been developed to calculate thermodynamic properties in Dymola® more conveniently. Within Dymola® it enables the direct call of functions relating to water and steam from the LibIF97 property library.

### 2.1 Installing FluidDYM

FluidDYM will be installed by means of a self-extracting setup file. Before you begin, it is best to close any Windows® applications, since Windows® may need to be rebooted during the installation process.

After you have downloaded and extracted the zip-file "CD\_FluidDYM\_LibIF97.zip", you will see the folder

CD\_FluidDYM\_LibIF97

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:

FluidDYM\_LibIF97\_Docu\_Eng.pdf

FluidDYM\_LibIF97\_Setup.exe

LibIF97.dll

Folder "Users\_Guide."

In order to run the installation of FluidDYM including the LibIF97 property library double-click the file

FluidDYM\_LibIF97\_Setup.exe.

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 (see Figure 2.1), "Choose Destination Location", the default path offered automatically for the installation of FluidDYM is

C:\Program Files\FluidDYM\LibIF97 (for English version of Windows)

C:\Programme\FluidDYM\LibIF97 (for German version of Windows)).

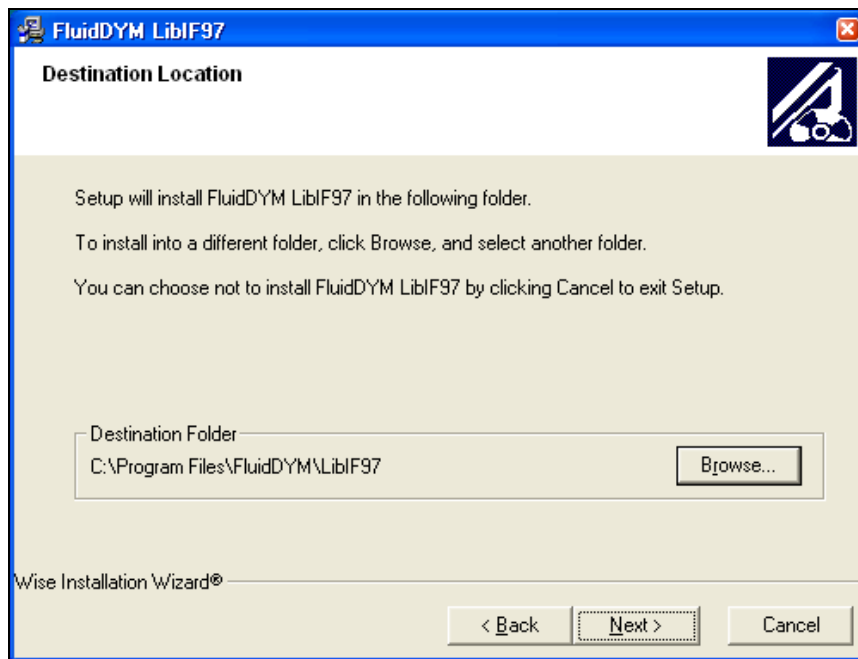


**Figure 2.1:** Dialog window "Destination Location"

By clicking the "Browse..." button, you can change the installation directory before installation. If you wish to change directory, click the "Browse..." button and select your desired directory. The instructions in this user's guide refer to the stated default directory. Leave this window by clicking the "Next>" button.

The dialog window "Start Installation" pops up. Click the "Next>" button to continue the installation. The FluidDYM files are now being copied onto your hard disk drive into the created directory. Click the "Finish>" button in the following window to finish installation.

The installation program has copied the following files into the directory

C:\Program Files\FuildDYM\LibIF97 (for English version of Windows)  
 C:\Programme\FuildDYM\LibIF97 (for German version of Windows)):

- Dynamic link library "LibIF97.dll"
- Folder "Users\_Guide"
- Link up Dynamic link library "LibIF97\_Dymola.dll" and other necessary system DLL files
- Library File "LibIF97\_Dymola.lib"
- Header File "LibIF97\_Dymola.h" and other necessary system DLL files
- Modelica File "FluidDYM\_LibIF97.mo", includes the following property functions:

|               |                |
|---------------|----------------|
| a_ptx_97      | p_vh_97        |
| alphap_ptx_97 | p_vu_97        |
| alphav_ptx_97 | Prandtl_ptx_97 |
| b_p_97        | ps_t_97        |
| b_t_97        | rho_ptx_97     |
| betap_ptx_97  | s_ph_97        |
| cp_ptx_97     | s_ptx_97       |

|                |            |
|----------------|------------|
| cv_ptx_97      | sigma_p_97 |
| deltat_ptx_97  | sigma_t_97 |
| dv_dp_T_ptx_97 | t_hs_97    |
| dv_dT_p_ptx_97 | t_ph_97    |
| e_ptx_97       | t_ps_97    |
| epsilon_ptx_97 | t_vh_97    |
| eta_ptx_97     | t_vu_97    |
| f_ptx_97       | ts_p_97    |
| fug_ptx_97     | u_ptx_97   |
| g_ptx          | v_ph_97    |
| h_ps_97        | v_ps_97    |
| h_ptx_97       | v_ptx_97   |
| kappa_ptx_97   | w_ptx_97   |
| kappat_ptx_97  | x_hs_97    |
| lambda_ptx_97  | x_ph_97    |
| my_ptx_97      | x_ps_97    |
| n_ptxwl_97     | x_vh_97    |
| ny_ptx_97      | x_vu_97    |
| p_hs_97        | z_ptx_97   |

Now, you have to overwrite the file "LibIF97.dll" and the folder "Users\_Guide" in your LibIF97 directory with the files of the same names provided in your CD folder with FluidDYM.

To do this, open the CD folder "CD\_FluidDYM\_LibIF97" in "My Computer" and click on the file "LibIF97.dll" in order to highlight it. Hold Ctrl and click on the folder "Users\_Guide" to mark it as well.

Then click on the "Edit" menu in your Explorer and select "Copy".

Now, open your LibIF97 directory (the standard being

C:\Program Files\FluidDYM\LibIF97 (for English version of Windows)

C:\Programme\FluidDYM\LibIF97 (for German version of Windows))

and insert the "LibIF97.dll" and the "Users\_Guide" folder by clicking the "Edit" menu in your Explorer and then select "Paste".

Answer the question whether you want to replace the files by clicking the "Yes" button. Now, you have overwritten the file "LibIF97.dll" and the folder "Users\_Guide" successfully.

## 2.2 Licensing the LibIF97 Property Library

The licensing procedure has to be carried out when Dymola<sup>®</sup> is running and a model simulation starts. In this case, you will see the "License Information" window (see Figure 2.2).

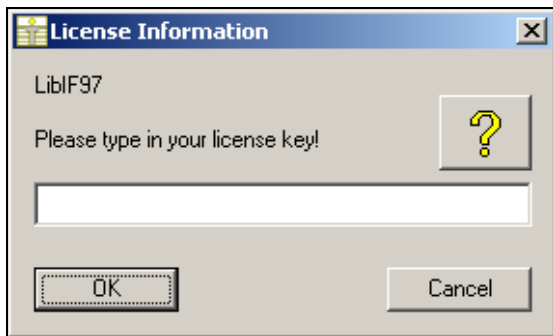


**Figure 2.2:** "License Information" window

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:

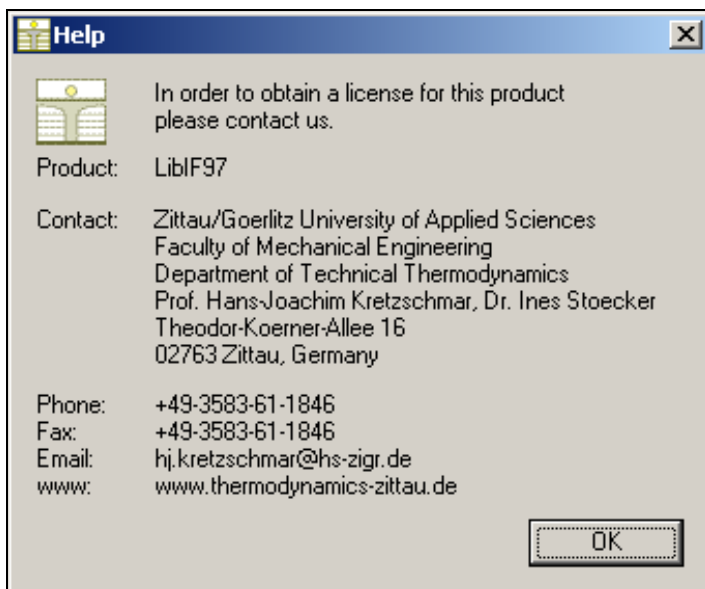


**Figure 2.3:** "Help" window

If you do not enter a valid license it is still possible to use Dymola<sup>®</sup> by clicking "Cancel". In this case, the LibIF97 property library will display the result "-1111111" for every calculation. The "License Information" window will appear every time you start Dymola.

Should you not wish to license the LibIF97 property library, you have to uninstall the FluidDYM LibIF97 property library following the description in section 2.4 of this User's Guide.

## 2.3 Example: Calculation of $h = f(p, t, x)$

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

Please carry out the following instructions:

- Start Windows Explorer®, Total Commander®, My Computer or another file manager program.  
The description here refers to Windows Explorer.
- Your Windows Explorer should be set to Details for a better view. Click the "View" button and select "Details".
- Switch into the program directory of FluidDYM in which you will find the folder "\LibIF97"; the standard location is:  
C:\Program Files\FluidDYM\LibIF97 (for English version of Windows)  
C:\Programme\FluidDYM\LibIF97 (for German version of Windows))
- Create the folder "\LibIF97\_Example" by clicking on "File" in the Explorer menu, then "New" in the menu which appears, and then selecting "Folder". Name the new folder "\LibIF97\_Example".
- You will see the following window:

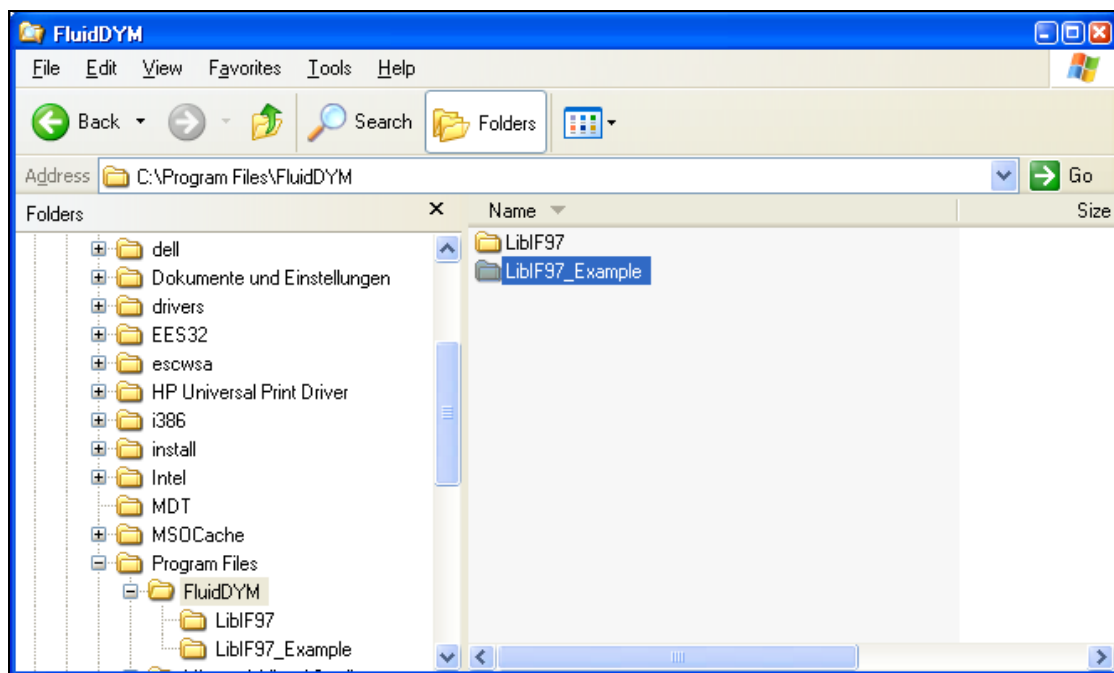


**Figure 2.4:** "LibIF97\_Example" and "LibIF97" directory in FluidDYM

- Switch into the directory "\LibIF97" within "\FluidDYM", the standard being:  
C:\Program Files\FluidDYM\LibIF97 (for English version of Windows)  
C:\Programme\FluidDYM\LibIF97 (for German version of Windows)).

