



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

**FluidPRIME  
with LibIF97  
for Mathcad Prime®**

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

## **LibIF97**

### **FluidPRIME for Mathcad Prime®**

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## 0. Package Contents

**Zip file "CD\_FluidPRIME\_LibIF97.zip" includes the following files:**

|                             |   |
|-----------------------------|---|
| FluidPRIME_LibIF97_Docu.pdf | - User's Guide                                |
| Functions_LibIF97.mcdx      | - Mathcad Prime® worksheet with all functions |
| LibIF97.msi                 | - MSI installer                               |
| setup.exe                   | - Setup installer                             |
| LibIF97.dll                 | - DLL with functions of the LibIF97 library   |

# 1. Program Functions

## 1.1 Range of Validity

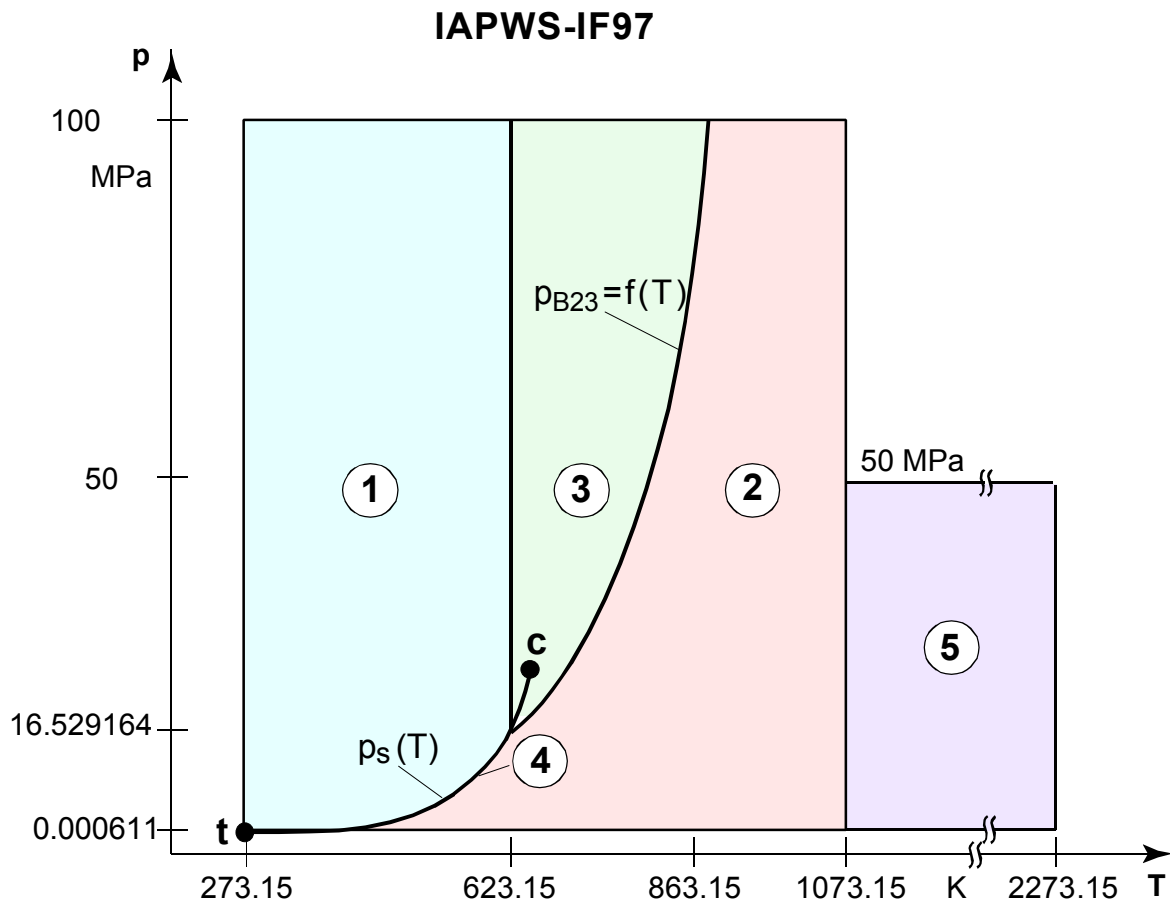
The International Association for the Properties of Water and Steam IAPWS issued the

"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-On FluidPRIME for Mathcad Prime 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)                   | Prandtl-number   | -                   |
| $p_s = f(t)$            | ps_t_97       | = PST97(T)                        | = C_PST97(PS, T)                           | Vapor pressure   | bar                 |
| $\rho = f(p, t, x)$     | rho_ptx_97    | = RHOPTX97(P, T, X)               | = C_RHOPTX97(RHO, P, T, X)                 | Density  | kg/m <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<br>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 FluidPRIME in Mathcad Prime®

FluidPRIME has been developed to calculate thermodynamic properties in Mathcad Prime® more conveniently. Within Mathcad Prime, it enables the direct call of functions relating to humid air from the LibIF97 property library.

### 2.1 Installing FluidPRIME

In this section, the installation of FluidPRIME LibIF97 is described.

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

CD\_FluidPRIME\_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 and a folders:

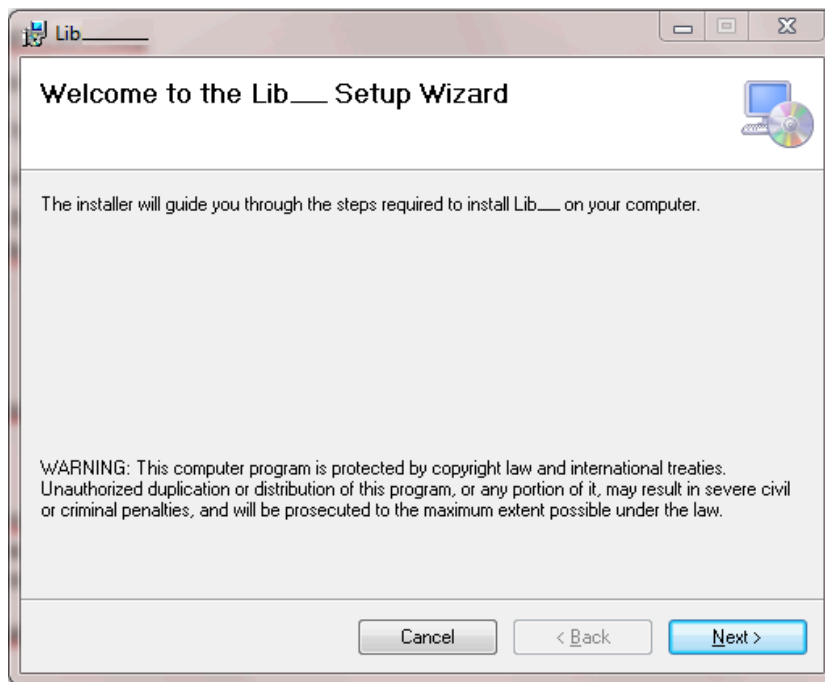
FluidPRIME\_LibIF97\_Docu.pdf  
Functions\_LibIF97.mcdx  
LibIF97.msi  
setup.exe  
LibIF97.dll

In order to run the installation of FluidPRIME double-click the file

setup.exe.

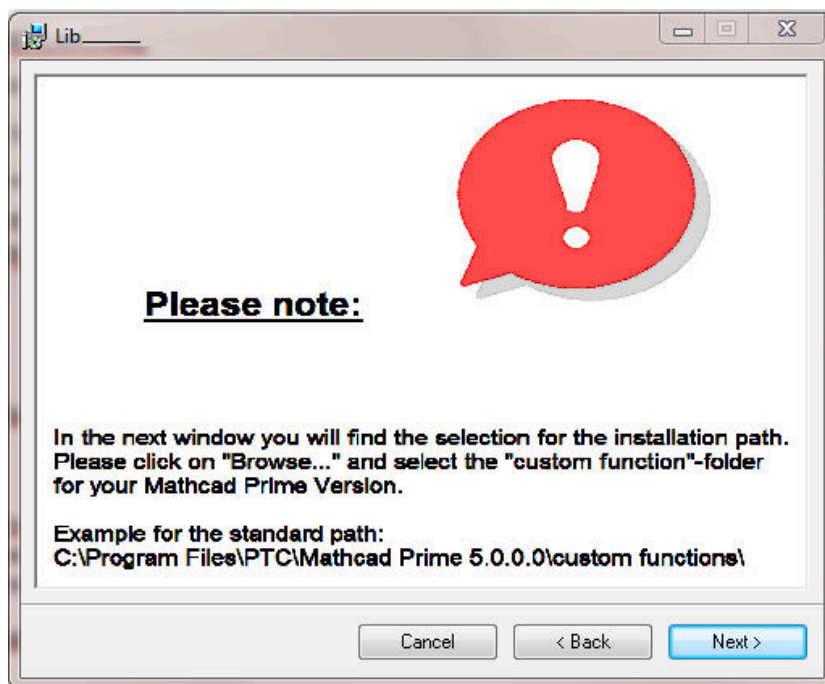
Note: If you get an error message during the installation, please try the LibIF97.msi instead of the setup.exe for the installation. The steps through the install assistant are similar on both the .exe and the .msi file.

After opening the installer-file you get the start window of the setup wizard (Figure 1.1). Please confirm with "Next".



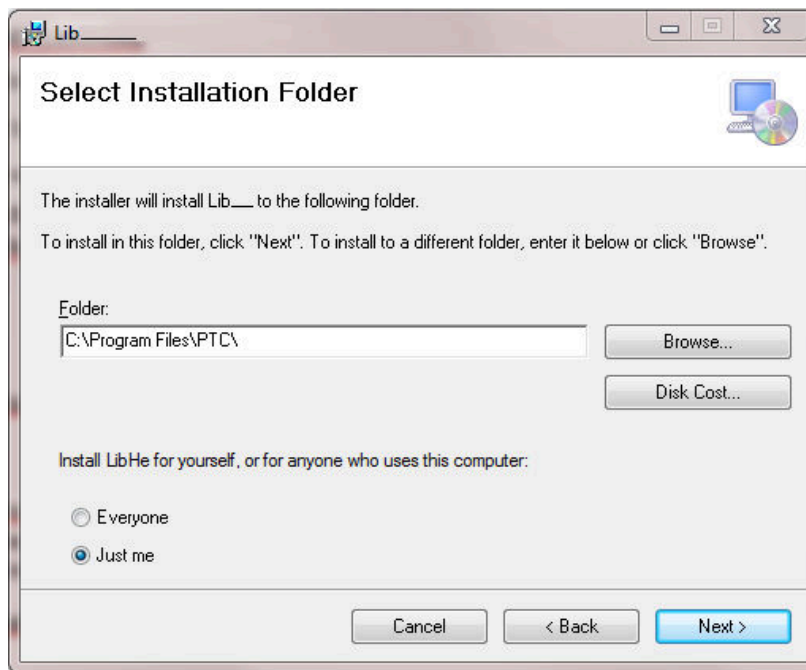
**Figure 2.1:** Setup Wizard

In Figure 2.2 you can see a note window that will inform you additionally to the next steps.



**Figure 2.2:** Note Window

Click on the "Next" button to get the "Select Installation Folder"-window (Figure 2.3).



**Figure 2.3:** Select Installation Folder

Please click on "Browse..." to get another window where you can select the installation path.

You will get the standard path:

C:\Program Files\PTC\

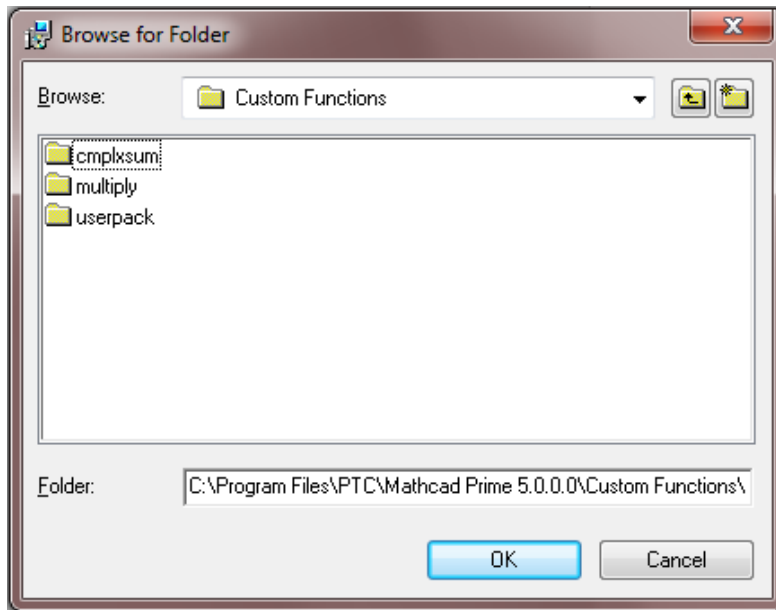
Now select your Mathcad Prime® version folder. For example

C:\Program Files\PTC\Mathcad Prime 5.0.0.0 (Version 5.0.0.0).

On the next step you have to choose the "Custom Functions" folder, so that your final installation path looks like

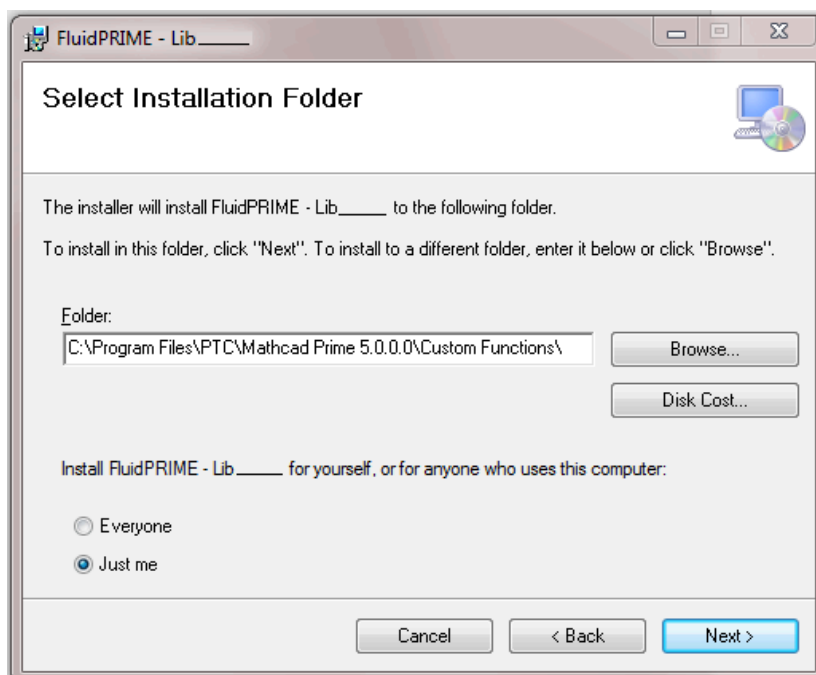
C:\Program Files\PTC\Mathcad Prime 5.0.0.0\Custom Functions\

that you can also see in Figure 2.4.



**Figure 2.4:** "Browse for Folder"-window with the full installation path

Please confirm with "OK" and continue in the further window (Figure 2.5) with "Next".



**Figure 2.5:** "Select Installation Folder"-window

To start the installation you have to click again on "Next".

After a few moments, you get a message that the installation was successful and you can exit the setup with "Close".

The installation of FluidPRIME with the library LibIF97 is finished.

Finally, please copy or overwrite the LibIF97.dll-file in the installation folder that is described before, with the file in the zip-file.

During the installation process the following files will have been copied into the destination folder chosen, the standard being

"C:\Program Files\PTC\Mathcad Prime 5.0.0.0\Custom Functions\":

|                 |              |                   |
|-----------------|--------------|-------------------|
| LC.dll          | LibIF97.dll  | PRIME_LibIF97.dll |
| libifcoremd.dll | libiomp5.dll | libmmd.dll.       |

**Note:**

The shown default installation path for Mathcad Prime® may be different depending on the installation on your machine. In addition, the Mathcad Prime® version can be another than 5.0.0.0 that is used in this manual.

The underscore after "Lib" in the figures before, is representative of the library name of the library to be installed.

## 2.2 Licensing the LibIF97 Property Library

Within the installation that was shown in chapter 2.1 the licensing key will be registered on your computer automatically.

## 2.3 Example: Calculation of the Enthalpy $h = f(p,t,x)$ for Water and Steam

Now we will calculate, step by step, the specific enthalpy  $h$  as a function of pressure  $p$ , temperature  $t$  and vapor fraction  $x$  for water and steam from the Industrial Formulation IAPWS-IF97, using FluidPRIME.

- Start Mathcad Prime.
- Type "p:" and enter the value for the pressure  $p$  in bar.  
(Range of validity of the IF97:  $p = 0.00611 \dots 1000$  bar)  
**e. g.: Enter "p:100" for the first operand**
- Type "t:" and enter the value for the temperature  $t$  in °C.  
(Range of validity of the IF97:  $0 \text{ °C} \dots 2000.00 \text{ °C}$  for  $p \leq 100$  bar  
 $0 \text{ °C} \dots 800.00 \text{ °C}$  for  $100 \text{ bar} < p \leq 1000$  bar)

**e. g.: Enter "t:400" for the second operand**

- Type "x:" and enter the value for the vapor fraction  $x$  in  $\text{kg}_{\text{sat. steam}} / \text{kg}_{\text{wet steam}}$ .  
Since the wet steam region is calculated automatically by the subprograms, the following fixed details on the vapor fraction  $x$  are to be considered when the value for  $x$  is entered:

### Single-phase region

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

### Wet-steam region

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

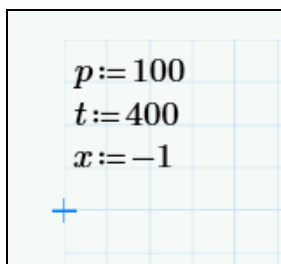
When calculating wet steam either the given value for  $t$  and  $p = -1$  or the given value for  $p$  and  $t = -1$  and in both cases the value for  $x$  between 0 and 1 must be entered.

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

Wet steam region of the IAPWS-IF97:  $t_t = 0 \text{ °C} \dots t_c = 373.946 \text{ K}$   
 $p_t = 0.00611 \text{ bar} \dots p_c = 220.64 \text{ bar}$

**e. g.: Enter "x:-1" for the third operand**

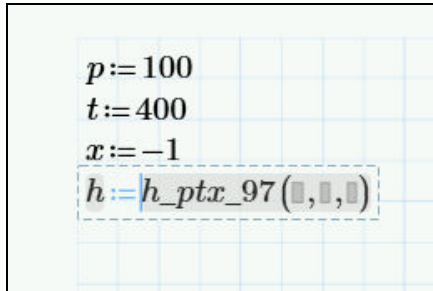
- Confirm your entry by pressing the "ENTER" key.
- Your Mathcad Prime calculation window should look like Figure 2.3:



**Figure 2.3:** Example Mathcad Prime® sheet after input of the given parameters



- Now, type open the file Functions\_LibIF97.mcdx. In this Mathcad Prime® worksheet you can find all the functions of the library
- Search the function  $h\_ptx\_IF97( , , )$  and mark it by drag a selection rectangle around it.
- Copy the marked function and paste it into your example worksheet
- Click it the function and type "h:" in front of it.
- Your Mathcad Prime calculation window should look like Figure 2.4:



**Figure 2.4:** Example Mathcad Prime® sheet i

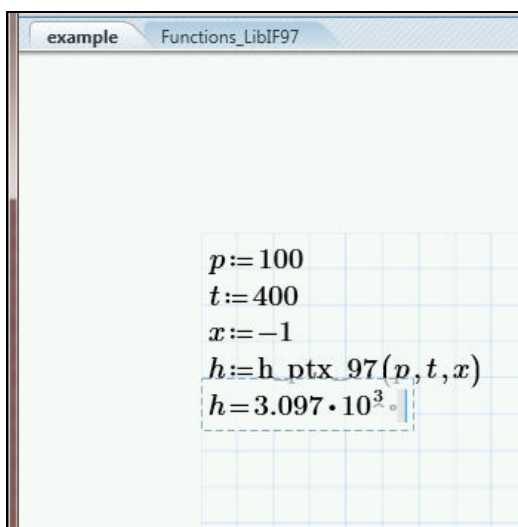
- Now click in the first operand in the brackets of the function. . You can now enter the value for  $p$  either by entering the value directly or by entering the name of the variable where the value was saved.