- You will see the following window:

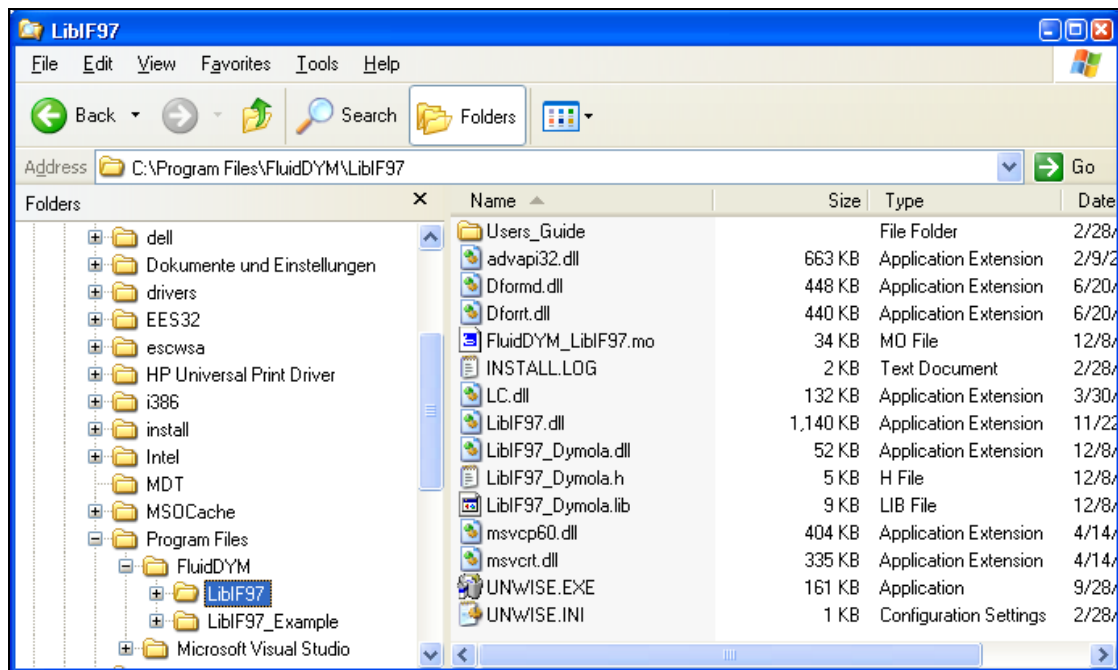


**Figure 2.5:** "LibIF97" directory including installed files

In order to calculate the function  $h = f(p, t, x)$ , the following files are necessary. Copy them into the directory

C:\Program Files\FluidDYM\LibIF97 (for English version of Windows)  
 C:\Programme\FluidDYM\LibIF97 (for German version of Windows)):

- "advapi32.dll"
- "Dformd.dll"
- "Dfortt.dll"
- "FluidDYM\_LibIF97.mo"
- "LC.dll"
- "LibIF97.dll"
- "LibIF97\_Dymola.dll"
- "LibIF97\_Dymola.h"
- "LibIF97\_Dymola.lib"
- "msvc60.dll"
- "Msvcrt.dll"
- the folder "Users\_Guide"

- Mark up these files, then click "Edit" in the upper menu bar and select "Copy".
- Switch into the directory

C:\Program Files\FluidDYM\LibIF97\_Example (for English version of Windows)  
 C:\Programme\FluidDYM\LibIF97\_Example (for German version of Windows)),

click "Edit" and then "Paste".

- You will see the following window:

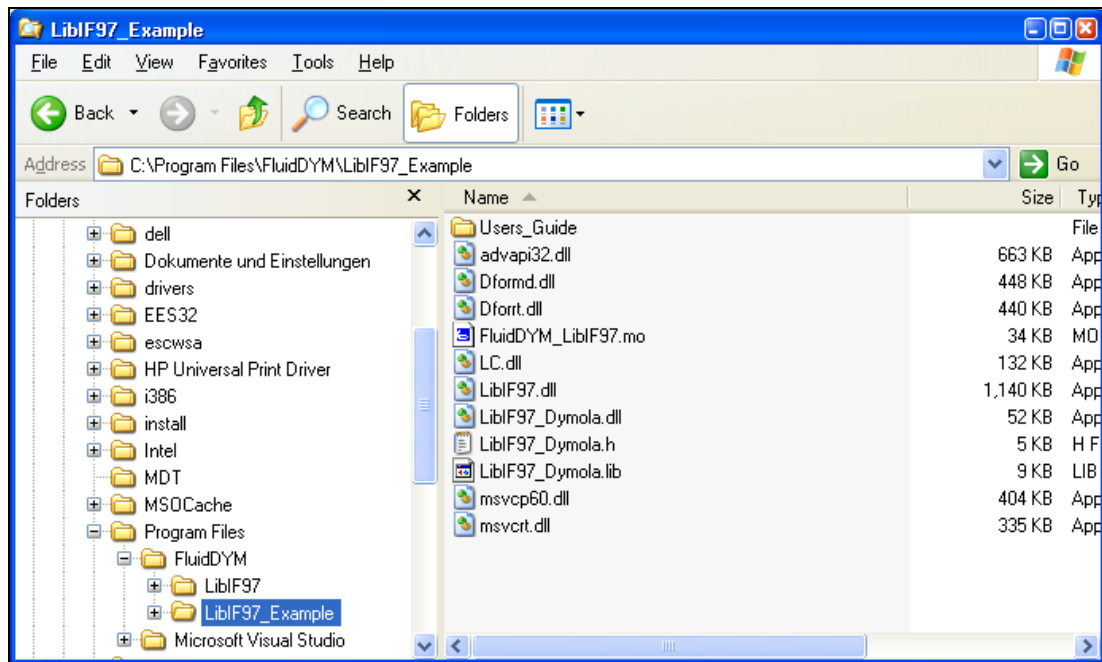


**Figure 2.6:** "LibIF97\_Example" directory including the newly-copied files

- Start Dymola®.
- Now click on "File" in the Dymola® menu bar and select "Open" (see Figure 2.7).

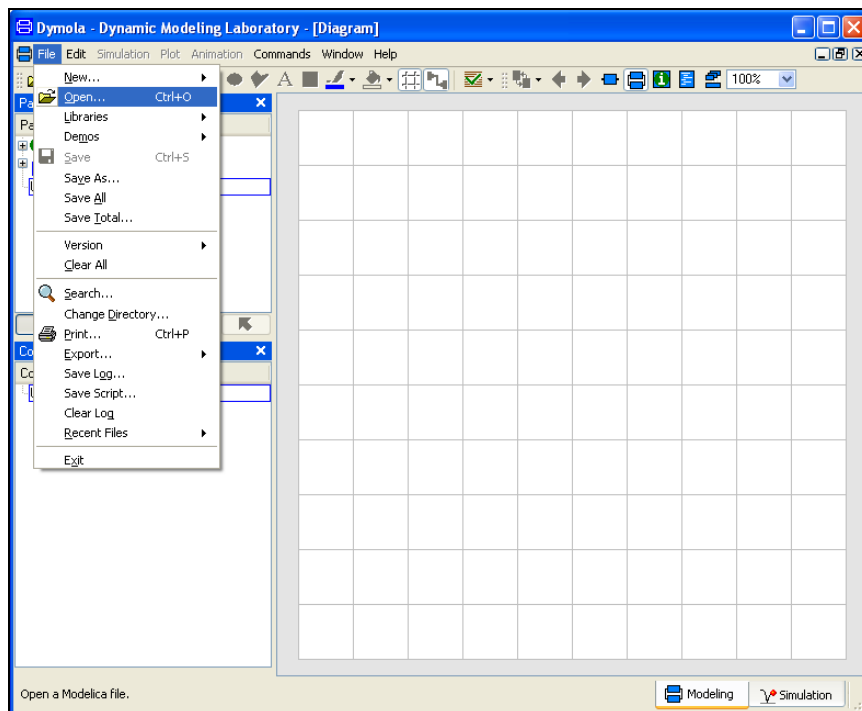


**Figure 2.7:** Selecting the menu entry "Open"

- Search and click on the directory  
     "C:\Program Files\FluidDYM\LibIF97\_Example"      (for English version of Windows)  
     "C:\Programme\FluidDYM\LibIF97\_Example"      (for German version of Windows)  
     in the appearing menu.

- Select the "FluidDYM\_LibIF97.mo" file and click on the "Open" button (see Figure 2.8).

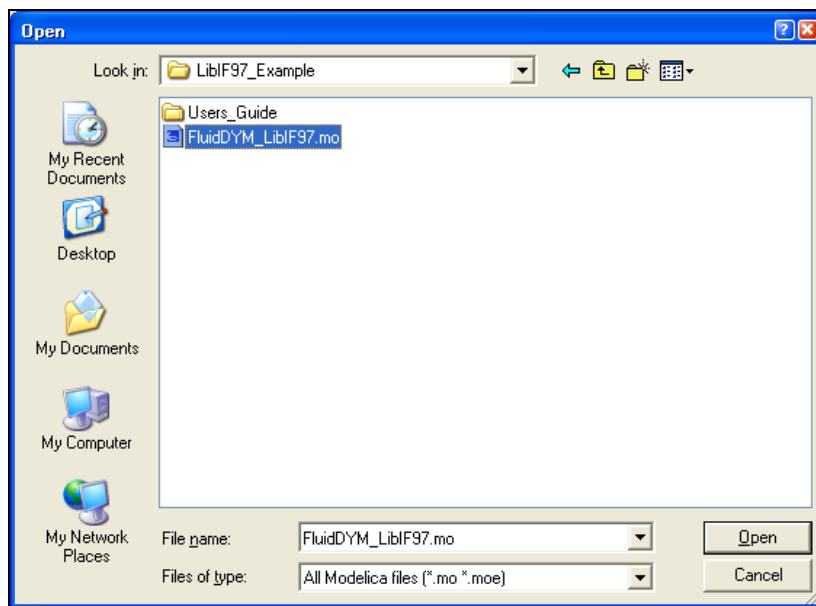


**Figure 2.8:** Selecting the "FluidDYM\_LibIF97.mo" file

- The library will be loaded by Dymola which may take a few seconds.
- After Dymola has finished loading the LibIF97 library, you will see the window shown in Figure 2.9.

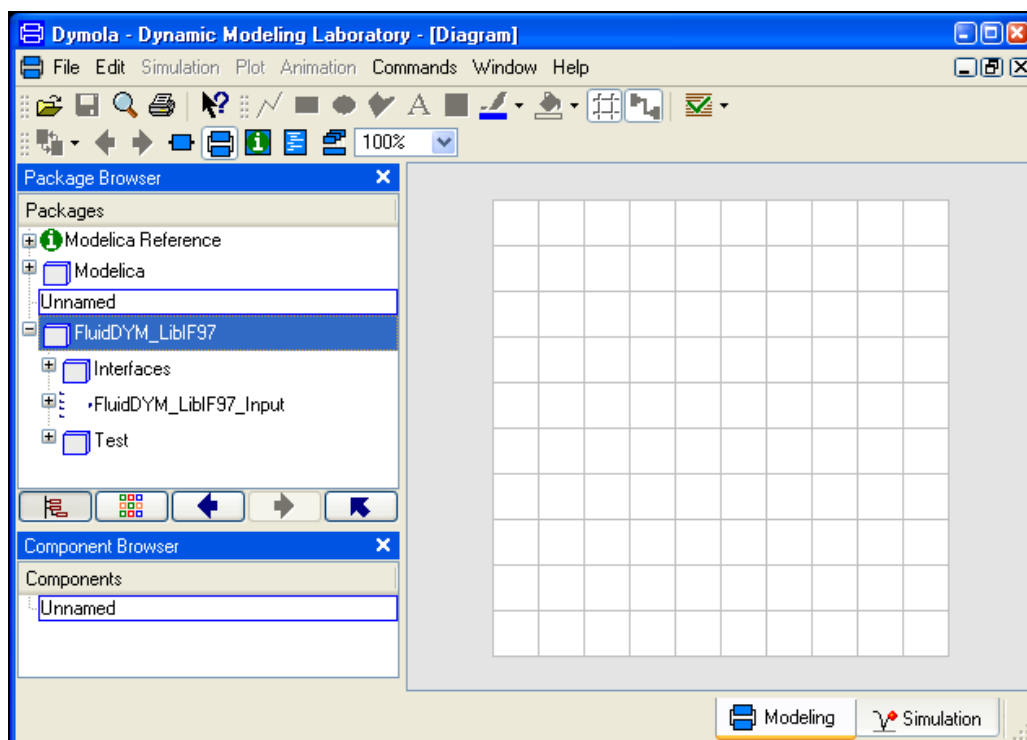


**Figure 2.9:** Dymola window after loading the "LibIF97" library

- Now, click on "File" in the Dymola menu bar and select "Change Directory..." in order to open the folder "LibIF97\_Example" (see Figure 2.10).

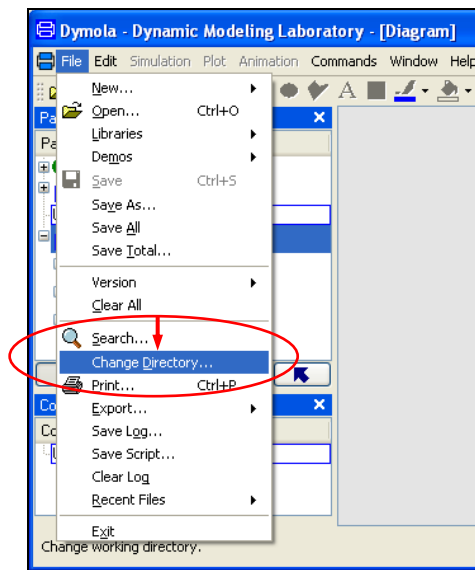


**Figure 2.10:** Selecting the menu entry "Change Directory..."

- Search and click on the directory
  - "C:\Program Files\FluidDYM\LibIF97\_Example" (for English version of Windows)
  - "C:\Programme\FluidDYM\LibIF97\_Example" (for German version of Windows)
 in the menu that appears (see Figure 2.11).

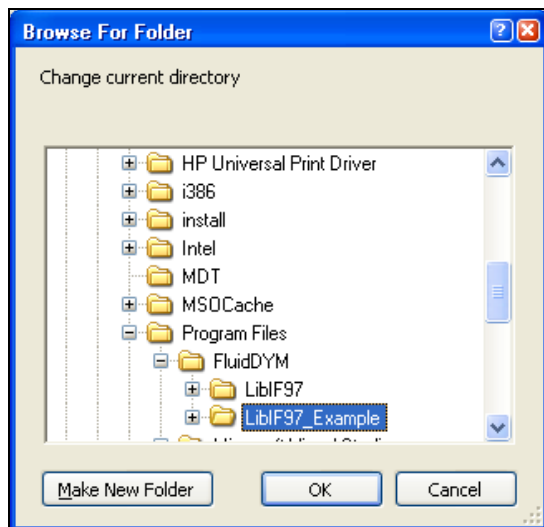


**Figure 2.11:** Selecting the "LibIF97\_Example" directory

- Confirm your selection by clicking the "OK" button.

As indicated in the table of property functions in Chapter 1, you have to call up the function "h\_ptx\_97" as follows for calculating  $h = f(p, t, x)$ .

- Click on the Dymola-Block "Testmodelle," which can be found in the FluidDYM\_LibIF97 package in the "Package Browser" on the left hand side of the Dymola window. Here choose Example1 by double-clicking on it.
- Now click on the  button in the Dymola menu bar in order to switch to the Diagram Mode. You will see the following window:

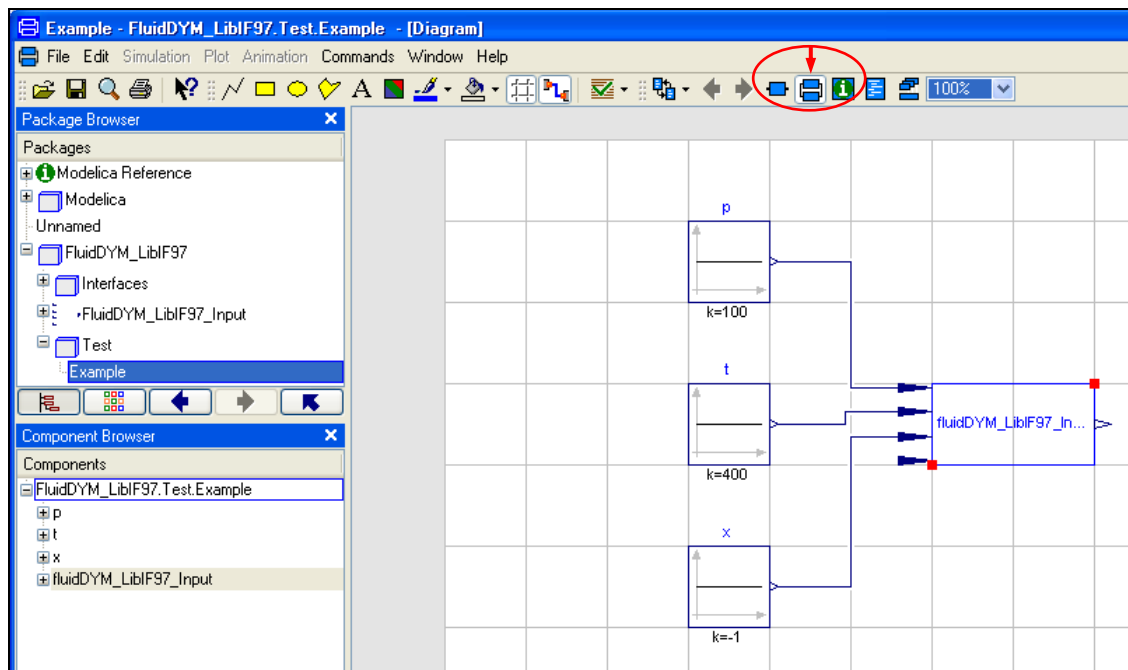


**Figure 2.12:** Dymola in Diagram Mode

- Now double-click on the "fluidDYM\_LibIF97\_Input" block on the right hand side of the Dymola window.
- Search and click the "h\_ptx\_97" function next to "Function Number" in the menu that appears (see Figure 2.13).

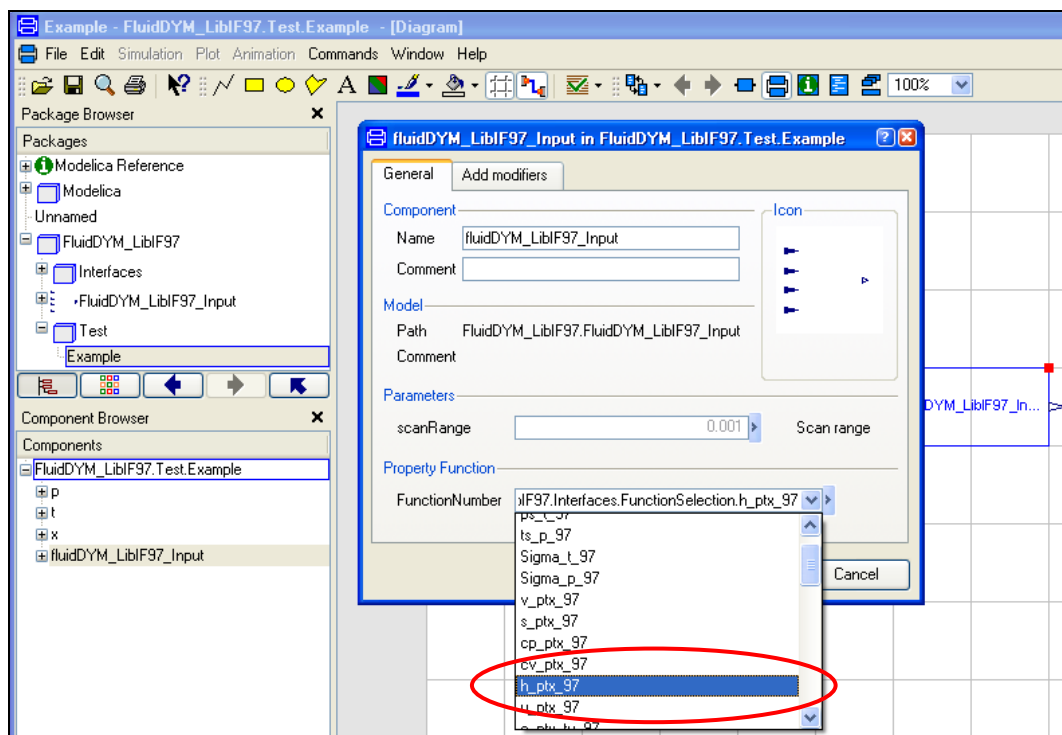


**Figure 2.13:** Choosing the function "h\_ptx\_97"

- You can set the scan range (how many times the property will be calculated per second) next to "scanRange". The preset value 0.001 means that the property will be calculated 1000 times per second. E.g. if you enter the value 1, the property will be calculated once per second. Do not change the preset value of 0.001 for our example calculation.

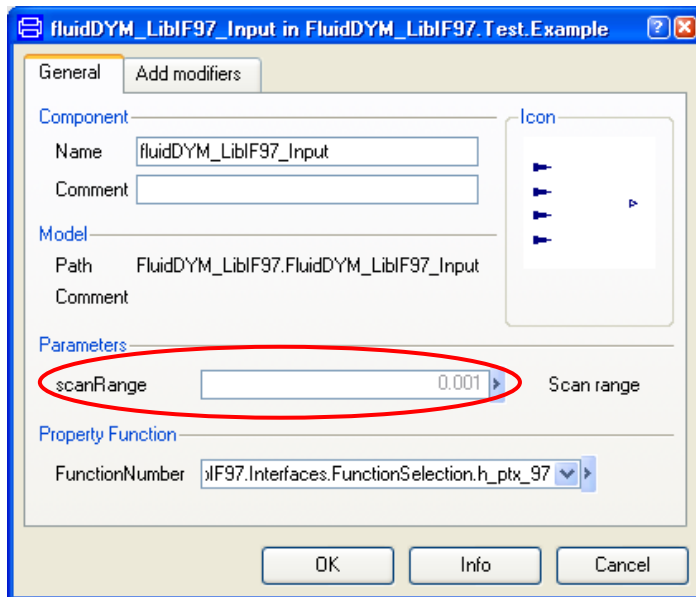


**Figure 2.14:** Setting the scan range

- Now we will configure the input parameters  $x_1$  to  $x_3$ , where  $x_1$  represents the pressure  $p$ ,  $x_2$  represents the temperature  $t$ , and  $x_3$  represents the vapor fraction  $x$ . When calculating a function with only one or two input parameters, the other input parameter(s) will not be defined.
- First, double click on the "Parameter\_x1" block which represents the first input parameter, here the pressure  $p$  in bar.