⇒ e.g.: Enter "p".

- Situate the cursor on the next placeholder and set all the variables we set above.
- Close the input formula by pressing the "Enter"-Key.
- You can now go on working with the variable  $h$  which we have just calculated.
- If you wish to see the result, you have to type the following command on the next line in the Mathcad Prime window:  
"h =".

You will now see the result  $h = 3.097 \times 10^3$ . The corresponding unit is kJ/kg (see table of the property functions in Chapter 1).

In the next figure you can see the calculated value.



**Figure 2.5:** Example Mathcad Prime® sheet with finished calculation

## 2.4 Removing FluidPRIME

To remove FluidPRIME with the library LibIF97 from your hard drive, carry out the following steps:

- Click "Start" in the lower task bar of your desktop, then "Settings" and then "Control Panel".
- Now, double click on "Add or Remove Programs".
- In the list box of the "Add or Remove Programs" window that appears select "FluidPRIME - LibIF97" by clicking on it and click the "Add/Remove..." button.
- In the following dialog box click "Yes" and wait until the windows is closing.
- Finally, close the "Add or Remove Programs" and "Control Panel" windows.

Now FluidPRIME with the library LibIF97 has been removed.

### 3. Program Documentation

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

Function Name: **a\_ptx\_97**  
 Sub-program with function value: **REAL\*8 FUNCTION APTX97(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Sub-program with parameter: **INTEGER\*4 FUNCTION C\_APTX97(A,P,T,X)**  
 for call from DLL **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

**APT97, 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 **APT97, 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: **REAL\*8 FUNCTION ALPHAVPTX97(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_ ALPHAVPTX97 (ALPHAV,P,T,X)**  
for call from DLL **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  $p_t = 0.00611$  bar to  $p_c = 220.64$  bar

### Results for wrong input values

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

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

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

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

|   |  |
|---|--|
| Function Name:  | <b>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  $t_t = 0$  °C to  $t_c = 373.946$  °C

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

### Results for wrong input values

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

Single phase region:  $p > 1000$  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 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  $t_l = 0$  °C to  $t_c = 373.946$  °C

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

### Results for wrong input values

Result **CVPTX97, CV = -1** or **cv\_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]



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

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

### Results for wrong input values

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

Single phase region:  $p > 1000$  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 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: **REAL\*8 FUNCTION EPSPTX97(P,T,X)**  
 for call from Fortran **REAL\*8 P,T,X**  
 Sub-program with parameter: **INTEGER\*4 FUNCTION C\_EPSPTX97 (BETAP,P,T,X)**  
 for call from DLL **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  $t_l = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

### Results for wrong input values

Result **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  $t_l = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

### Results for wrong input values

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

**Results for wrong input values**

Result **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  $t_l = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

### Results for wrong input values

Result **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:  
for call from Fortran **REAL\*8 FUNCTION ETAPTX97(P,T,X)**  
**REAL\*8 P,T,X**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_ETAPTX97(ETA,P,T,X)**  
**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  $p < 0.00611\text{ bar}$  or  
 at  $p > 220.64\text{ bar}$  or  $p < 0.00611\text{ bar}$   
 and  $t > 373.946\text{ °C}$  or  $t < 0\text{ °C}$   
 at  $|t - t_s(p)| > 0.1\text{ K}$

### References:

[7], internal calculation from  $\rho$  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: **REAL\*8 FUNCTION HPTX97(P,T,X)**  
for call from Fortran **REAL\*8 P,T,X**

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_HPTX97(H,P,T,X)**  
for call from DLL **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  $t_l = 0$  °C to  $t_c = 373.946$  °C

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

### Results for wrong input values

Result **KAPPTX97, KAPPA = -1** or **kappa\_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]

**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:  
for call from Fortran **REAL\*8 FUNCTION LAMPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_LAMPTX97(LAM,P,T,X)**  
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  $t_t = 0\text{ °C}$  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 **LAMPTX97, LAM = -1** or **lambda\_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:**

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

**Results for wrong input values**

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

Single phase region:  $p > 1000$  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:**

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: **Rho\_ptx\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION RHOPTX97(P,T,X)**  
REAL\*8 P,T,X

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_RHOPTX97(RHO,P,T,X)**  
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: **s\_ph\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION SPH97(P,H)**  
REAL\*8 P,H

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_SPH97(S,P,H)**  
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: **REAL\*8 FUNCTION SPTX97(P,T,X)**  
for call from Fortran REAL\*8 P,T,X

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_SPTX97(S,P,T,X)**  
for call from DLL 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  $t_l = 0$  °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:  | <b>t_hs_97</b>   |
| Sub-program with function value:<br>for call from Fortran | <b>REAL*8 FUNCTION THS97(H,S)</b><br>REAL*8 H,S          |
| Sub-program with parameter:<br>for call from DLL          | <b>INTEGER*4 FUNCTION C_THS97(T,H,S)</b><br>REAL*8 T,H,S |

### Input values

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

### Result

**THS97, T or t\_hs\_97** - Temperature  $t$  in °C

### Range of validity

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

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

### Details on the calculation of wet steam

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

### Results for wrong input values

Result **THS97, T = -1** or **t\_hs\_97 = -1** for input values:

$s < -0.009$  kJ/kg K

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

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

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

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

Sub-program with function value: **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: **t\_ps\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION TPS97(P,S)**  
**REAL\*8 P,S**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_TPS97(T,P,S)**  
**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]

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

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

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

Sub-program with parameter: **INTEGER\*4 FUNCTION C\_TVH97(T,V,H)**  
for call from DLL **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  $p_t = 0.00611$  bar to  $p_c = 220.64$  bar

### Results for wrong input values

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

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

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

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

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# 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: **REAL\*8 FUNCTION TVU97(V,U)**  
for call from Fortran **REAL\*8 V,U**

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

**Input values**

**V** - Specific volume  $v$  in  $\text{m}^3/\text{kg}$   
**U** - Specific internal energy  $u$  in  $\text{kJ}/\text{kg}$

**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  $0^{\circ}\text{C}$  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  $u$  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: **v\_ph\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION VPH97(P,H)**  
REAL\*8 P,H

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_VPH97(V,P,H)**  
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: **v\_ps\_97**

Sub-program with function value:  
for call from Fortran **REAL\*8 FUNCTION VPS97(P,S)**  
**REAL\*8 P,S**

Sub-program with parameter:  
for call from DLL **INTEGER\*4 FUNCTION C\_VPS97(V,P,S)**  
**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 (kg saturated steam)/(kg wet steam)

**Range of validity**

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

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

**Details on the calculation of wet steam**

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

**Results for wrong input values**

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

if the state point is located in the single phase region

$p > 220.64 \text{ bar}$  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  $t_l = 0\text{ °C}$  to  $t_c = 373.946\text{ °C}$

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

### Results for wrong input values

Result **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]

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

### Water and Steam

#### Library LibIF97

- Industrial Formulation IAPWS-IF97 (Revision 2007)
- Supplementary Standards IAPWS-IF97-S01, -S03rev, -S04, and -S05
- IAPWS Revised Advisory Note No. 3 on Thermodynamic Derivatives (2008)

#### Library LibIF97\_META

- Industrial Formulation IAPWS-IF97 (Revision 2007) for metastable steam

### Humid Combustion Gas Mixtures

#### Library LibHuGas

- Model: Ideal mixture of the real fluids:  
 $\text{CO}_2$  - Span, Wagner  $\text{H}_2\text{O}$  - IAPWS-95  
 $\text{O}_2$  - Schmidt, Wagner  $\text{N}_2$  - Span et al.  
 Ar - Tegeler et al.  
 and of the ideal gases:  
 $\text{SO}_2$ ,  $\text{CO}$ , Ne  
 (Scientific Formulation of Bücker et al.)  
 Consideration of:  
 • Dissociation from VDI 4670  
 • Poynting effect

### Humid Air

#### Library LibHuAir

- Model: Ideal mixture of the real fluids:  
 • Dry air from Lemmon et al.  
 • Steam, water and ice from IAPWS-IF97 and IAPWS-06  
 Consideration of:  
 • Condensation and freezing of steam  
 • Dissociation from VDI 4670  
 • Poynting effect from ASHRAE RP-1485

### Extremely Fast Property Calculations

- Spline-Based Table  
 Look-up Method (SBTL)

#### Library LibSBTL\_IF97 Library LibSBTL\_95 Library LibSBTL\_HuAir

- For steam, water, humid air, carbon dioxide and other fluids and mixtures according IAPWS Guideline 2015 for Computational Fluid Dynamics (CFD), real-time and non-stationary simulations

### Carbon Dioxide Including Dry Ice

#### Library LibCO2

- Formulation of Span and Wagner (1996)

### Seawater

#### Library LibSeaWa

- IAPWS Industrial Formulation 2013

### Ice

#### Library LibICE

- Ice from IAPWS-06, Melting and sublimation pressures from IAPWS-08, Water from IAPWS-IF97, Steam from IAPWS-95 and -IF97

### Ideal Gas Mixtures

#### Library LibIdGasMix

- Model: Ideal mixture of the ideal gases:
- |               |                      |               |            |
|---------------|----------------------|---------------|------------|
| Ar            | NO                   | He            | Propylene  |
| Ne            | $\text{H}_2\text{O}$ | $\text{F}_2$  | Propane    |
| $\text{N}_2$  | $\text{SO}_2$        | $\text{NH}_3$ | Iso-Butane |
| $\text{O}_2$  | $\text{H}_2$         | Methane       | n-Butane   |
| CO            | $\text{H}_2\text{S}$ | Ethane        | Benzene    |
| $\text{CO}_2$ | OH                   | Ethylene      | Methanol   |
| Air           |                      |               |            |

Consideration of:

- Dissociation from the VDI Guideline 4670

#### Library LibIDGAS

- Model: Ideal gas mixture from VDI Guideline 4670

Consideration of:

- Dissociation from the VDI Guideline 4670

### Humid Air

#### Library ASHRAE LibHuAirProp

- Model: Virial equation from ASHRAE Report RP-1485 for real mixture of the real fluids:  
 - Dry air  
 - Steam

Consideration of:

- Enhancement of the partial saturation pressure of water vapor at elevated total pressures

[www.ashrae.org/bookstore](http://www.ashrae.org/bookstore)

### Dry Air Including Liquid Air

#### Library LibRealAir

- Formulation of Lemmon et al. (2000)

### Refrigerants

#### Ammonia

#### Library LibNH3

- Formulation of Tillner-Roth et al. (1993)

#### R134a

#### Library LibR134a

- Formulation of Tillner-Roth and Baehr (1994)

#### Iso-Butane

#### Library LibButane\_Iso

- Formulation of Bücker and Wagner (2006)

#### n-Butane

#### Library LibButane\_n

- Formulation of Bücker and Wagner (2006)

### Mixtures for Absorption Processes

#### Ammonia/Water Mixtures

#### Library LibAmWa

- IAPWS Guideline 2001 of Tillner-Roth and Friend (1998)  
 Helmholtz energy equation for the mixing term (also useable for calculating the Kalina Cycle)

#### Water/Lithium Bromide Mixtures

#### Library LibWaLi

- Formulation of Kim and Infante Ferreira (2004)  
 Gibbs energy equation for the mixing term

### Liquid Coolants

#### Liquid Secondary Refrigerants

#### Library LibSecRef

- Liquid solutions of water with
- |                                   |                     |
|-----------------------------------|---------------------|
| $\text{C}_2\text{H}_6\text{O}_2$  | Ethylene glycol     |
| $\text{C}_3\text{H}_8\text{O}_2$  | Propylene glycol    |
| $\text{C}_2\text{H}_5\text{OH}$   | Ethanol             |
| $\text{CH}_3\text{OH}$            | Methanol            |
| $\text{C}_3\text{H}_8\text{O}_3$  | Glycerol            |
| $\text{K}_2\text{CO}_3$           | Potassium carbonate |
| $\text{CaCl}_2$                   | Calcium chloride    |
| $\text{MgCl}_2$                   | Magnesium chloride  |
| $\text{NaCl}$                     | Sodium chloride     |
| $\text{C}_2\text{H}_3\text{KO}_2$ | Potassium acetate   |
| $\text{CHKO}_2$                   | Potassium formate   |
| $\text{LiCl}$                     | Lithium chloride    |
| $\text{NH}_3$                     | Ammonia             |
- Formulation of the International Institute of Refrigeration (IIR 2010)

### Ethanol

#### Library LibC2H5OH

Formulation of  
Schroeder et al. (2014)

### Methanol

#### Library LibCH3OH

Formulation of  
de Reuck and Craven (1993)

### Propane

#### Library LibPropane

Formulation of  
Lemmon et al. (2009)

### Siloxanes as ORC Working Fluids

Octamethylcyclotetrasiloxane  $C_8H_{24}O_4Si_4$  **Library LibD4**

Decamethylcyclopentasiloxane  $C_{10}H_{30}O_5Si_5$  **Library LibD5**

Tetradecamethylhexasiloxane  $C_{14}H_{42}O_6Si_6$  **Library LibMD4M**

Hexamethyldisiloxane  $C_6H_{18}OSi_2$  **Library LibMM**

Formulation of Colonna et al. (2006)

Dodecamethylcyclohexasiloxane  $C_{12}H_{36}O_6Si_6$  **Library LibD6**

Decamethyltetrasiloxane  $C_{10}H_{30}O_3Si_4$  **Library LibMD2M**

Dodecamethylpentasiloxane  $C_{12}H_{36}O_4Si_5$  **Library LibMD3M**

Octamethyltrisiloxane  $C_8H_{24}O_2Si_3$  **Library LibMDM**

Formulation of Colonna et al. (2008)

### Nitrogen and Oxygen

#### Libraries LibN2 and LibO2

Formulations of Span et al. (2000)  
and Schmidt and Wagner (1985)

### Hydrogen

#### Library LibH2

Formulation of  
Leachman et al. (2009)

### Helium

#### Library LibHe

Formulation of  
Arp et al. (1998)

### Hydrocarbons

Decane  $C_{10}H_{22}$  **Library LibC10H22**

Isopentane  $C_5H_{12}$  **Library LibC5H12\_Iso**

Neopentane  $C_5H_{12}$  **Library LibC5H12\_Neo**

Isohexane  $C_6H_{14}$  **Library LibC6H14**

Toluene  $C_7H_8$  **Library LibC7H8**

Formulation of Lemmon and Span (2006)

### Further Fluids

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

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

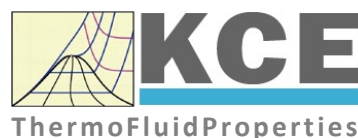
Hydrogen sulfide **H<sub>2</sub>S** **Library LibH2S**

Nitrous oxide **N<sub>2</sub>O** **Library LibN2O**

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

Acetone  $C_3H_6O$  **Library LibC3H6O**

Formulation of Lemmon and Span (2006)



### For more information please contact:

KCE-ThermoFluidProperties UG & Co. KG  
Prof. Dr. Hans-Joachim Kretzschmar  
Wallotstr. 3  
01307 Dresden, Germany

Internet: [www.thermofluidprop.com](http://www.thermofluidprop.com)  
Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810

## 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  $Pr$
- Thermal diffusivity  $a$

### Backward Functions

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

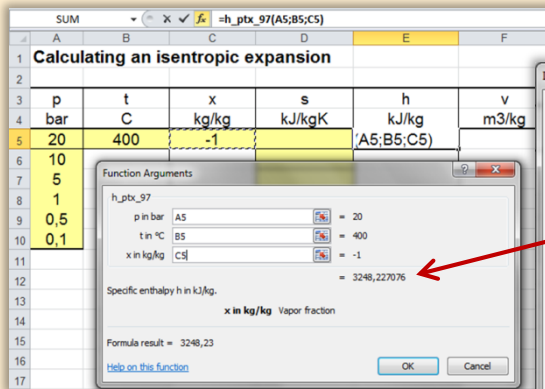
### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

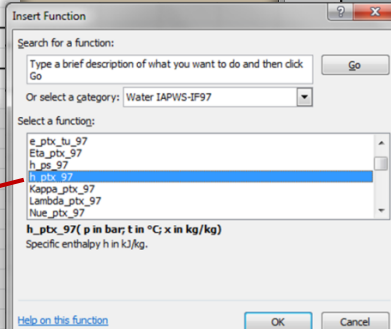
<sup>a</sup> Not all of these property functions are available in all property libraries.

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

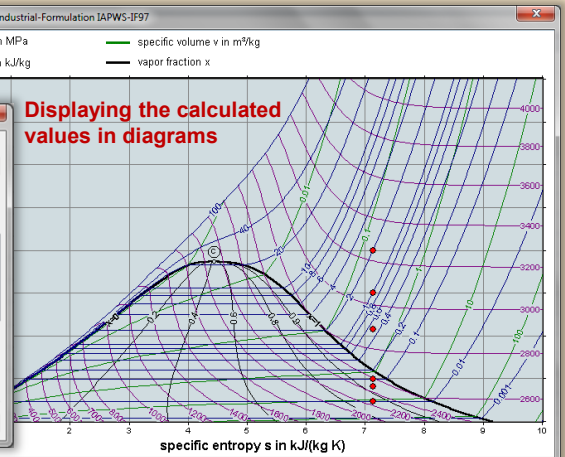
Add-In **FluidEXL** Graphics for Excel®



Choosing a property library and a function



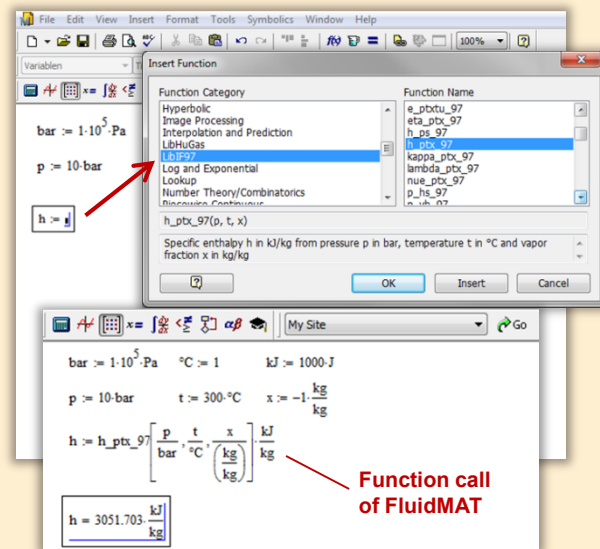
Displaying the calculated values in diagrams