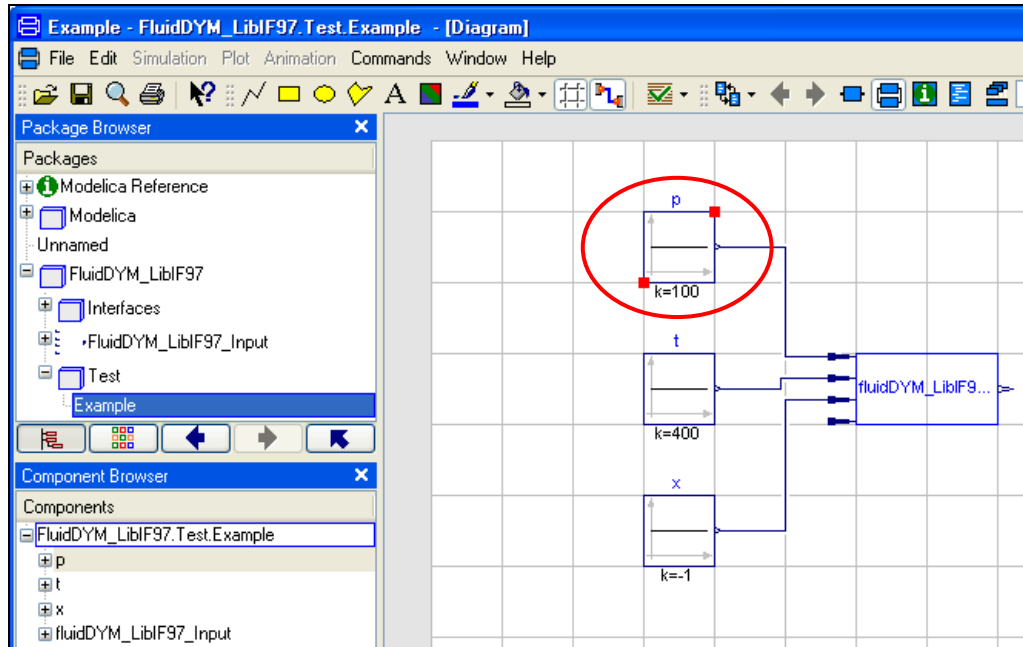


**Figure 2.15:** "Parameter\_x1" block in Dymola

- Enter the value 100 on the line next to "k" in the dialog window which appears  
(Range of validity of the IF97:  $p = 0.00611 \dots 1000$  bar  
 $p = 0.00611 \dots 500$  bar for high temperature region)
- Then click the "OK" button (see Figure 2.16).

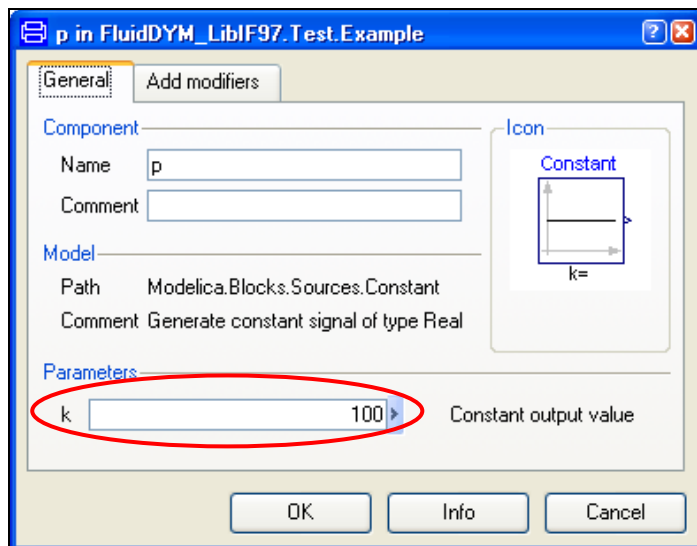


**Figure 2.16:** Entering the value for the pressure  $p$

- Now, double click on the "Parameter\_x2" block which represents the second input parameter, here the temperature  $t$  in °C.
- Enter the value 400 on the line next to "k" in the dialog window which appears  
(Range of validity of the IF97:  $t = 0 \dots 800$  °C  
high temperature region up to 2000 °C)
- Then click the "OK" button (see Figure 2.17).

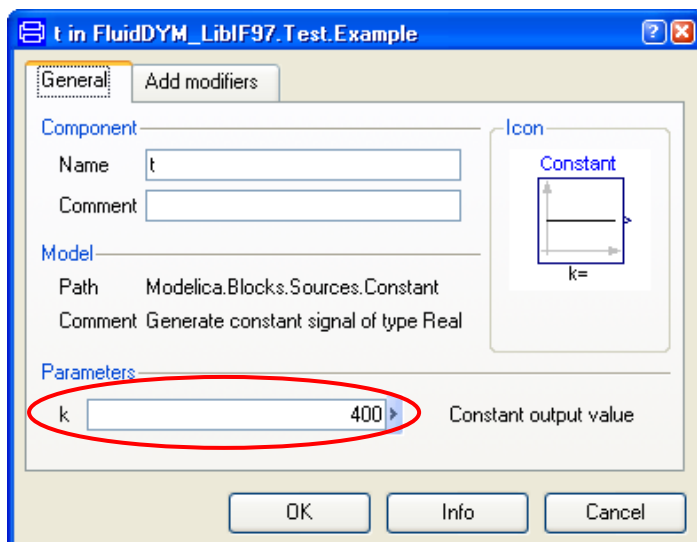


**Figure 2.17:** Entering the value for the temperature  $t$

- Now, double click on the "Parameter\_x3" block which represents the third input parameter, here the vapor fraction  $x$  in kg/kg.

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  $-1$ .

- Enter the value -1 on the line next to "k" in the dialog window which appears
- Then click the "OK" button (see Figure 2.18)

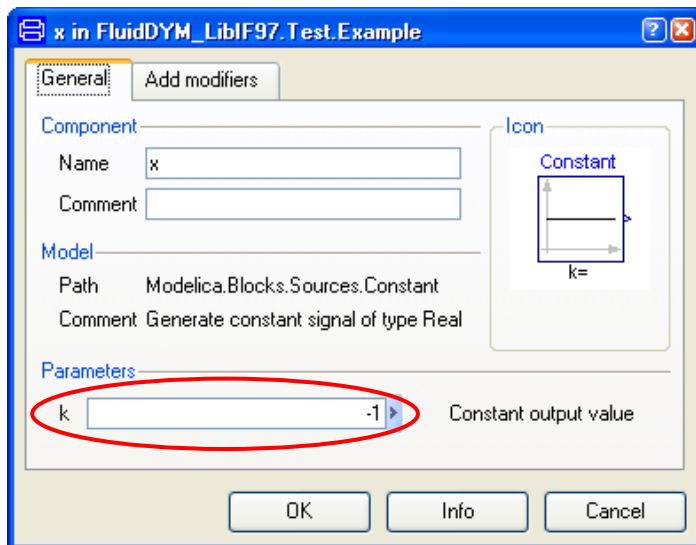
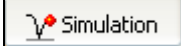


**Figure 2.18:** Entering the value for the vapor fraction  $x$

All parameters have now been defined.

- Click on the  button in the lower right area of Dymola in order to switch into the "Simulation Mode".

In Figure 2.19 you can see how the Dymola "Simulation Mode" looks like.

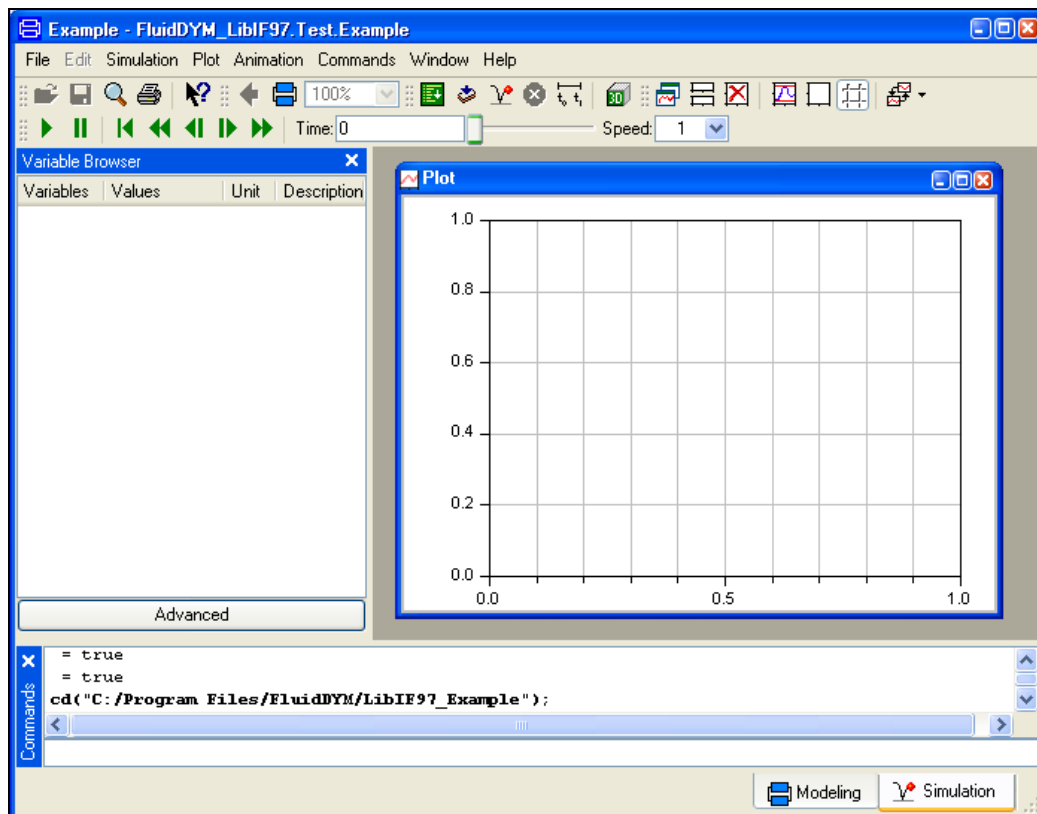


**Figure 2.19:** "Simulation Mode" window

- Click on the "Simulate" Button  in the Dymola menu bar to start the calculation. Now the model will be compiled and the simulation started.
- Afterwards you will see the following entries within the "Variable Browser" window in Dymola (see Figure 2.20):

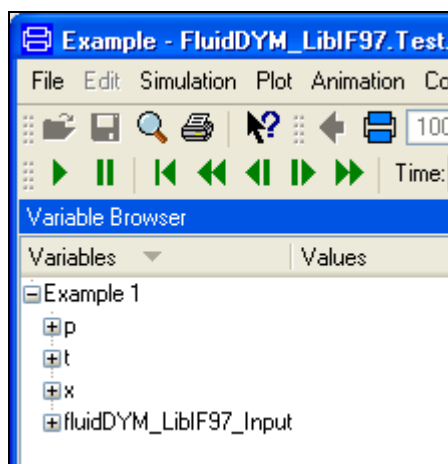


**Figure 2.20:** "Variable Browser" with new entries

- By clicking on the "New Plot Window" button , a new diagram window will be opened.
- Click on "fluidDYM\_LibIF97\_Input" within the "Variable Browser"; then you will see the input and output parameters "scanRange", "FunctionNumber", "z", "x1", "x2" and "x3" (see Figure 2.21).