Menu for the input of given property values

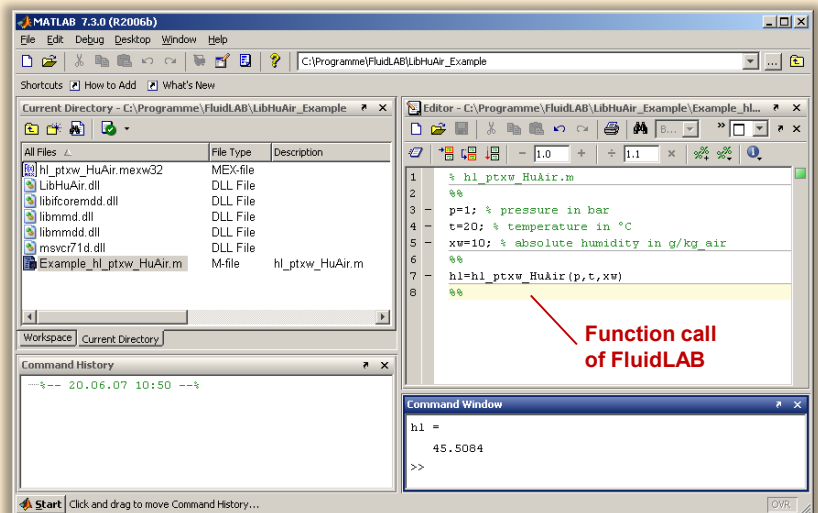
Add-On **FluidMAT** for Mathcad®  
Add-On **FluidPRIME** for Mathcad Prime®

The property libraries can be used in Mathcad® and Mathcad Prime®.



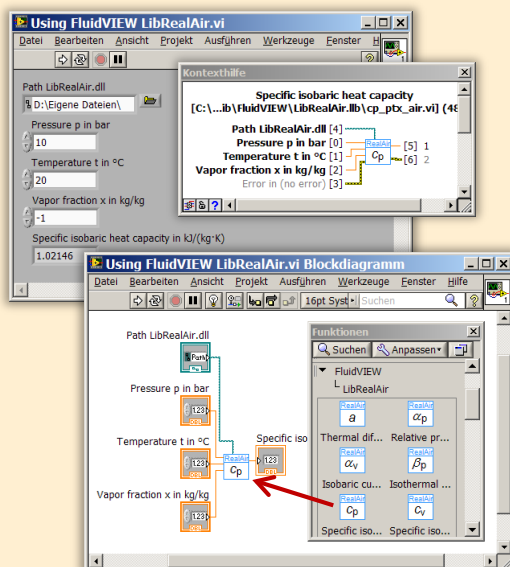
Add-On **FluidLAB** for MATLAB® and SIMULINK®

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



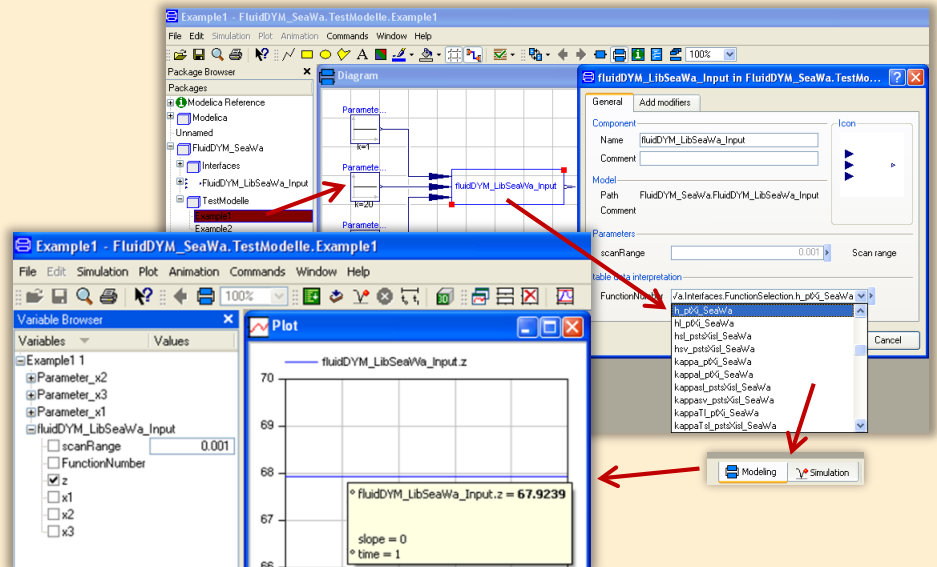
Add-On **FluidVIEW** for LabVIEW™

The property functions can be calculated in LabVIEW™.



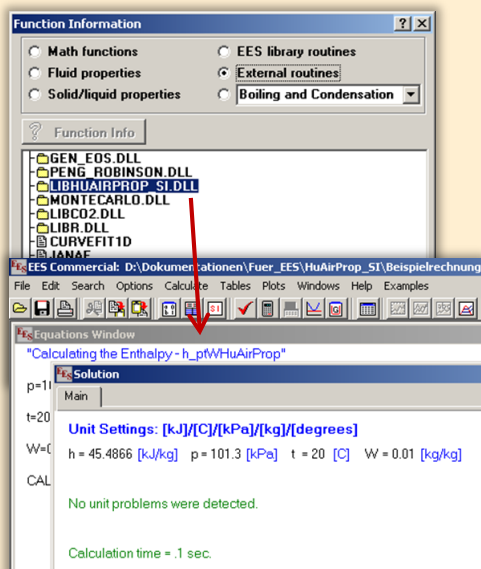
Add-On **FluidDYM** for DYMOLA® (Modelica) and SimulationX®

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

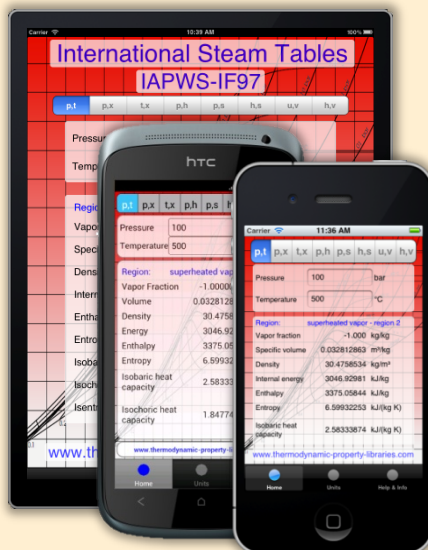




## Add-On FluidEES for Engineering Equation Solver®



## App International Steam Tables for iPhone, iPad, iPod touch, Android Smartphones and Tablets



## Online Property Calculator at [www.thermofluidprop.com](http://www.thermofluidprop.com)

**Zittau's Fluid Property Calculator**

Fluid:

Function:

Unit System:

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

Pressure p:  bar

Temperature t:  °C

Vapor fraction x:  kg/kg

**Calculate / Recalculate**

**Result:**

Specific enthalpy h = 3097.38 kJ/kg

For further information on property libraries available for EXCEL®, MATLAB®, Mathcad®, Engineering Equation Solver®, DYMOLA® (Modelica), SimulationX®, and LabView® click [here](#)

An App for calculating steam properties on iPhone, iPad, and iPod touch can be found [here](#)

PDF with the description

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[www.thermofluidprop.com](http://www.thermofluidprop.com)  
[www.thermofluidprop.com](http://www.thermofluidprop.com)

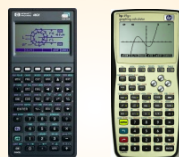
## Property Software for Pocket Calculators

### FluidCasio



fx 9750 G II    CFX 9850 fx-GG20    CFX 9860 G Graph 85    ALGEBRA FX 2.0

### FluidHP



HP 48    HP 49

### FluidTI



TI Nspire CX CAS    TI 83    TI 84    TI 89    TI 92

## For more information please contact:



KCE-ThermoFluidProperties UG & Co. KG  
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Email: [info@thermofluidprop.com](mailto:info@thermofluidprop.com)  
Phone: +49-351-27597860  
Mobile: +49-172-7914607  
Fax: +49-3222-1095810

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  $Pr$
- Thermal diffusivity  $\alpha$

### Backward Functions

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

### Thermodynamic Derivatives

- Partial derivatives used in process modeling can be calculated.

<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: 05/2018

The following companies and institutions use the property libraries

- FluidEXL *Graphics* for Excel®
- FluidLAB for MATLAB®
- FluidMAT for Mathcad®
- FluidEES for Engineering Equation Solver® EES
- FluidDYM for Dymola® (Modelica) and SimulationX®
- FluidVIEW for LabVIEW™.

### 2018

|   |         |
|---|---------|
| Universität Madrid, Madrid, Spanien             | 05/2018 |
| HS Zittau/ Görlitz, Fakultät Wirtschaft, Zittau | 05/2018 |
| HS Niederrhein, Krefeld                         | 05/2018 |
| GRS, Köln                                       | 03/2018 |
| RONAL AG, Härklingen, Schweiz                   | 02/2018 |
| Ingenieurbüro Leipert, Riegelsberg              | 02/2018 |
| AIXPROCESS, Aachen                              | 02/2018 |
| KRONES, Neutraubling                            | 02/2018 |
| Doosan Lentjes, Ratingen                        | 01/2018 |

### 2017

|   |         |
|---|---------|
| Compact Kältetechnik, Dresden                                   | 12/2017 |
| Endress + Hauser Messtechnik GmbH +Co. KG, Hannover             | 12/2017 |
| TH Mittelhessen, Gießen   | 11/2017 |
| Haarslev Industries, Sønderød, Denmark                          | 11/2017 |
| Hochschule Zittau/Görlitz, Fachgebiet Energiesystemtechnik      | 11/2017 |
| ATESTEO, Alsdorf  | 10/2017 |
| Wijbenga, PC Geldermalsen, Netherlands                          | 10/2017 |
| Fels-Werke GmbH, Elbingerode                                    | 10/2017 |
| KIT Karlsruhe, Institute für Neutronenphysik und Reaktortechnik | 09/2017 |
| Air-Consult, Jena   | 09/2017 |
| Papierfabrik Koehler, Oberkirch                                 | 09/2017 |
| ZWILAG, Würenlingen, Switzerland                                | 09/2017 |
| TLK-Thermo Universität Braunschweig, Braunschweig               | 08/2017 |
| Fichtner IT Consulting AG, Stuttgart                            | 07/2017 |
| Hochschule Ansbach, Ansbach                                     | 06/2017 |
| RONAL, Härkingen, Switzerland                                   | 06/2017 |
| BORSIG Service, Berlin  | 06/2017 |



|   |         |
|---|---------|
| BOGE Kompressoren, Bielefeld                                | 06/2017 |
| STEAG Energy Services, Zwingenberg                          | 06/2017 |
| CES clean energy solutions, Wien, Austria                   | 04/2017 |
| Princeton University, Princeton, USA                        | 04/2017 |
| B2P Bio-to-Power, Wadersloh                                 | 04/2017 |
| TU Dresden, Institute for Energy Engineering, Dresden       | 04/2017 |
| SAINT-GOBAIN, Vaujours, France                              | 03/2017 |
| TU Bergakademie Freiberg, Chair of Thermodynamics, Freiberg | 03/2017 |
| SCHMIDT + PARTNER, Therwil, Switzerland                     | 03/2017 |
| KAESER Kompressoren, Gera                                   | 03/2017 |
| F&R, Praha, Czech Republic                                  | 03/2017 |
| ULT Umwelt-Lufttechnik, Löbau                               | 02/2017 |
| JS Energie & Beratung, Erding                               | 02/2017 |
| Kelvion Braze PHE, Nobitz-Wilchwitz                         | 02/2017 |
| MTU Aero Engines, München                                   | 02/2017 |
| Hochschule Zittau/Görlitz, IPM                              | 01/2017 |
| CombTec ProCE, Zittau                                       | 01/2017 |
| SHELL Deutschland Oil, Wesseling                            | 01/2017 |
| MARTEC Education Center, Frederikshaven, Denmark            | 01/2017 |
| SynErgy Thermal Management, Krefeld                         | 01/2017 |

## 2016

|  |         |
|--|---------|
| BOGE Druckluftsysteme, Bielefeld       | 12/2016 |
| BFT Planung, Aachen                    | 11/2016 |
| Midiplan, Bietigheim-Bissingen         | 11/2016 |
| BBE Barnich IB                         | 11/2016 |
| Wenisch IB,                            | 11/2016 |
| INL, Idaho Falls                       | 11/2016 |
| TU Kältetechnik, Dresden               | 11/2016 |
| Kopf SynGas, Sulz                      | 11/2016 |
| INTVEN, Bellevue (USA)                 | 11/2016 |
| DREWAG Dresden, Dresden                | 10/2016 |
| AGO AG Energie+Anlagen, Kulmbach       | 10/2016 |
| Universität Stuttgart, ITW, Stuttgart  | 09/2016 |
| Pöry Deutschland GmbH, Dresden         | 09/2016 |
| Siemens AG, Erlangen                   | 09/2016 |
| BASF über Fichtner IT Consulting AG    | 09/2016 |
| B+B Engineering GmbH, Magdeburg        | 09/2016 |
| Wilhelm Büchner Hochschule, Pfungstadt | 08/2016 |

|   |                           |
|---|---------------------------|
| Webasto Thermo & Comfort SE, Gliching                       | 08/2016                   |
| TU Dresden, Dresden   | 08/2016                   |
| Endress+Hauser Messtechnik GmbH+Co. KG, Hannover            | 08/2016                   |
| D + B Kältetechnik, Althausen                               | 07/2016                   |
| Fichtner IT Consulting AG, Stuttgart                        | 07/2016                   |
| AB Electrolux, Krakow, Poland                               | 07/2016                   |
| ENEXIO Germany GmbH, Herne                                  | 07/2016                   |
| VPC GmbH, Vetschau/Spreewald                                | 07/2016                   |
| INWAT, Lodz, Poland   | 07/2016                   |
| E.ON SE, Düsseldorf   | 07/2016                   |
| Planungsbüro Waidhas GmbH, Chemnitz                         | 07/2016                   |
| EEB Enerko, Aldershoven                                     | 07/2016                   |
| IHEBA Naturenergie GmbH & Co. KG, Pfaffenhofen              | 07/2016                   |
| SSP Kälteplaner AG, Wolfertschwenden                        | 07/2016                   |
| EEB ENERKO Energiewirtschaftliche Beratung GmbH, Berlin     | 07/2016                   |
| BOGE Kompressoren Otto BOGE GmbH & Co KG, Bielefeld         | 06/2016                   |
| Universidad Carlos III de Madrid, Madrid, Spain             | 04/2016                   |
| INWAT, Lodzi, Poland  | 04/2016                   |
| Planungsbüro Waidhas GmbH, Chemnitz                         | 04/2016                   |
| STEAG Energy Services GmbH, Laszlo Küppers, Zwingenberg     | 03/2016                   |
| WULFF & UMAG Energy Solutions GmbH, Husum                   | 03/2016                   |
| FH Bielefeld, Bielefeld                                     | 03/2016                   |
| EWT Eckert Wassertechnik GmbH, Celle                        | 03/2016                   |
| ILK Institut für Luft- und Kältetechnik GmbH, Dresden       | 02/2016, 06/2016 (2x)     |
| IEV KEMA - DNV GV – Energie, Dresden                        | 02/2016                   |
| Allborg University, Department of Energie, Aalborg, Denmark | 02/2016                   |
| G.A.M. Heat GmbH, Gräfenhainichen                           | 02/2016                   |
| Institut für Luft- und Kältetechnik, Dresden                | 02/2016, 05/2016, 06/2016 |
| Bosch, Stuttgart  | 02/2016                   |
| INL Idaho National Laboratory, Idaho, USA                   | 11/2016, 01/2016          |
| Fiedl ID, Wien, Austria                                     | 01/2016                   |
| Technical University of Dresden, Dresden                    | 01/2016                   |

## 2015

|   |         |
|---|---------|
| EES Enerko, Aachen  | 12/2015 |
| Ruldolf IB, Strau, Austria                                  | 12/2015 |
| Allborg University, Department of Energie, Aalborg, Denmark | 12/2015 |
| University of Lyubljana, Slovenia                           | 12/2015 |
| Steinbrecht IB, Berlin                                      | 11/2015 |
| Universidad Carlos III de Madrid, Madrid, Spain             | 11/2015 |
| STEAK, Essen  | 11/2015 |

|   |         |
|---|---------|
| Bosch, Lohmar   | 10/2015 |
| Team Turbo Machines, Rouen, France                              | 09/2015 |
| BTC – Business Technology Consulting AG, Oldenburg              | 07/2015 |
| KIT Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen | 07/2015 |
| ILK, Dresden  | 07/2015 |
| Schniewindt GmbH & Co. KG, Neuenwalde                           | 08/2015 |

## 2014

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| PROJEKTPLAN, Dohna                             | 04/2014 |
| Technical University of Vienna, Austria        | 04/2014 |
| MTU Aero Engines AG, Munich                    | 04/2014 |
| GKS, Schweinfurt                               | 03/2014 |
| Technical University of Nuremberg              | 03/2014 |
| EP-E, Niederstetten                            | 03/2014 |
| Rückert NatUrgas GmbH, Lauf                    | 03/2014 |
| YESS-World, South Korea                        | 03/2014 |
| ZAB, Dessau                                    | 02/2014 |
| KIT-TVT, Karlsruhe                             | 02/2014 |
| Stadtwerke Neuburg                             | 02/2014 |
| COMPAREX, Leipzig<br>for RWE Essen             | 02/2014 |
| Technical University of Prague, Czech Republic | 02/2014 |
| HS Augsburg                                    | 02/2014 |
| Envi-con, Nuremberg                            | 01/2014 |
| DLR, Stuttgart                                 | 01/2014 |
| Doosan Lentjes, Ratingen                       | 01/2014 |
| Technical University of Berlin                 | 01/2014 |
| Technical University of Munich                 | 01/2014 |
| Technical University of Braunschweig           | 01/2014 |
| M&M Turbinentechnik, Bielefeld                 | 01/2014 |

## 2013

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|---------------------------------------|------------------|
| TRANTER-GmbH, Artern                  | 12/2013          |
| SATAKE, Shanghai, China               | 12/2013          |
| VOITH, Kunshan, China                 | 12/2013          |
| ULT, Löbau                            | 12/2013          |
| MAN, Copenhagen, Dänemark             | 11/2013          |
| DREWAG, Dresden                       | 11/2013          |
| Haarslev Industries, Herlev, Dänemark | 11/2013          |
| STEAG, Herne                          | 11/2013, 12/2013 |
| Ingersoll-Rand, Oberhausen            | 11/2013          |
| Wilhelm-Büchner HS, Darmstadt         | 10/2013          |