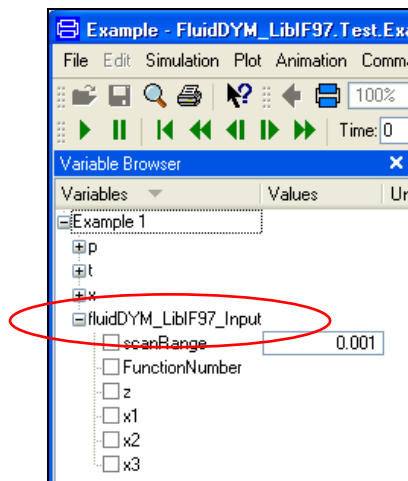


**Figure 2.21:** Parameters of "fluidDYM\_LibIF97\_Input"

- After clicking on the output parameter "z", the calculated property will be represented graphically in the "PlotWindow".
- Move the mouse over the curve to see the result of the simulation at a specific point in time (see Figure 2.22).

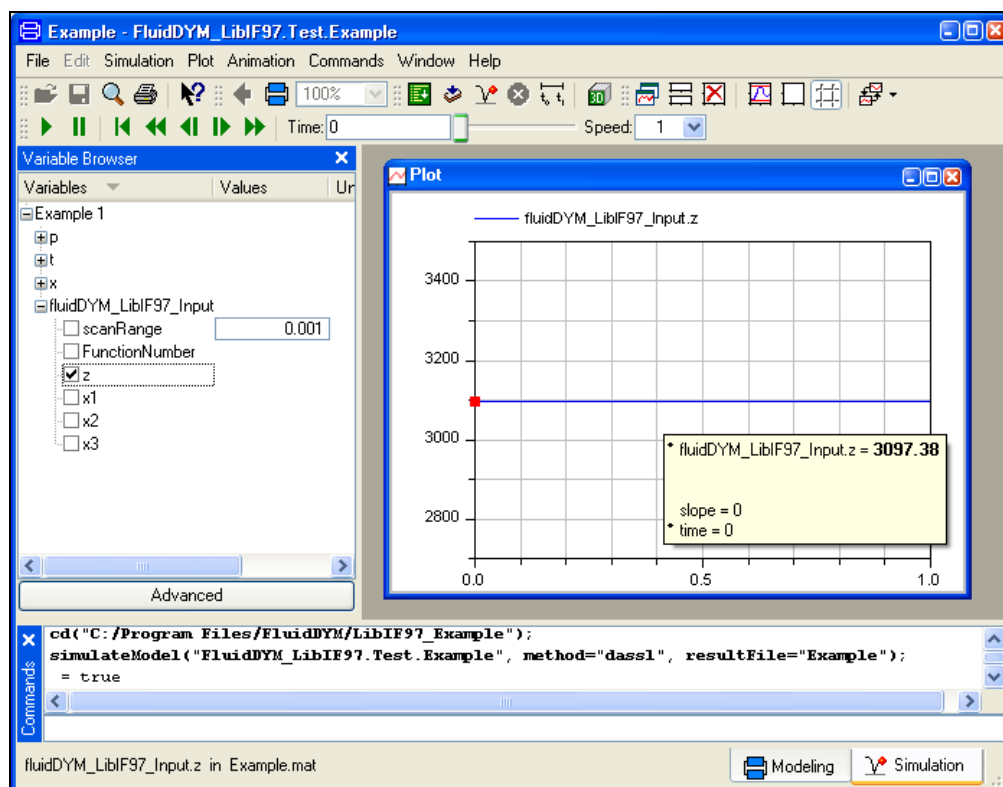


**Figure 2.22:** "DiagramWindow" showing the result

The result for  $h$  appears in the "DiagramWindow"

⇒ The result in our sample calculation here is: " $h = 3097.38$ ".

The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

- Now click on the Modeling button  in the lower right area of Dymola in order to switch into the "Modeling Mode". Here you can arbitrarily change the values for  $p$ ,  $t$ , and  $x$  in the appropriate blocks.

## Help Systems in Dymola®

Dymola® provides detailed help functions. You can choose to read the program documentation or the help page of a specific property function, as desired.

Within the "Modeling-Mode"  Modeling the help may be accessed via two different steps.

First we will show you how to access the program documentation of the property library.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM\_LibIF97" Block at the left and then click on "Users\_Guide" (see Figure 2.23).

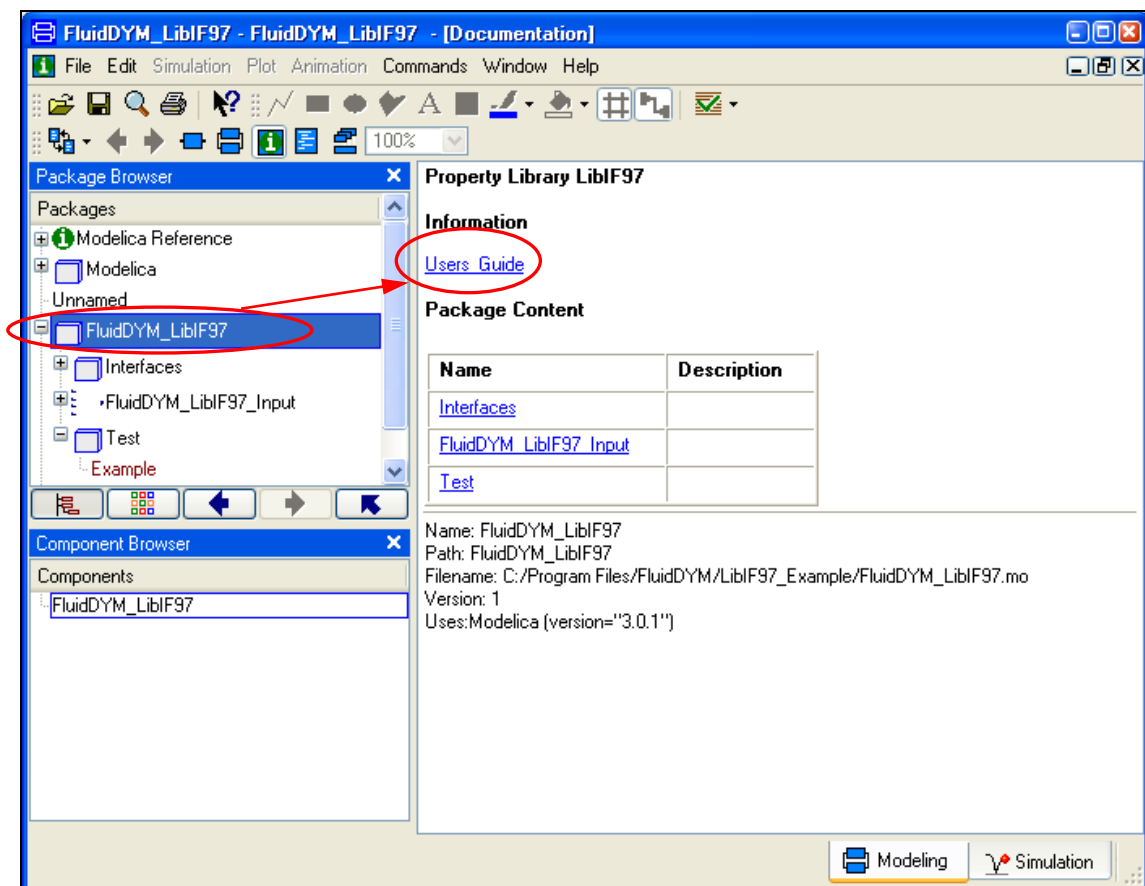


**Figure 2.23:** Selecting the "Users\_Guide"

- The program documentation will be displayed within your default web browser.

Now, we will show you how to access the help page of a specific property function.

- Make sure Dymola is set to the "Modeling-Mode".
- Now click the  button in the Dymola menu bar to choose the "Documentation Mode".
- Double-click on the "FluidDYM\_LibIF97\_Input" block on the left (see Figure 2.24).

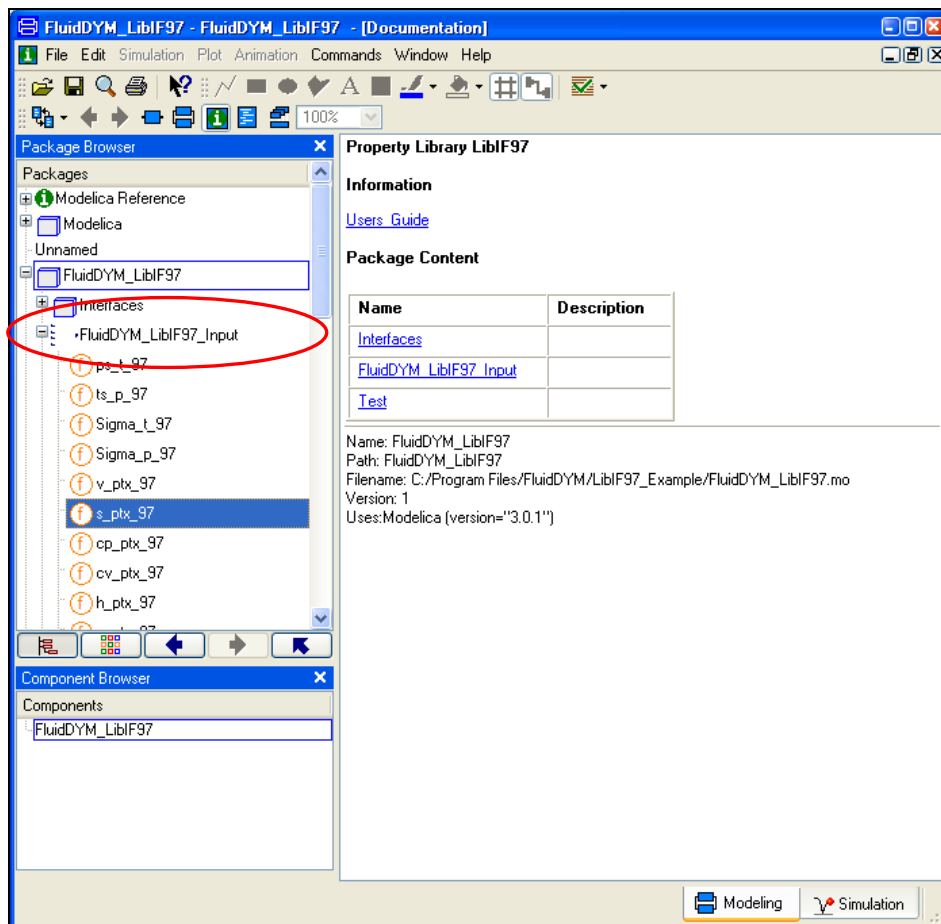


**Figure 2.24:** Selected "FluidDYM\_LibIF97\_Input" Block

- Below "FluidDYM\_LibIF97\_Input" you will see all functions of the LibIF97 property function (see Figure 2.24).
- Now select a function, e.g. "h\_ptx\_97", and then click on "Users\_Guide" (see Figure 2.25).

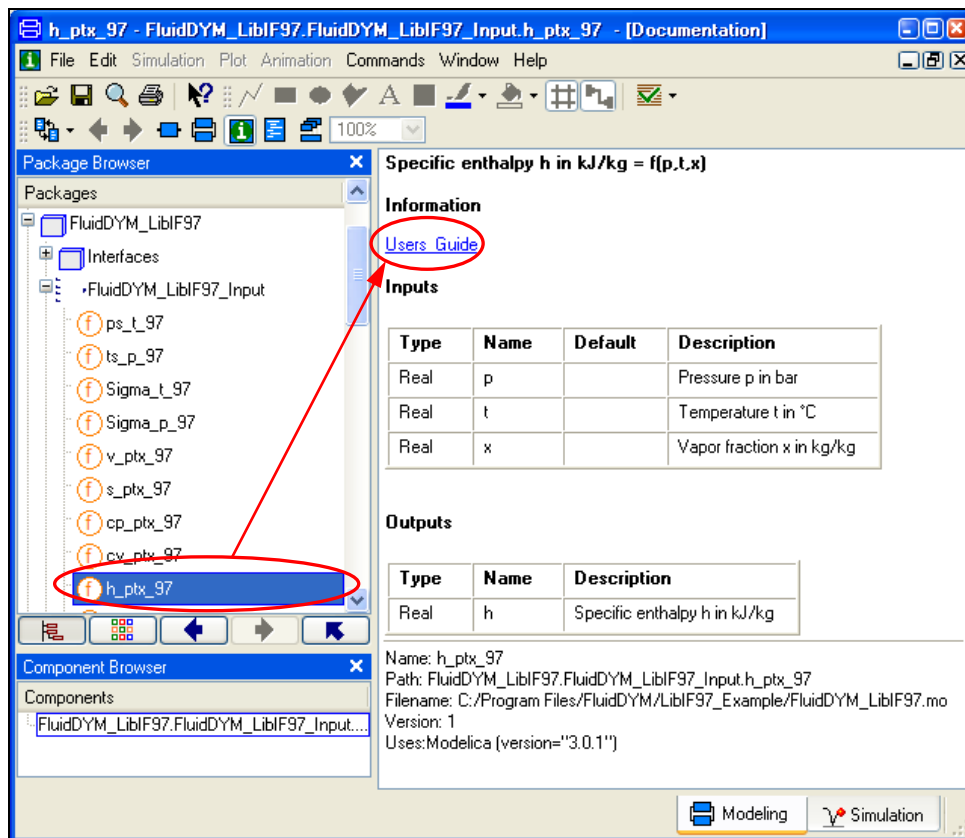


Figure 2.25: Marking the "h\_ptx\_97" function and selecting the "Users\_Guide"

- You will now see the help page of the selected function, here "h\_ptx\_97", in your default web browser (see Figure 2.26).

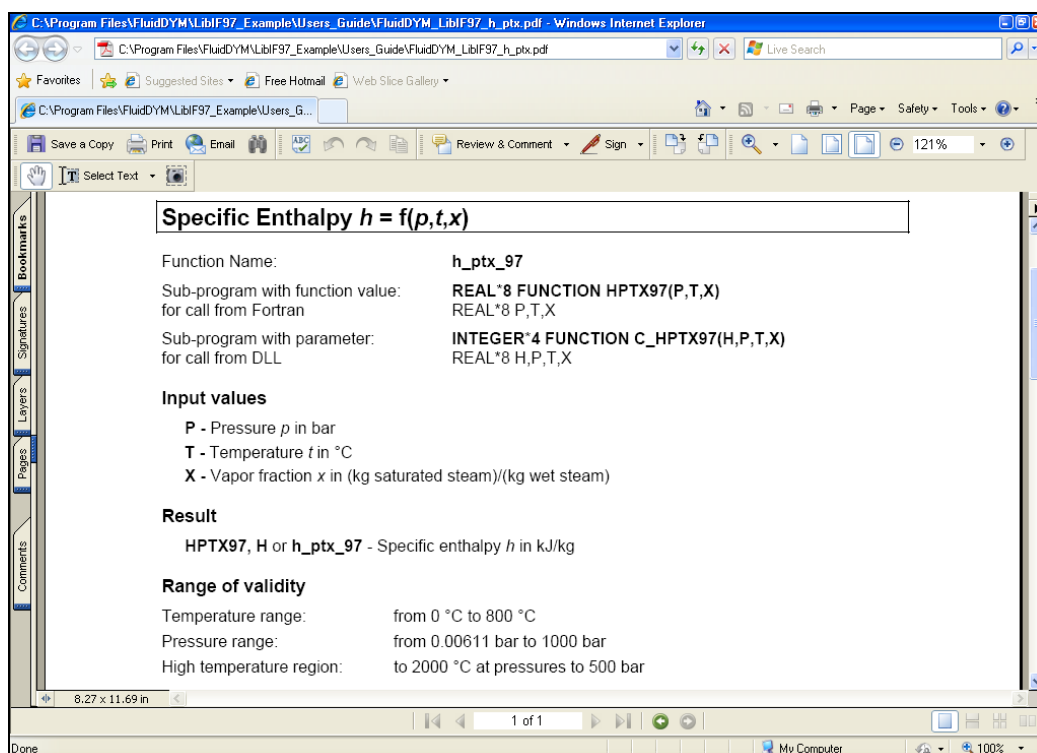


Figure 2.26: Help page of the function "h\_ptx\_97" in the web browser

## 2.4 Removing LibIF97 in Dymola

In order to remove the property library LibIF97 from your hard drive in Windows<sup>®</sup>, click "Start" in the lower task bar, then "Settings" and "Control Panel".

Afterwards double-click on "Add or Remove Programs".

In the list box of the "Add or Remove Programs" menu which appears, select "FluidDYM LibIF97" by clicking on it and then clicking the "Change/Remove" button.

In the following dialogue box click "Automatic" and then "Next>".

Confirm the "Perform Uninstall" menu which appears by clicking the "Finish" button.

Finally, close the "Add or Remove Programs" and "Control Panel" windows.

"FluidDYM LibIF97" has now been removed.

If LibIF97 is the only library installed, the directory "FluidDYM" will be removed as well.

### 3. Program Documentation

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

Function Name: **a\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION APTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_APTX97(A,P,T,X)**  
**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<sup>2</sup>/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:  $p > 1000$  bar or  $p < 0.00611$  bar or  
 ( $x = -1$ )  $t > 900$  °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  
 or  $p < 0.00611$  bar or at  $p > 220.64$  bar or  $p < 0.00611$  bar  
 and  $t > 373.946$  °C or  $t < 0$  °C  
 or  $|t - t_s(p)| > 0.1$  K

#### References:

Internal calculation from  $\rho$  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:  
for call from Fortran **REAL\*8 FUNCTION ALPHAPPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ALPHAPPTX97 (ALPHAP,P,T,X)**  
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  $K^{-1}$

### Range of validity

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

### Details on the vapor fraction $x$ and on the calculation of saturated liquid and saturated steam

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

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

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

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

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

(Saturated liquid and saturated vapor line:

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

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

### Results for wrong input values

Result **ALPHAPPTX97, ALPHAP = -1** or **alphap\_ptx\_97 = -1** for input values:

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

Saturation lines: at  $p = -1$  and  $t > 373.946\text{ °C}$  or  $t < 0\text{ °C}$  or

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

### References:

Internal calculation from  $\rho$  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:  
for call from Fortran **REAL\*8 FUNCTION ALPHAVPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ ALPHAVPTX97 (ALPHAV,P,T,X)**  
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 expansion coefficient  $\alpha_v$  in K<sup>-1</sup>

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

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

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

## Laplace Coefficient $b = f(p)$

|                                                           |                                                       |
|-----------------------------------------------------------|-------------------------------------------------------|
| Function Name:                                            | <b>b_p_97</b>                                         |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION BP97(P)</b><br>REAL*8 P            |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_ BP97 (B,P)</b><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  $p_t = 0.00611 \text{ bar}$  to  $p_c = 220.64 \text{ bar}$

### Results for wrong input values

Result **BP97, B = -1** or **b\_p\_97 = -1** for input values:

Saturation lines: at  $p > 220.64 \text{ bar}$  or  $p < 0.00611 \text{ bar}$

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

## Laplace Coefficient $b = f(t)$

|                                                           |                                                       |
|-----------------------------------------------------------|-------------------------------------------------------|
| Function Name:                                            | <b>b_t_97</b>                                         |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION BT97(T)</b><br>REAL*8 T            |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_ BT97 (B,T)</b><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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

### Results for wrong input values

Result **BT97, B = -1** or **b\_t\_97 = -1** for input values:

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

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

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

Function Name: **betap\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION BETAPPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ BETAPPTX97 (BETAP,P,T,X)**  
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/m<sup>3</sup>

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

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

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

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

Function Name: **cp\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION CPPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_CPPTX97(CP,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

### Results for wrong input values

Result **CPPTX97, CP = -1** or **cp\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **cv\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION CVPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_CVPTX97(CV,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **CVPTX97, CV = -1** or **cv\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **deltat\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION DELTATPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_DELTATPTX97 (DELTAT,P,T,X)**  
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  $\text{kJ kg}^{-1} \text{ kPa}^{-1}$

### Range of validity

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

### Details on the vapor fraction $x$ and on the calculation of saturated liquid and saturated steam

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

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

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

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

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

(Saturated liquid and saturated vapor line:

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

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

### Results for wrong input values

Result **DELTATPTX97, DELTAT = -1** or **deltat\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **dv\_dp\_T\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION DVDPT97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_DVDPT97(DVDPT,P,T,X)**  
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  $\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{kPa}^{-1}$

### Range of validity

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

### Details on the vapor fraction $x$ and on the calculation of saturated liquid and saturated steam

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

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

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

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

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

(Saturated liquid and saturated vapor line:

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

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

### Results for wrong input values

Result **dv\_dp\_T\_ptx\_97** or **DVDPT97** = **-1** for input values:

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

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

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

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

Function Name: **dv\_dT\_p\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION DVDTP97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_DVDTP97(DVDTP,P,T,X)**  
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  $\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$

### Range of validity

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

### Details on the vapor fraction $x$ and on the calculation of saturated liquid and saturated steam

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

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

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

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

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

(Saturated liquid and saturated vapor line:

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

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

### Results for wrong input values

Result **dv\_dT\_p\_ptx\_97** or **DVDTP97** = **-1** for input values:

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

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

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

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

Function Name: **e\_ptx\_tu\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION EPTXTU97(P,T,X,TU)**  
REAL\*8 P,T,X,TU

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_EPTXTU97(E,P,T,X,TU)**  
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:  $p > 1000$  bar or  $p < 0.00611$  bar or  
 ( $x = -1$ )  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **epsilon\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION EPSPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ EPSPTX97 (BETAP,P,T,X)**  
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  $\varepsilon$

### Range of validity

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

### Details on the vapor fraction $x$ and on the calculation of saturated liquid and saturated steam

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

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

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

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

(Saturated liquid and saturated vapor line:

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

### Results for wrong input values

Result **EPSPTX97, EPS = -1** or **epsilon\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **f\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION FPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ FPTX97 (F,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **FPTX97, F = -1** or **f\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **fug\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION FUGPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_FUGPTX97 (FUG,P,T,X)**  
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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

**Results for wrong input values**

Result **FUGPTX97, FUG = -1** or **fug\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **g\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION GPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ GPTX97 (G,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **GPTX97, G = -1** or **g\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **Eta\_ptx\_97**  
 Sub-program with function value: **REAL\*8 FUNCTION ETAPTX97(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Sub-program with parameter: **INTEGER\*4 FUNCTION C\_ETAPTX97(ETA,P,T,X)**  
 for call from DLL **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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **ETAPTX97, ETA = -1** or **eta\_ptx\_97 = -1** for input values:

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

### References:

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>h_ps_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION HPS97(P,S)</b><br>REAL*8 P,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_HPS97(H,P,S)</b><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  
 at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **h\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION HPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_HPTX97(H,P,T,X)**  
**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:  $t_t = 0\text{ °C} \dots t_c = 373.946\text{ °C}$   
 $p_t = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$ )