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| IAV, Chemnitz                                    | 10/2013          |
| Technical University of Regensburg               | 10/2013          |
| PD-Energy, Bitterfeld                            | 09/2013          |
| Thermofin, Heinsdorfergrund                      | 09/2013          |
| SHI, New Jersey, USA                             | 09/2013          |
| M&M Turbinentechnik, Bielefeld                   | 08/2013          |
| BEG-BHV, Bremerhaven                             | 08/2013          |
| TIG-Group, Husum                                 | 08/2013          |
| COMPAREX, Leipzig                                | 08/2013, 11/2013 |
| for RWE Essen                                    | 12/2013          |
| University of Budapest, Hungary                  | 08/2013          |
| Siemens, Frankenthal                             | 08/2013, 10/2013 |
|  | 11/2013          |
| VGB, Essen                                       | 07/2013, 11/2013 |
| Brunner Energieberatung, Zurich, Switzerland     | 07/2013          |
| Technical University of Deggendorf               | 07/2013          |
| University of Maryland, USA                      | 07/2013, 08/2013 |
| University of Princeton, USA                     | 07/2013          |
| NIST, Boulder, USA                               | 06/2013          |
| IGUS GmbH, Dresden                               | 06/2013          |
| BHR Bilfinger, Essen                             | 06/2013          |
| SÜDSALZ, Bad Friedrichshall                      | 06/2013, 12/2013 |
| Technician School of Berlin                      | 05/2013          |
| KIER, Gajeong-ro, Südkorea                       | 05/2013          |
| Schwing/Stetter GmbH, Memmingen                  | 05/2013          |
| Vattenfall, Berlin                               | 05/2013          |
| AUTARK, Kleinmachnow                             | 05/2013          |
| STEAG, Zwingenberg                               | 05/2013          |
| Hochtief, Düsseldorf                             | 05/2013          |
| University of Stuttgart                          | 04/2013          |
| Technical University -Bundeswehr, Munich         | 04/2013          |
| Rerum Cognitio Forschungszentrum, Frankfurt      | 04/2013          |
| Kältetechnik Dresden + Bremen, Alfhausen         | 04/2013          |
| University Auckland, New Zealand                 | 04/2013          |
| MASDAR Institut, Abu Dhabi, United Arab Emirates | 03/2013          |
| Simpelkamp, Dresden                              | 02/2013          |
| VEO, Eisenhüttenstadt                            | 02/2013          |
| ENTEC, Auerbach                                  | 02/2013          |
| Caterpillar, Kiel                                | 02/2013          |
| Technical University of Wismar                   | 02/2013          |
| Technical University of Dusseldorf               | 02/2013          |

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| ILK, Dresden                           | 01/2013, 08/2013 |
| Fichtner IT, Stuttgart                 | 01/2013, 11/2013 |
| Schnepf Ingeniuerbüro, Nagold          | 01/2013          |
| Schütz Engineering, Wadgassen          | 01/2013          |
| Endress & Hauser, Reinach, Switzerland | 01/2013          |
| Oschatz GmbH, Essen                    | 01/2013          |
| frischli Milchwerke, Rehburg-Loccum    | 01/2013          |

## 2012

|   |                  |
|---|------------------|
| Voith, Bayreuth                                       | 12/2012          |
| Technical University of Munich                        | 12/2012          |
| Dillinger Huette                                      | 12/2012          |
| University of Stuttgart                               | 11/2012          |
| Siemens, Muehlheim                                    | 11/2012          |
| Sennheiser, Hannover                                  | 11/2012          |
| Oschatz GmbH, Essen                                   | 10/2012          |
| Fichtner IT, Stuttgart                                | 10/2012, 11/2012 |
| Helbling Technik AG, Zurich, Switzerland              | 10/2012          |
| University of Duisburg                                | 10/2012          |
| Rerum Cognitio Forschungszentrum, Frankfurt           | 09/2012          |
| Pöry Deutschland GmbH, Dresden                        | 08/2012          |
| Extracciones, Guatemala                               | 08/2012          |
| RWE, Essen  | 08/2012          |
| Weghaus Consulting Engineers, Wuerzburg               | 08/2012          |
| GKS, Schweinfurt                                      | 07/2012          |
| COMPAREX, Leipzig<br>for RWE Essen                    | 07/2012          |
| GEA, Nobitz   | 07/2012          |
| Meyer Werft, Papenburg                                | 07/2012          |
| STEAG, Herne  | 07/2012          |
| GRS, Cologne  | 06/2012          |
| Fichtner IT Consult, Chennai, India                   | 06/2012          |
| Siemens, Freiburg                                     | 06/2012          |
| Nikon Research of America, Belmont, USA               | 06/2012          |
| Niederrhein University of Applied Sciences, Krefeld   | 06/2012          |
| STEAG, Zwingenberg                                    | 06/2012          |
| Mainova, Frankfurt on Main<br>via Fichtner IT Consult | 05/2012          |
| Endress & Hauser                                      | 05/2012          |
| PEU, Espenheim  | 05/2012          |
| Luzern University of Applied Sciences, Switzerland    | 05/2012          |

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|---|------------------|
| BASF, Ludwigshafen (general license)<br>via Fichtner IT Consult | 05/2012          |
| SPX Balcke-Dürr, Ratingen                                       | 05/2012, 07/2012 |
| Gruber-Schmidt, Wien, Austria                                   | 04/2012          |
| Vattenfall, Berlin  | 04/2012          |
| ALSTOM, Baden   | 04/2012          |
| SKW, Piesteritz   | 04/2012          |
| TERA Ingegneria, Trento, Italy                                  | 04/2012          |
| Siemens, Erlangen   | 04/2012, 05/2012 |
| LAWI Power, Dresden   | 04/2012          |
| Stadtwerke Leipzig  | 04/2012          |
| SEITZ, Wetzikon, Switzerland                                    | 03/2012, 07/2012 |
| M & M, Bielefeld  | 03/2012          |
| Sennheiser, Wedemark  | 03/2012          |
| SPG, Montreuil Cedex, France                                    | 02/2012          |
| German Destillation, Sprendlingen                               | 02/2012          |
| Lopez, Munguia, Spain   | 02/2012          |
| Endress & Hauser, Hannover                                      | 02/2012          |
| Palo Alto Research Center, USA                                  | 02/2012          |
| WIPAK, Walsrode   | 02/2012          |
| Freudenberg, Weinheim   | 01/2012          |
| Fichtner, Stuttgart   | 01/2012          |
| airinotec, Bayreuth   | 01/2012, 07/2012 |
| University Auckland, New Zealand                                | 01/2012          |
| VPC, Vetschau   | 01/2012          |
| Franken Guss, Kitzingen   | 01/2012          |

## 2011

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|---|---------|
| XRG-Simulation, Hamburg                               | 12/2011 |
| Smurfit Kappa PPT, AX Roermond, Netherlands           | 12/2011 |
| AWTEC, Zurich, Switzerland                            | 12/2011 |
| eins-energie, Bad Elster                              | 12/2011 |
| BeNow, Rodenbach                                      | 11/2011 |
| Luzern University of Applied Sciences, Switzerland    | 11/2011 |
| GMVA, Oberhausen                                      | 11/2011 |
| CCI, Karlsruhe  | 10/2011 |
| W.-Büchner University of Applied Sciences, Pfungstadt | 10/2011 |
| PLANAIR, La Sagne, Switzerland                        | 10/2011 |
| LAWI, Dresden   | 10/2011 |
| Lopez, Munguia, Spain                                 | 10/2011 |
| University of KwaZulu-Natal, Westville, South Africa  | 10/2011 |

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

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| University of Stuttgart  | 12/2010          |
| HS Cooler, Wittenburg  | 12/2010          |
| Visteon, Novi Jicin, Czech Republic                              | 12/2010          |
| CompuWave, Brunntal  | 12/2010          |
| Stadtwerke Leipzig   | 12/2010          |
| MCI Innsbruck, Austria   | 12/2010          |
| EVONIK Energy Services, Zwingenberg                              | 12/2010          |
| Caliqua, Basel, Switzerland                                      | 11/2010          |
| Shanghai New Energy Resources Science & Technology, China        | 11/2010          |
| Energieversorgung Halle  | 11/2010          |
| Hochschule für Technik Stuttgart, University of Applied Sciences | 11/2010          |
| Steinmueller, Berlin   | 11/2010          |
| Amberg-Weiden University of Applied Sciences                     | 11/2010          |
| AREVA NP, Erlangen   | 10/2010          |
| MAN Diesel, Augsburg   | 10/2010          |
| KRONES, Neutraubling   | 10/2010          |
| Vaillant, Remscheid  | 10/2010          |
| PC Ware, Leipzig   | 10/2010          |
| Schubert Consulting Engineers, Weißenberg                        | 10/2010          |
| Fraunhofer Institut UMSICHT, Oberhausen                          | 10/2010          |
| Behringer Consulting Engineers, Tagmersheim                      | 09/2010          |
| Saacke, Bremen   | 09/2010          |
| WEBASTO, Neubrandenburg  | 09/2010          |
| Concordia University, Montreal, Canada                           | 09/2010          |
| Compañía Eléctrica de Sochagota, Bogota, Colombia                | 08/2010          |
| Hannover University of Applied Sciences                          | 08/2010          |
| ERGION, Mannheim   | 07/2010          |
| Fichtner IT Consulting, Stuttgart                                | 07/2010          |
| TF Design, Matieland, South Africa                               | 07/2010          |
| MCE, Berlin  | 07/2010, 12/2010 |
| IPM, Zittau/Goerlitz University of Applied Sciences              | 06/2010          |
| TUEV Sued, Dresden   | 06/2010          |
| RWE IT, Essen  | 06/2010          |
| Glen Dimplex, Kulmbach   | 05/2010, 07/2010 |
|  | 10/2010          |
| Hot Rock, Karlsruhe  | 05/2010          |
| Darmstadt University of Applied Sciences                         | 05/2010          |
| Voith, Heidenheim  | 04/2010          |
| CombTec, Zittau  | 04/2010          |
| University of Glasgow, Great Britain                             | 04/2010          |
| Universitaet der Bundeswehr, Munich                              | 04/2010          |



|   |                  |
|---|------------------|
| Technical University of Hamburg-Harburg                     | 04/2010          |
| Vattenfall Europe, Berlin                                   | 04/2010          |
| HUBER Consulting Engineers, Berching                        | 04/2010          |
| VER, Dresden  | 04/2010          |
| CCP, Marburg  | 03/2010          |
| Offenburg University of Applied Sciences                    | 03/2010          |
| Technical University of Berlin                              | 03/2010          |
| NIST Boulder CO, USA  | 03/2010          |
| Technical University of Dresden                             | 02/2010          |
| Siemens Energy, Nuremberg                                   | 02/2010          |
| Augsburg University of Applied Sciences                     | 02/2010          |
| ALSTOM Power, Baden, Switzerland                            | 02/2010, 05/2010 |
| MIT Massachusetts Institute of Technology Cambridge MA, USA | 02/2010          |
| Wieland Werke, Ulm  | 01/2010          |
| Siemens Energy, Goerlitz                                    | 01/2010, 12/2010 |
| Technical University of Freiberg                            | 01/2010          |
| ILK, Dresden  | 01/2010, 12/2010 |
| Fischer-Uhrig Consulting Engineers, Berlin                  | 01/2010          |