**Results for wrong input values**

Result **HPTX97, H = -1** or **h\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **Kappa\_ptx\_97**  
 Sub-program with function value: **REAL\*8 FUNCTION KAPPTX97(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Sub-program with parameter: **INTEGER\*4 FUNCTION C\_KAPPTX97(KAPPA,P,T,X)**  
 for call from DLL **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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **KAPPTX97, KAPPA = -1** or **kappa\_ptx\_97 = -1** for input values:

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

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

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

Function Name: **kappat\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION KAPPATPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ KAPPATPTX97 (KAPPAT,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

**Results for wrong input values**

Result **KAPPATPTX97, KAPPAT = -1** or **kappat\_ptx\_97 = -1** for input values:

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

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

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

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

Function Name: **Lambda\_ptx\_97**

Sub-program with function value: **REAL\*8 FUNCTION LAMPTX97(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_LAMPTX97(LAM,P,T,X)**  
for call from DLL **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:  $p > 1000$  bar or  $p < 0.00611$  bar or  
 ( $x = -1$ )  $t > 900$  °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 or  $p < 0.00611$  bar or  
 at  $p > 220.64$  bar or  $p < 0.00611$  bar  
 and  $t > 373.946$  °C or  $t < 0$  °C  
 at  $|t - t_s(p)| > 0.1$  K

**References:**

[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:  
for call from Fortran **REAL\*8 FUNCTION MYPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_MYPTX97 (MY,P,T,X)**  
**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<sup>-1</sup>

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

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

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

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

Function Name: **n\_ptxwl\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION NPTXWL97(P,T,X,WL)**  
REAL\*8 P,T,X,WL

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ NPTXWL97 (N,P,T,X,WL)**  
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  $\mu\text{m}$  to 1.1  $\mu\text{m}$

**Details on the vapor fraction  $x$  and on the calculation of saturated liquid and saturated steam**

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

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

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

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

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

(Saturated liquid and saturated vapor line:

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

**Results for wrong input values**

Result **NPTXWL97, N = -1** or **n\_ptxwl\_97 = -1** for input values:

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

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

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

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

Function Name: **Ny\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION NYPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_NYPTX97(NY,P,T,X)**  
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  $\text{m}^2 / \text{s}$

**Range of validity**

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

**Details on the vapor fraction  $x$  and on the calculation of saturated liquid and saturated steam**

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

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

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

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

(Saturated liquid and saturated vapor line:

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

**Results for wrong input values**

Result **NYPTX97, NY = -1 or ny\_ptx\_97 = -1** for input values:

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

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

**References:**

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>p_hs_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION PHS97(H,S)</b><br>REAL*8 H,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_PHS97(P,H,S)</b><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  
 $h < h'(0.00611 \text{ bar}, x)$  at  $h'(0.00611 \text{ bar}) < h < h''(0.00611 \text{ bar})$

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

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

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

### Input values

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

**H** - Specific enthalpy  $h$  in  $\text{kJ/kg}$

### 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:

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

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

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

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

|                                                           |                                                         |
|-----------------------------------------------------------|---------------------------------------------------------|
| Function Name:                                            | <b>p_vu_97</b>                                          |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION PVU97(V,U)</b><br>REAL*8 V,U         |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_VU97(P,V,U)</b><br>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:

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

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

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

Function Name: **Pr\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION PRPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_PRPTX97(PR,P,T,X)**  
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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

**Results for wrong input values**

Result **PRPTX97, Pr = -1** or **Pr\_ptx\_97 = -1** for input values:

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

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

**References:**

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

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

|                                                           |                                                        |
|-----------------------------------------------------------|--------------------------------------------------------|
| Function Name:                                            | <b>ps_t_97</b>                                         |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION PST97(T)</b><br>REAL*8 T            |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_PST97(PS,T)</b><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:                                            | <b>Rho_ptx_97</b>                                                   |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION RHOPTX97(P,T,X)</b><br>REAL*8 P,T,X              |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_RHOPTX97(RHO,P,T,X)</b><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 kg/m<sup>3</sup>

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

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

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>s_ph_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION SPH97(P,H)</b><br>REAL*8 P,H          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_SPH97(S,P,H)</b><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  
 at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **s\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION SPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_SPTX97(S,P,T,X)**  
**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:  $t_t = 0\text{ °C} \dots t_c = 373.946\text{ °C}$   
 $p_t = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$ )

**Results for wrong input values**

Result **SPTX97, S = -1** or **s\_ptx\_97 = -1** for input values:

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

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

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

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

|                                                           |                                                                 |
|-----------------------------------------------------------|-----------------------------------------------------------------|
| Function Name:                                            | <b>Sigma_p_97</b>                                               |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION SIGMAP97(P)</b><br>REAL*8 P                  |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_SIGMAP97(SIGMA,P)</b><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 · 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:                                            | <b>Sigma_t_97</b>                                               |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION SIGMAT97(T)</b><br>REAL*8 T                  |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_SIGMAT97(SIGMA,T)</b><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·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:  
for call from Fortran **REAL\*8 FUNCTION THS97(H,S)**  
**REAL\*8 H,S**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_THS97(T,H,S)**  
**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]

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

Function Name: **t\_ph\_97**

Sub-program with function value: **REAL\*8 FUNCTION TPH97(P,H)**  
for call from Fortran **REAL\*8 P,H**

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_TPH97(T,P,H)**  
for call from DLL **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  
at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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# FUNC\_97\_200

<sup>K</sup> Backward function: Temperature  $t = f(p,h)$

<sup>S</sup> Backward function: Temperature,  $t = f(p,h)$

<sup>+</sup> SUCH:200

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>t_ps_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION TPS97(P,S)</b><br>REAL*8 P,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_TPS97(T,P,S)</b><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  
 at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **t\_vh\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION TVH97(V,H)**  
**REAL\*8 V,H**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_TVH97(T,V,H)**  
**REAL\*8 T,V,H**

### Input values

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

**H** - Specific enthalpy  $h$  in  $\text{kJ/kg}$

### Result

**TVH97, T** or **t\_vh\_97** - Temperature  $t$  in  $^{\circ}\text{C}$

### Range of validity

Pressure range: from 0.00611 bar to 1000 bar

Enthalpy range: according temperatures from  $0^{\circ}\text{C}$  to  $800^{\circ}\text{C}$

High temperature region: to 500 bar and to enthalpy regarding  $2000^{\circ}\text{C}$

### 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  $p_t = 0.00611 \text{ bar}$  to  $p_c = 220.64 \text{ bar}$

### Results for wrong input values

Result **TVH97, T = -1** or **t\_vh\_97 = -1** for input values:

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

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

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

---

# FUNC\_97\_212

<sup>K</sup> Backward function: Temperature  $t = f(v,h)$

<sup>S</sup> Backward function: Temperature,  $t = f(v,h)$

<sup>+</sup> SUCH:212

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

Function Name: **t\_vu\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION TVU97(V,U)**  
**REAL\*8 V,U**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_TVU97(T,V,U)**  
**REAL\*8 T,V,U**

**Input values**

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

**U** - Specific internal energy  $u$  in  $\text{kJ/kg}$

**Result**

**TVU97, T** or **t\_vu\_97** - Temperature  $t$  in  $^\circ\text{C}$

**Range of validity**

Pressure range: from 0.00611 bar to 1000 bar

Enthalpy range: according temperatures from  $0\text{ }^\circ\text{C}$  to  $800\text{ }^\circ\text{C}$

High temperature region: to 500 bar and to enthalpy regarding  $2000\text{ }^\circ\text{C}$

**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  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$

**Results for wrong input values**

Result **TVU97, T = -1** or **t\_vu\_97 = -1** for input values:

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

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

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

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# FUNC\_97\_214

<sup>K</sup> Backward function: Temperature  $t = f(v,u)$

<sup>S</sup> Backward function: Temperature,  $t = f(v,u)$

<sup>+</sup> SUCH:214

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

|                                                           |                                                        |
|-----------------------------------------------------------|--------------------------------------------------------|
| Function Name:                                            | <b>ts_p_97</b>                                         |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION TSP97(P)</b><br>REAL*8 P            |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_TSP97(TS,P)</b><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:  
for call from Fortran **REAL\*8 FUNCTION UPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_UPTX97(U,P,T,X)**  
**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:  $t_t = 0\text{ °C} \dots t_c = 373.946\text{ °C}$   
 $p_t = 0.00611\text{ bar} \dots p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **UPTX97, U = -1** or **u\_ptx\_97 = -1** for input values:

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

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

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>v_ph_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION VPH97(P,H)</b><br>REAL*8 P,H          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_VPH97(V,P,H)</b><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<sup>3</sup>/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  
 at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>v_ps_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION VPS97(P,S)</b><br>REAL*8 P,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_VPS97(V,P,S)</b><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 m<sup>3</sup>/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  
 at internal calculation result  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **v\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION VPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_VPTX97(V,P,T,X)**  
**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<sup>3</sup>/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:  $p > 1000$  bar or  $p < 0.00611$  bar or  
 ( $x = -1$ )  $t > 2000$  °C or  $t < 0$  °C or  
 $t > 800$  °C at  $p > 500$  bar

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

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

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

Function Name: **w\_ptx\_97**

Sub-program with function value: **REAL\*8 FUNCTION WPTX97(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_WPTX97(W,P,T,X)**  
for call from DLL **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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **WPTX97, W = -1** or **w\_ptx\_97 = -1** for input values:

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

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

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>x_hs_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION XHS97(H,S)</b><br>REAL*8 H,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_XHS97(X,H,S)</b><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:                                            | <b>x_ph_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION XPH97(P,H)</b><br>REAL*8 P,H          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_XPH97(X,P,H)</b><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:                                            | <b>x_vh_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION XVH97(V,H)</b><br>REAL*8 V,H          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_XVH97(X,V,H)</b><br>REAL*8 X,V,H |

**Input values**

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

**H** - Specific enthalpy  $h$  in  $\text{kJ/kg}$

**Result**

**XVH97, X or x\_vh\_97** - Vapor fraction  $x$  in  $(\text{kg saturated steam})/(\text{kg wet steam})$

**Range of validity**

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

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

**Details on the calculation of wet steam**

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

**Results for wrong input values**

Result **XVH97, X = -1** or **x\_vh\_97 = -1** for input values:

if the state point is located in the single phase region

$p > 220.64 \text{ bar}$  or  $p < 0.00611 \text{ bar}$

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

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

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

### Input values

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$

**U** - Specific internal energy  $u$  in  $\text{kJ/kg}$

### 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

$p > 220.64 \text{ bar}$  or  $p < 0.00611 \text{ bar}$

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

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

|                                                           |                                                          |
|-----------------------------------------------------------|----------------------------------------------------------|
| Function Name:                                            | <b>x_ps_97</b>                                           |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION XPS97(P,S)</b><br>REAL*8 P,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_XPS97(X,P,S)</b><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:  
for call from Fortran **REAL\*8 FUNCTION ZPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ZPTX97 (Z,P,T,X)**  
**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  $t_t = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$   
 Pressure ranges from  $p_t = 0.00611\text{ bar}$  to  $p_c = 220.64\text{ bar}$ )

### Results for wrong input values

Result **ZPTX97, Z = -1** or **z\_ptx\_97 = -1** for input values:

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

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

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



## 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<sub>2</sub> - Span and Wagner      O<sub>2</sub> - Schmidt and Wagner  
H<sub>2</sub>O - IAPWS-95              Ar - Tegeler et al.  
N<sub>2</sub> - Span et al.
- and of the ideal gases:
- SO<sub>2</sub>, CO, Ne (Scientific Formulation of Bucker 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              | NO               | He              | Propylene  |
| Ne              | H <sub>2</sub> O | F <sub>2</sub>  | Propane    |
| N <sub>2</sub>  | SO <sub>2</sub>  | NH <sub>3</sub> | Iso-Butane |
| O <sub>2</sub>  | H <sub>2</sub>   | Methane         | n-Butane   |
| CO              | H <sub>2</sub> S | Ethane          | Benzene    |
| CO <sub>2</sub> | OH               | Ethylene        | Methanol   |
| Air             |                  |                 |            |

- Consideration of:
- Dissociation from the VDI Guideline 4670

#### Library LibIDGAS

Model: Ideal gas mixture from VDI Guideline 4670

- Consideration of:
- Dissociation from the VDI Guideline 4670

### 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 Bucker et al. (2003)

#### n-Butane

#### Library LibButane\_n

Formulation of Bucker 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 <sub>2</sub> H <sub>6</sub> O <sub>2</sub>  | Ethylene glycol     |
| C <sub>3</sub> H <sub>8</sub> O <sub>2</sub>  | Propylene glycol    |
| C <sub>2</sub> H <sub>5</sub> OH              | Ethyl alcohol       |
| CH <sub>3</sub> OH                            | Methyl alcohol      |
| C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>  | Glycerol            |
| K <sub>2</sub> CO <sub>3</sub>                | Potassium carbonate |
| CaCl <sub>2</sub>                             | Calcium chloride    |
| MgCl <sub>2</sub>                             | Magnesium chloride  |
| NaCl                                          | Sodium chloride     |
| C <sub>2</sub> H <sub>3</sub> KO <sub>2</sub> | Potassium acetate   |

Formulation of the International Institute of Refrigeration (1997)

### Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane  $\text{C}_8\text{H}_{24}\text{O}_4\text{Si}_4$  **Library LibD4**

Decamethylcyclopentasiloxane  $\text{C}_{10}\text{H}_{30}\text{O}_5\text{Si}_5$  **Library LibD5**

Tetradecamethylhexasiloxane  $\text{C}_{14}\text{H}_{42}\text{O}_6\text{Si}_6$  **Library LibMD4M**

Hexamethyldisiloxane  $\text{C}_6\text{H}_{18}\text{OSi}_2$  **Library LibMM**

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane  $\text{C}_{12}\text{H}_{36}\text{O}_6\text{Si}_6$  **Library LibD6**

Decamethyltetrasiloxane  $\text{C}_{10}\text{H}_{30}\text{O}_3\text{Si}_4$  **Library LibMD2M**

Dodecamethylpentasiloxane  $\text{C}_{12}\text{H}_{36}\text{O}_4\text{Si}_5$  **Library LibMD3M**

Octamethyltrisiloxane  $\text{C}_8\text{H}_{24}\text{O}_2\text{Si}_3$  **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  $\text{C}_{10}\text{H}_{22}$  **Library LibC10H22**

Isopentane  $\text{C}_5\text{H}_{12}$  **Library LibC5H12\_ISO**

Neopentane  $\text{C}_5\text{H}_{12}$  **Library LibC5H12\_NEO**

Isohexane  $\text{C}_6\text{H}_{14}$  **Library LibC5H14**

Toluene  $\text{C}_7\text{H}_8$  **Library LibC7H8**

Formulation of Lemmon and Span (2006)

### Further Fluids

Carbon monoxide **CO** **Library LibCO**

Carbonyl sulfide **COS** **Library LibCOS**

Hydrogen sulfide **H<sub>2</sub>S** **Library LibH2S**

Dinitrogen monoxide **N<sub>2</sub>O** **Library LibN2O**

Sulfur dioxide **SO<sub>2</sub>** **Library LibSO2**

Acetone **C<sub>3</sub>H<sub>6</sub>O** **Library LibC3H6O**

Formulation of Lemmon and Span (2006)

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Fax.: +49-3583-61-1846

### The following thermodynamic and transport properties can be calculated<sup>a</sup>:

#### 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  $Pr$

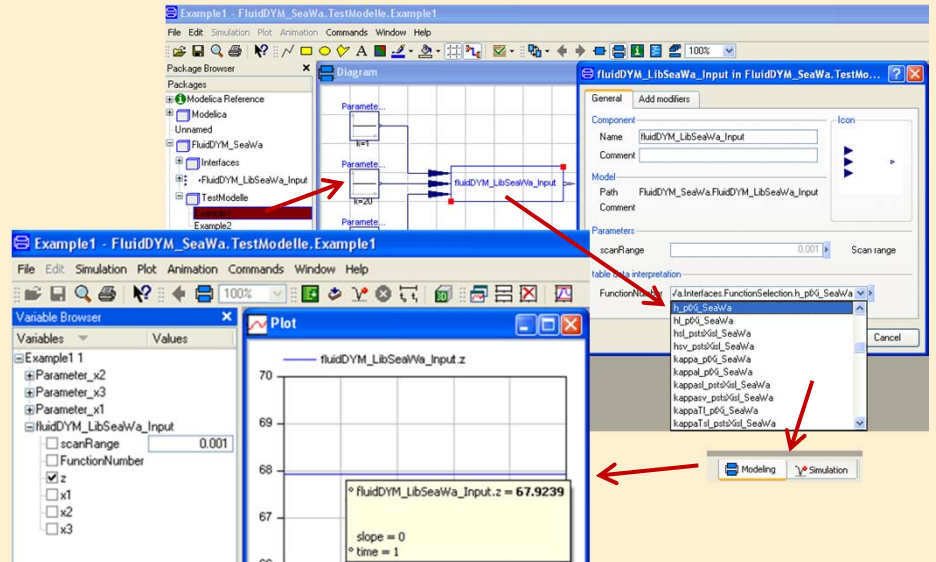
#### Backward Functions

- $T, v, s(p, h)$
- $T, v, h(p, s)$
- $p, T, v(h, s)$
- $p, T(v, h)$
- $p, T(v, u)$

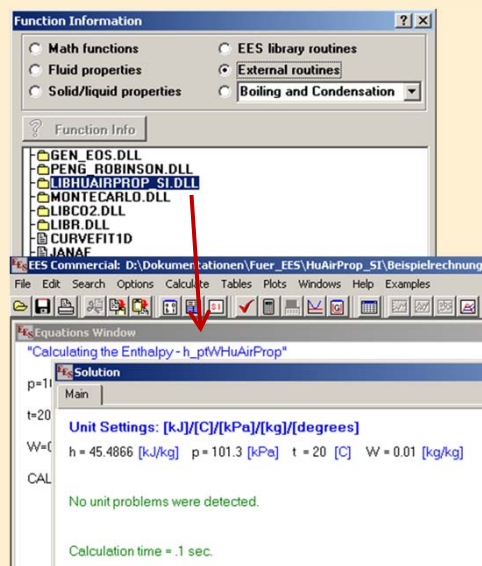
#### Thermodynamic Derivatives

- Partial derivatives can be calculated.

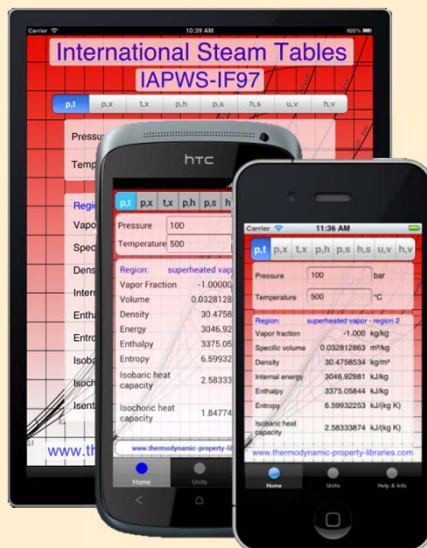
<sup>a</sup> Not all of these property functions are available in all property libraries.



## Add-In FluidEES for Engineering Equation Solver®



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



## Online Property Calculator at [www.thermodynamics-zittau.de](http://www.thermodynamics-zittau.de)

**Zittau's Fluid Property Calculator**

Fluid:

Function:

Unit System:

Enter given values: [Range of validity](#)

Pressure p:  bar

Temperature t:  °C

Vapor fraction x:  kg/kg

**Calculate / Recalculate**

**Result:**

Specific enthalpy h =  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

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[www.thermodynamic-property-libraries.com](http://www.thermodynamic-property-libraries.com)  
[www.international-steam-tables.com](http://www.international-steam-tables.com)  
[www.thermodynamic-formelsammlung.de](http://www.thermodynamic-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 Voyage 200    TI 92

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Theodor-Koerner-Allee 16  
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Internet: [www.thermodynamics-zittau.de](http://www.thermodynamics-zittau.de)  
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The following thermodynamic and transport properties<sup>a</sup> 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.

<sup>a</sup> Not all of these property functions are available in all property libraries.

## 5. References

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## 6. Satisfied Customers

Date: 10/2011

The following companies and institutions use the property libraries

- FluidEXL<sup>Graphics</sup> for Excel<sup>®</sup>
- FluidLAB for MATLAB<sup>®</sup>
- FluidMAT for Mathcad<sup>®</sup>
- FluidEES for Engineering Equation Solver<sup>®</sup> EES
- FluidDYM for Dymola<sup>®</sup> (Modelica)
- FluidVIEW for LabVIEW<sup>®</sup>:

### 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,<br>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,<br>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                      |

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|------------------------------------|---------------------------------------|
| 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,<br>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 |

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|-----------------------------------------------------|-----------------------------|
| 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<br>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                     |

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|-------------------------------------------------------------|------------------|
| 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,<br>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                      |

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|----------------------------------------------------------|---------|
| 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

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|------------------------------------------------------------------------|------------------|
| 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,<br>Professorship of Building Services | 07/2008          |
| Technical University of Cottbus,<br>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          |

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|-----------------------------------------------------------------------------------------|------------------|
| 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,<br>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,<br>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 |

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|---------------------------------------------------------------------------------|------------------|
| Energieversorgung Halle                                                         | 10/2007          |
| AL-KO, Jettingen                                                                | 10/2007          |
| Grenzebach BSH, Bad Hersfeld                                                    | 10/2007          |
| Wiesbaden University of Applied Sciences,<br>Department of Engineering Sciences | 10/2007          |
| Endress+Hauser Messtechnik, Hannover                                            | 11/2007          |
| Munich University of Applied Sciences,<br>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,<br>Department of Mechanical Engineering and Mechatronics | 02/2006          |
| University of Stuttgart,<br>Department of Thermal Fluid Flow Engines                                | 02/2006          |
| Technical University of Munich,<br>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,<br>Department of Thermodynamics                               | 04/2006          |
| EnviCon & Plant Engineering, Nuremberg                                                              | 04/2006          |
| Brassel Engineering, Dresden                                                                        | 05/2006          |
| University of Halle-Merseburg,<br>Department of USET Merseburg incorporated society                 | 05/2006          |
| Technical University of Dresden,<br>Professorship of Thermic Energy Machines and Plants             | 05/2006          |

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| 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

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|-------------------------------------------------------------------------------------------------------------|------------------------------|
| 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                      |

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|--------------------------------------------------------------------------------------------|---------|
| 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,<br>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

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|-----------------------------------------------------------------------------------------|------------------|
| 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,<br>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          |
| Pettersson+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          |

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|----------------------------------------------------------------------------|---------|
| 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,<br>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,<br>Department of Thermo- and Fluid Dynamics | 01/2002 |
| SAAS, Possendorf/Dresden                                                           | 02/2002 |
| Siemens, Karlsruhe<br>(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<br>(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<br>(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 |

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|---------------------------------------------------------------------------------------|------------------|
| 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 |

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|----------------------------------------------|---------|
| 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 |