## 2009

|  |                             |
|--|-----------------------------|
| ALSTOM Power, Baden, Schweiz                                 | 01/2009, 03/2009<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                     |

|  |         |
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| Technical University of Berlin                           | 06/2009 |
| Fraunhofer Institut UMSICHT, Oberhausen                  | 07/2009 |
| Bischoff, Aurich   | 07/2009 |
| Fichtner IT Consulting, Stuttgart                        | 07/2009 |
| Techsoft, Linz, Austria                                  | 08/2009 |
| DLR, Stuttgart   | 08/2009 |
| Wienstrom, Vienna, Austria                               | 08/2009 |
| RWTH Aachen University                                   | 09/2009 |
| Vattenfall, Hamburg                                      | 10/2009 |
| AIC, Chemnitz  | 10/2009 |
| Midiplan, Bietigheim-Bissingen                           | 11/2009 |
| Institute of Air Handling and Refrigeration ILK, Dresden | 11/2009 |
| FZD, Rossendorf  | 11/2009 |
| Techgroup, Ratingen                                      | 11/2009 |
| Robert Sack, Heidelberg                                  | 11/2009 |
| EC, Heidelberg   | 11/2009 |
| MCI, Innsbruck, Austria                                  | 12/2009 |
| Saacke, Bremen   | 12/2009 |
| ENERKO, Aldenhoven                                       | 12/2009 |

## 2008

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

|   |                  |
|---|------------------|
| Technip Benelux BV, Zoetermeer, Netherlands   | 08/2008          |
| Fennovoima Oy, Helsinki, Finland  | 08/2008          |
| Fichtner Consulting & IT, Stuttgart   | 09/2008          |
| PEU, Espenhain  | 09/2008          |
| Poyry, Dresden  | 09/2008          |
| WINGAS, Kassel  | 09/2008          |
| TUEV Sued, Dresden  | 10/2008          |
| Technical University of Dresden,<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 |
| 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,  | 02/2006          |
| Department of Thermal Fluid Flow Engines  |                  |
| Technical University of Munich,   | 02/2006          |
| Chair in Apparatus and Plant Engineering  |                  |
| 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,   | 04/2006          |
| Department of Thermodynamics  |                  |
| EnviCon & Plant Engineering, Nuremberg  | 04/2006          |
| Brassel Engineering, Dresden  | 05/2006          |
| University of Halle-Merseburg,  | 05/2006          |
| Department of USET Merseburg incorporated society   |                  |
| Technical University of Dresden,  | 05/2006          |
| Professorship of Thermic Energy Machines and Plants   |                  |
| 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          |

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| Caliqua, Basel, Switzerland (company license)  | 09/2006 |
| Atlas-Stord, Rodovre, Denmark  | 09/2006 |
| Konstanz University of Applied Sciences,<br>Course of Studies Construction and Development | 10/2006 |
| Siemens Power Generation, Duisburg   | 10/2006 |
| Hannover University of Applied Sciences,<br>Department of Mechanical Engineering           | 10/2006 |
| Siemens Power Generation, Berlin   | 11/2006 |
| Zikesch Armaturentechnik, Essen  | 11/2006 |
| Wismar University of Applied Sciences, Seafaring Department                                | 11/2006 |
| BASF, Schwarzheide   | 12/2006 |
| Enertech Energie und Technik, Radebeul   | 12/2006 |

## 2005

|   |                  |
|---|------------------|
| TUEV Nord, Hannover   | 01/2005          |
| J.H.K Plant Engineering and Service, Bremerhaven  | 01/2005          |
| Electrowatt-EKONO, Zurich, Switzerland  | 01/2005          |
| FCIT, Stuttgart   | 01/2005          |
| Energietechnik Leipzig (company license)  | 02/2005, 04/2005 |
|   | 07/2005          |
| eta Energieberatung, Pfaffenhofen   | 02/2005          |
| FZR Forschungszentrum, Rossendorf/Dresden   | 04/2005          |
| University of Saarbruecken  | 04/2005          |
| Technical University of Dresden   | 04/2005          |
| Professorship of Thermic Energy Machines and Plants   |                  |
| Grenzebach BSH, Bad Hersfeld  | 04/2005          |
| TUEV Nord, Hamburg  | 04/2005          |
| Technical University of Dresden, Waste Management   | 05/2005          |
| Siemens Power Generation, Goerlitz  | 05/2005          |
| Duesseldorf University of Applied Sciences,<br>Department of Mechanical Engineering and Process Engineering | 05/2005          |
| Redacom, Nidau, Switzerland   | 06/2005          |
| Dumas Verfahrenstechnik, Hofheim  | 06/2005          |
| Alensys Engineering, Erkner   | 07/2005          |
| Stadtwerke Leipzig  | 07/2005          |
| SaarEnergie, Saarbruecken   | 07/2005          |
| ALSTOM ITC, Rugby, Great Britain  | 08/2005          |
| Technical University of Cottbus, Chair in Power Plant Engineering   | 08/2005          |
| Vattenfall Europe, Berlin (group license)   | 08/2005          |
| Technical University of Berlin  | 10/2005          |
| Basel University of Applied Sciences,<br>Department of Mechanical Engineering, Switzerland                  | 10/2005          |

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| 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

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| Paper Factory, Utzenstorf, Switzerland | 01/2003 |
| MAB Plant Engineering, Vienna, Austria | 01/2003 |

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| 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          |
| 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

|  |         |
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| 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 |

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| 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                              | 06/2002 |
| (general EBSILON program license)                |         |
| 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              | 08/2002 |
| (company licenses and distribution)              |         |
| 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                 | 12/2002 |
| (general license and training test benches)      |         |
| VEAG, Berlin (group license)                     | 12/2002 |

## 2001

|  |                             |
|--|-----------------------------|
| ALSTOM Power, Baden, Switzerland   | 01/2001, 06/2001<br>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   | 04/2001                     |
| (company licenses and distribution)  |                             |
| Muenstermann GmbH, Telgte-Westbevern   | 05/2001                     |
| SaarEnergie, Saarbruecken  | 05/2001                     |
| Siemens, Karlsruhe   | 08/2001                     |
| (general license for the WinIS information system)                           |                             |
| Neusiedler AG, Ulmerfeld, Austria  | 09/2001                     |



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| h s energieranlagen, 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

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|---|------------------|
| SOFBID, Zwingenberg<br>(general EBSILON program license)                              | 01/2000          |
| AG KKK - PGW Turbo, Leipzig   | 01/2000          |
| PREUSSAG NOELL, Wuerzburg   | 01/2000          |
| M&M Turbine Technology, Bielefeld   | 01/2000          |
| IBR Engineering Reis, Nittendorf-Undorf   | 02/2000          |
| GK, Hannover  | 03/2000          |
| KRUPP-UHDE, Dortmund (company license)  | 03/2000          |
| UMAG W. UDE, Husum  | 03/2000          |
| VEAG, Berlin (group license)  | 03/2000          |
| Thinius Engineering, Erkrath  | 04/2000          |
| SaarEnergie, Saarbruecken   | 05/2000, 08/2000 |
| DVO Data Processing Service, Oberhausen   | 05/2000          |
| RWTH Aachen University  | 06/2000          |
| VAUP Process Automation, Landau   | 08/2000          |
| Knuerr-Lommatec, Lommatzsch   | 09/2000          |
| AVACON, Helmstedt   | 10/2000          |
| Compania Electrica, Bogota, Colombia  | 10/2000          |
| G.U.N.T. Geraetebau, Barsbuettel<br>(general license for training test benches)       | 11/2000          |
| Steinhaus Informationssysteme, Datteln<br>(general license for process data software) | 12/2000          |

## 1999

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

## 1998

|  |         |
|--|---------|
| Technical University of Cottbus, Chair in Power Plant Engineering                                | 05/1998 |
| Fichtner Consulting & IT (CADIS information systems) Stuttgart<br>(general KPRO program license) | 05/1998 |
| M&M Turbine Technology Bielefeld   | 06/1998 |
| B+H Software Engineering Stuttgart   | 08/1998 |
| Alfa Engineering, Switzerland  | 09/1998 |
| VEAG Berlin (group license)  | 09/1998 |
| NUTEC Engineering, Bisikon, Switzerland  | 10/1998 |
| SCA Hygiene Products, Munich   | 10/1998 |
| RWE Energie, Neurath   | 10/1998 |
| Wilhelmshaven University of Applied Sciences   | 10/1998 |
| BASF, Ludwigshafen (group license)   | 11/1998 |
| Energieversorgung, Offenbach   | 11/1998 |

**1997**

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